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# Forgetting Distractors: Inhibition or Decay?

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# FORGETTING DISTRACTORS: INHIBITION OR DECAY?

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**ABSTRACT**

Forgetting distractors: Inhibition or decay?

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Research on forgetting irrelevant information in working memory (WM) has supported two conflicting theories, inhibition (Oberauer & Lewndowsky, 2016) and decay (Dagry et al., 2017; Dagry & Barrouillet, 2017). However, these conflicting results may be due to the fact that different methods were used to assess each model. In Experiment 1, we combined those methods to create a modified distractor span task that allows for a direct comparison of the models. Participants processed words that were to be remembered (targets) and others that were to be forgotten (distractors); the amount of free time after each distractor varied, with total trial time held constant across conditions. There were more distractor intrusions on a working memory reconstruction task when less free time was available, supporting an inhibition model. However, this free time difference disappeared on a long-term memory recognition task, which could support either model. In Experiment 2, we tested whether there were individual differences in the modified distractor span task. Individual differences typically arise in active control but not passive processes; therefore, they can be used to adjudicate between the models. We found low WM participants, as compared to high WM, mistakenly remembered more distractors when given less free time. This suggests that forgetting distractors may be an active process that is sensitive to the amount of time available to inhibit, in line with the SOB-CS model. Therefore, inhibition, as proposed by the SOB-CS model, best accounts for forgetting in working memory but the ramifications of that inhibition for long-term memory remains inconclusive.

*Keywords: decay, inhibition, working memory, forgetting distractors*

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# CHAPTER 1 INTRODUCTION

The world can be a distracting place with a variety of stimuli vying for one's attention - radios blaring, cars passing, people talking, and dogs barking to name a few examples. Working memory aids in filtering out these unnecessary distractors and allows people to meaningfully focus their attention on relevant items or tasks (Barrouillet & Camos, 2012; 2015; Cowan, 2016; Engle, 2002; Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012). The most common way to measure the capacity of working memory is through complex span tasks (Daneman & Carpenter, 1980; Conway et al., 2005; Kane et al., 2004; Redick et al., 2012; Unsworth, Heitz, Schrock, & Engle, 2005).

All complex span tasks require participants to perform a distractor task (i.e., a processing component) while concurrently maintaining target information (i.e., a storage component) (Conway et al., 2005). As shown in *Figure 1*, reading span entails reading sentences aloud then judging the truthfulness of the sentence (the processing component), while also maintaining the last word of each sentence for a later recall test (the storage component) (Daneman & Carpenter, 1980). Information from the processing component (i.e., the sentences) is considered a distraction, and is not meant to be maintained in working memory. If distractors are maintained, they can interfere with the ability to retain important information because working memory capacity is very small, about 3 to 5 items (Cowan, 2000; 2010). For instance in the reading span task, if participants maintain non-target words from the sentences, then they cannot maintain as many important final words (Robert, Borella, Fagot, Lecerf, & De Ribaupierre, 2009; Salthouse, 1991). Thus, forgetting distractors is important to efficient remembering (Kuhl, Dudukovic, Kahn, & Wagner, 2007; Levy & Anderson, 2002).

But how is distracting information forgotten from working memory? There are two competing theories that propose different forgetting mechanisms. According to the serial order box- complex span model (SOB-CS; Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012), distracting information has to be actively inhibited in order to remove it from working memory space. However, the time-based resource sharing model (TBRS; Barrouillet & Camos, 2012; 2015) assumes that distractors automatically decay from working memory over the course of time. The assumptions made by both of these models have found some support, which leaves the question of how distractors are forgotten an open question (Dagry, Vergauwe & Barrouillet, 2017; Dagry & Barrouillet, 2017; Oberauer & Lewandowsky, 2016).

## Working Memory Models

### Serial Order Box-Complex Span

The SOB-CS (i.e., serial order box- complex span) is a computational model of complex span performance, where working memory is assumed to be a 2-layer distributed connectionist network in which list position of a representation is bound to a memory item at encoding via Hebbian learning (Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012). This model assumes that both distractors and targets are automatically encoded and distractors create interference with the targets (Logan, 1988; Oberauar & Lewandowsky, 2008). For example, if a participant had to memorize the list ABCD in serial order, the memory item A is bound to position marker 1 and memory item B is bound to position marker 2, and so on. If distractors are present in the list, they are associated with the memory item, and position marker that precedes them during encoding (Oberauer, Farrell, Jarrold, Pasiecznick, & Greaves, 2012). Then at retrieval, people use the list position as a cue to remember the items associated with each marker, which can include distractors (Lewandowsky & Farrell, 2008).

Interference from distractors is reduced by inhibiting content-context bindings, which actively decouples the distractor from the positional marker through Hebbian antilearning (Anderson, 1991). When this process is complete, it permanently removes the binding between the item and its corresponding serial position. This type of inhibition differs from item inhibition, which suppresses the activity of the item representation rather than the content-context bindings. The process of inhibiting the binding requires attention and time, which means that distractors can only be removed during free time in a task (Oberauer, 2001).

Free time is defined as any time that attention is not occupied by processing activities. The less free time available in a span task (i.e., a short free time condition), the more interference is expected to occur because there are more distractors bound to the serial position markers. Ultimately leading to a reduction in the number of targets remembered in working memory. For example, imagine memorizing the following list AeBfCgD, where the capital letters are targets and the lowercase letters are distractors. Target item A and distractor item e are both bound to serial position 1. When there is not enough time to remove the distractor during study, then at test both the target and distractor representation are activated, thus creating interference between the target and distractor. But when there is more free time (i.e., a long free time condition) then the bindings between distractors and their serial position markers are removed, which results in less interference because the distractor representation will not be activated. Therefore, this model proposes that working memory capacity is constrained by interference, which can be reduced by the removal of distractors.

**The Time-Based Resource Sharing Model**

In contrast to the SOB-CS model, the time-based resource-sharing model (TBRS; Barrouillet & Camos, 2012; 2015) characterizes working memory performance as a race between decaying traces of working memory representations and refreshing mechanisms. This model assumes that the storage and processing component of a span task share the same limited attentional resource. This resource is constrained by a bottleneck, which allows only one function to take place at a time (Garavan, 1998; Rohrer, Pashler, & Etchegaray, 1998). As soon as attention is switched from either processing or storage, any memory representations (e.g., targets and distractors) associated with that process begin to decay (Barrouillet, Portrat, Vergauwe, Diependaele, & Camos, 2011). Attentional refreshing[1] can counteract decay, which pulls memory traces (primarily targets) from activated long-term memory into the focus of attention in order to strengthen those memory traces (Cowan, 1992).

Attentional refreshing requires attention and time; therefore, it can only occur during free time in a complex span task. Free time is not limited to the amount of time between components of a task; there can also be free time during a processing activity if the activity does not require all the attentional resources for the duration of the task (i.e., when the task is easy or is given at a slow space; Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007). However, when all the attentional resources are required by the processing task, then target representations suffer from more decay (Barrouillet, Bernardin, & Camos, 2004). This is referred to as cognitive load, which is the amount of attention being used for processing. Higher cognitive loads, such as having to solve a difficult math problem or complete a task at a fast pace, create greater memory loss. Thus, this model proposes that working memory capacity (i.e., number of targets correctly

[1] Attentional refreshing pulls memory traces from long-term memory into the focus of attention, which is different from articulatory rehearsal in which items are only rehearsed in the focus of attention. This distinction is supported by the finding that varying opportunities for refreshing impacted long-term memory traces, but rehearsal did not leave lasting traces (Camos & Portrat , 2015;Loaiza & McCabe, 2013). Moreover, these two different processes use different brain networks (Raye, Johnson, Mitchell, Greene, & Johnson, 2007).

recalled) depends upon the amount of time available for refreshing, rather than the amount of interference as in the SOB-CS model.

**Forgetting Distractors**

The aforementioned models propose different processes for forgetting distractors. The SOB-CS model proposes that distractors must be actively removed (i.e., inhibited) from working memory space, whereas the TBRS model proposes that distractors decay automatically when attention has been turned away from them. These assumptions have been tested with modified complex span tasks (see Figure 2) that varies the amount of free time (either short or long) available after distractors and then measures the availability of these distractors with a recall, recognition, or reconstruction test (Dagry et al., 2017; Dagry & Barrouillet, 2017; Oberauer & Lewandowsky, 2016). This free time manipulation directly tests an assumption made by the SOB-CS model, which assumes that time is needed to remove distractors; if there is not enough time (i.e., short free time condition) to remove distractors, then more distractors and fewer targets will be remembered. However, the TBRS model does not predict a difference in the memory of distractors in different free time conditions because forgetting distractors is an automatic process.

Recently both of these assumptions have found some support. SOB-CS proponents, Oberauer and Lewandowsky (2016), found a decrease in the number of distractors remembered in working memory when there was a long time interval after distractor presentation. This supports the SOB-CS model, which assumes that distractors are actively removed when there is time to do so. However, TBRS proponents found a small increase in the number of distractors remembered in long-term memory (Dagry et al., 2017) and in working memory[2] (Dagry & Barrouillet, 2017) when there was a long time interval after distractor presentation. This means that they found evidence against the SOB-CS model, but this evidence is not consistent with their model because distractor memory should be similar across conditions. Taken together these studies paint a confusing picture of distractor forgetting and it is difficult to compare their results because they used differing methods.

**Method Differences**

One of the most important differences between these studies was the assessment of distractor memory. SOB-CS proponents, Oberauer and Lewandowsky (2016), indirectly probed distractor activation at working memory by estimating the number of mistakenly chosen distractors in a reconstruction task[3]. Meaning they never directly asked participants to choose distractors to assess their memory of distractors. In contrast, TBRS proponents explicitly asked participants to recognize distractors in long-term memory (Dagry et al. 2017) and had them freely recall distractors in working memory (Dagry & Barrouillet, 2017). The difference between distractor memory assessments makes it difficult to compare results across the studies, especially considering that TBRS proponents are primarily measuring accessibility of the distractors and not their attachment to serial position, which is a core assumption of the SOB-CS model.

Another difference between these studies was the difference in encoding procedures. Oberauer and Lewandowsky (2016) allowed participants to view the distractor words at their

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[2] This finding should be interpreted with caution, because Dagry and Barrouillet (2017) reduced interference between targets and distractors by using letters as targets, and words as distractors.

[3] A reconstruction task has participants choose targets in serial order from a matrix of words that has distractors, targets, and lures.

own pace, which is an issue because self-paced procedures cannot be used to assess decay[4] (Barrouillet, Portrat, Vergauwe, Diependaele, & Camos, 2011). In contrast, Dagry et al. (2017) and Dagry and Barrouillet (2017) displayed the distractor words for varying amounts of time depending upon the amount of free time. In their study, distractor words were displayed for a longer amount of time when there was more free time (900ms) than when there was less free time (450ms). Therefore, they not only manipulated free time, but they also manipulated the amount of encoding time for distractors. This manipulation could possibly account for the increase in the number of distractors recalled when there was more free time, because it is possible that these distractors were just better encoded.

These studies also differed in the number of distractors used. Oberauer and Lewandowsky (2016) used one distractor for every target, whereas Dagry et al. (2017) and Dagry and Barrouillet (2017) used two distractors for every target. This could be another contributing factor to the increase of distractors recalled in the long free time condition in the Dagry et al. (2017) study, because there were potentially more distractors encoded into the system. Finally, these studies also differed in the encoding methods used for the target and distractor. Oberauer and Lewandowsky (2016) had participants make judgements on both the target and distractor, in order to ensure both were equally encoded. However, Dagry et al. (2017) and Dagry and Barrouillet (2017) only had participants make judgments on the distractor word, in order to distinguish the target from the distractor word. This means that the participants may have encoded the targets and distractors differently because they only made a judgment on the distractors and not the targets.

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[4] Decay is time-dependent and self-paced procedures do not control for overall time of the task. Therefore, it is possible that participants switch to refreshing during a self-paced task. This can be reduced when time parameters are controlled.

The first study aimed to fix these aforementioned issues by creating a redesigned complex span task (distractor span) to address these issues by: (1) Measuring working memory distractors indirectly and long-term memory distractors directly in order to investigate whether it accounts for any differences in the findings. (2) Having participants view the distractor and target words for the same amount of time in both free time conditions (long and short) in order to eliminate any encoding time confounds. (3) Holding the amount of time it takes to complete a trial constant between the short and long conditions to account for overall decay across a trial, which previous studies failed to do. (4) Having an equal number of distractor and target words. (5) Ensuring that target and distractor words are equally encoded by having participants make judgments on both the target and distractor words. Incorporating these measures allowed us to test the assumptions of each model with a standard method, which may illuminate reasons for their different results.

**Individual Differences**

In addition to testing the models with a standard method, we also examined whether there are individual differences in people's ability to remove distractors and subsequently if the results lend support to one model over the other. People differ in their ability to handle distractions and in their performance of span tasks; or, said differently, people differ in their workin

g memory capacity. When people are placed on a continuum, the extreme poles are referred to as high spans and low spans. People with high working memory spans, or high spans, generally have higher IQs and higher reading comprehension scores as compared to those with lower working memory spans, or low spans (Ackerman, Beier, & Boyle, 2005; Conway, Kane, & Engle, 2003; Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999; Engle, 2002; Kyllonen & Christal, 1990). Individual differences have a long history in working memory research as a way to test the contributing factors to capacity limits (Conway, Jarrold, Kane, Miyake, & Towse, 2007). Therefore, any theory of working memory should be able to explain individual differences; in this case, individual differences in forgetting distractors. The SOB-CS and the TBRS models make different predictions regarding the nature of individual differences.

**SOB-CS**

According to the SOB-CS model, individual differences in complex span performance are due to differences in removal rate, which is the amount of time it takes to remove the bindings between serial position and an item from working memory (Oberauer et al., 2012; Oberauer, 2005). This model assumes that low spans take longer to remove distractor bindings from working memory, and thus recall more distractors as compared to high spans. This has been partially supported by the finding that low spans recall more distractors than high spans (Carretti, Cornoldi, De Beni, & Palladino, 2004; De Beni, Palladina, Pazzaglia, & Cornoldi, 1998). However, there is no support for a relationship between removal speed and working memory capacity, which presents a challenge to their theory (Ecker, Lewandowsky, & Oberauer, 2014). One potential reason removal speed was not correlated with working memory capacity could be that the measure was not challenging enough (as evidenced by high accuracy) for individual differences to emerge (Ecker et al., 2014). In sum, the SOB-CS model predicts that low spans will remember more distractors than high spans.

**TBRS**

The TBRS model characterizes individual differences in distractor forgetting completely differently from the SOB-CS model. This model proposes that the source of individual differences in working memory capacity are the same factors responsible for developmental increases in working memory capacity in childhood (Barrouillet & Camos, 2015; Barrouillet, Gavens, Vergauewe, Gaillard, & Camos, 2009). One of those factors is decay rate, with a small number of studies finding that younger children (who typically have smaller working memory capacities than older children or adults) have a faster decay rate than older children[5] (Cowan et al., 2000; Keller & Cowan, 1994). This model assumes that low span adults will also have a faster decay rate, similar to younger children. However, this assumption has not yet been tested with an adult sample (Gaillard, Barrouillet, Jarrold, & Camos, 2011). In other words, this model predicts that low spans will have a faster decay rate as compared to high spans, which means that they will remember fewer distractors. This study is the first study to investigate whether distractor representations decay faster for low spans than high spans.

## Distractors in Long-term Memory

There been limited research on what happens to distractors from a working memory span task in the long term. Prior research has established that working memory traces generate long-term memory traces, including information that is meant to be forgotten, which has been found to be less accessible than targets but more accessible than novel words (Festini & Reuter-Lorenz, 2013; McCabe, 2008; Loaiza & McCabe, 2012, 2013). However, this finding is from a working memory directed forgetting task, which is different from a complex span task because the to-be-forgotten words are identified after encoding and not before as in a span task. Therefore, another goal of this research was to examine the long-term memory traces of working memory distractors from a span task, and whether their accessibility is modulated by the amount of free time.

[5] It should be noted that Saults & Cowan (1996) found no difference in decay rate for younger and older children. Thus, this finding should be treated as tentative.

Dagry et al. (2017) is the only study that has investigated the long-term memory traces of distractor removal with a modified distractor span task (i.e., a complex span task that varied free time). As stated above, they found a small increase in the number of distractors recognized in the long condition, which is a finding not predicted by either the SOB-CS or the TBRS model. The TBRS model predicts no difference in the number of distractors remembered in long-term memory as a function of free time, because they should decay at the same rate when overall time and cognitive load is equated between conditions (Dagry et al., 2017).

In contrast, the SOB-CS model proposes permanent removal of bindings between distractors and their serial positions in working memory (Lewis-Peacock, Kessler, & Oberauer, 2018). This means that when participants are given enough free time, they remove the binding between serial position and an item. Considering this, it remains a possibility that these items are still in long-term memory but are no longer attached to a particular serial position. Thus, the SOB-CS model should predict no difference between the short and long condition in long-term memory (the same outcome prediction made by the TBRS model), albeit the SOB-CS model has not explicitly predicted this.

**Individual Differences in Long-term Memory**

Distractor accessibility in long-term memory may not only be influenced by the amount of free time in a span task, but it may also be impacted by a person's working memory capacity. There is a strong correlation between long-term memory and working memory capacity, which means that high spans perform better than low spans on many types of long-term memory tasks. This may be due to high spans' greater control over information as compared to low spans (Unsworth, 2016). For instance, high spans are better at distinguishing between irrelevant and target words in long-term memory as compared to low spans (Unsworth, 2007). In consideration of this, would high spans also demonstrate a reduced accessibility of span distractors in long-term memory?

Prior research by Carretti, Cornoldi, De Beni, and Palladion (2004) has shown that high spans had a similar memory for distractors as low spans on a long-term memory recognition test, although, low spans had a better memory for distractors than high spans on the working memory test. These findings suggest that inhibition is temporary and that the word is not inhibited in long-term memory. This could support the SOB-CS model prediction that there are no individual differences in long-term memory, especially on a recognition task (Oberauer, 2005). It will be interesting to see whether these results are replicated with our span task. However, it is also possible that low spans will remember fewer distractors than high spans in long-term memory, which is predicted by the TBRS model.

**Summary**

Working memory is the ability to actively maintain information while managing distractions. The most common way to measure working memory capacity is via complex span tasks, because they use a distracting processing task to place greater demands on simple storage. In order to keep working memory capacity free for storage, distractors from the processing task must be forgotten. For this reason, distractor forgetting is an essential mechanism to the functioning of working memory. Distractors are thought to be forgotten either through active inhibition, as proposed by the SOB-CS model, or they are forgotten via a decay process, as proposed by the TBRS model. The primary goal of the proposed research is to understand distractor forgetting by investigating these processes and the claims made by the SOB-CS and TBRS models.

Inhibition, as defined by the SOB-CS model, is a process that requires time and thus is sensitive to the amount of free time after a distractor. This means that if there is little free time after viewing a distractor, then there may not be enough time to remove a distractor from working memory. On the other hand, decay, as defined by the TBRS model, is a process that does not change based upon the available free time after viewing a distractor, rather it is only time dependent in the sense of the overall cognitive load and length of the task. Both of these processes have found support in two recent research studies. Oberauer and Lewandowsky (2016) found distractor forgetting to operate through inhibition, which supports the SOB-CS model, whereas Dagry et al. (2017) and Dagry and Barrouillet (2017) found distractor forgetting to operate through a decay process, which supports the TBRS model. However, they used different methods, which does not allow for comparison. Therefore, the first major aim of this research is to combine their methods in order to pit these theories against each other with the same task.

The methods from Dagry et al. (2017; Experiment 1 & 3) and Oberauer and Lewandowsky (2016; Experiment 1) were combined to create a task that fixed confounds of the prior studies, such as the type of memory being tested and timing. In this redesigned complex span task (see Figure 3), participants processed a series of words, some of which are to be remembered (targets) and others that are to be forgotten (distractors). The primary manipulation in this task was the amount of free time available after viewing a distractor, either a short (.2s) or long amount of time (1.5s), with total time held constant across trial conditions. Participants then did a reconstruction test that includes targets, distractors, and lures with the goal of selecting the targets; but occasionally participants mistakenly select distractors when they are still present in memory. Hence, the number of distractors remembered at test measured how well distractors had been forgotten. After a number of working memory trials, long-term memory was tested with a standard recognition task that asked participants to indicate whether a word was old (distractor or target) or new.

With this new task, we can adequately test the claims made by the SOB-CS and the TBRS models. The SOB-CS predicts that participants will remember more distractors when there is less free time than when there is more, and this pattern will disappear in long-term memory. In contrast, the TBRS model predicts that participants will remember the same number of distractors for short and long free time; and this pattern will persist into long-term memory.

Another major goal of this research was to investigate how differences in working memory capacity may impact the ability to forget distractors. The SOB-CS model assumes individual differences arise in inhibitory processes. Thus, low spans are predicted to remember more distractors than high spans. This pattern is expected to disappear into long-term memory. In contrast, the TBRS model assumes that there are individual differences in decay rate. The TBRS model would predict that lows spans will remember fewer distractors than high spans with no major difference between short and long free time. This research will help distinguish between the theories while also investigating mechanisms of working memory capacity.

# CHAPTER 2

## EXPERIMENT 1

Experiment 1 combined the methods of Dagry et al. (2017; Experiment 1 & 3) and Oberauer and Lewandowsky (2016; Experiment 1) to create a redesigned distractor span task (see Figure 3). This task addresses several methodological issues of the previous tasks (Dagry et al., 2017; Oberauer & Lewandowsky, 2016) that did not allow for direct comparison of the SOB-CS and TBRS models. Thus, we are able to investigate distractor forgetting while also investigating the working memory models.

### Participants

Twenty- Eight participants (Male =5, Female=23; $M_{age}$ =19.21 years) from the University of Nevada Las Vegas were recruited from the undergraduate subject pool. All participants were given course credit for their participation in this experiment. Five participants were excluded because they skipped over 20% of the questions during the study phase.

### Materials

Words were used as the stimuli for the distractor span task. These words were selected from the MRC Psycholinguistic database (Coltheart, 1981), available online at http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm, based upon frequency (KF = 1 - 312) and letter length (4 to 7 letters). In total, there were 400 words, which consist of 100 distractors, 100 targets, 100 lures, and 100 new words.

### Procedure

A redesigned complex span task was created by combining methods from Dagry et al. (2017; Experiment 1 & 3) and Oberauer and Lewandowsky (2016; Experiment 1). For this task (see Figure 3), participants memorized words (i.e., targets) while making size judgments about each word. The participants were instructed that the words in red (i.e., target words) need to be memorized for a recognition task, and the words in black (i.e., distractor words) should not be memorized. Each trial contains 10 words (i.e., 5 targets and 5 distractors) and an immediate recognition test to assess their working memory. The main difference between trials was the amount of free time following each distractor word, which is the primary manipulation of this experiment. For short free time trials (i.e., short trials), participants had a 200ms unfilled retention interval after the distractor word, and in the long free time trials (i.e., long trials) participants had a 1.5s unfilled retention interval after the distractor word. Then after 20 trials, participants completed a delayed recognition test to assess their long-term memory.

Each trial of the complex span task began with a fixation cross that appears in the center of the screen for 5.5s that informs the participants to wait for the next trial. This fixation cross was then replaced with the first target word, and the participant will indicate whether the object is bigger than soccer ball. After 1.7s has passed the target word disappeared from the screen regardless of whether they responded or not, and the screen will be blank for .2s. Following this target-distractor interval of .2s, a distractor word appeared on screen, and participants again had 1.7s to make a size judgment. The distractor word disappeared from the screen after a 1.7s and there was an unfilled retention interval of either .2s (short trials) or 1.5s (long trials) depending upon the condition.

This cycle continued until participants viewed 5 targets and 5 distractors. In long trials, the working memory test occurred after an interval of 1.5 s after the last word. In the short trials, the working memory test occurred after a .2s unfilled retention interval and a 6.5s filled retention interval. During the filled retention interval, participants were asked to decide whether two simple shapes were the same or different. The reconstruction working memory test presented participants with a 5 x 3 matrix that contained 5 distractor words, 5 targets, and 5 lures. They were instructed to choose the targets from the matrix in the order in which they viewed them. To do this, participants clicked on the words on the screen; once the word was clicked it disappeared and reappeared so that it can be chosen again. After the fifth word was clicked, the screen went blank for 5.5s, and the next trial begin. The accuracy and the order of the words was recorded.

The participants completed 20 trials, which consisted of 10 short trials and 10 long trials in a random order. When these trials were finished, participants preformed simple math equations for 2 minutes to divert their attention prior to the long-term memory test. After the 2 minutes passed, participants received a surprise delayed recognition test. In the delayed recognition test, participants viewed 200 distractors, 200 targets, and 200 new words (lures used in working memory tests were not included) one at time in a random order. For each word, participants were asked to indicate whether they viewed (i.e., old) or did not view the word (i.e., new) during any of the trials regardless of whether it was a distractor or target word. Each word remained on the screen until a response was made; accuracy and response times were recorded. At the completion of this task, participants were thanked and debriefed.

## Results

For both experiments, we used Bayes Factors (BF) to analyze the data, which were computed using the Bayesfactor package for R (Morey, 2015; Morey & Rouder, 2015) and/or JASP (JASP Team, 2018). A BF determines the relative strength of evidence for a particular model. A Bayesian t-test assesses the strength of evidence in favor of the alternative hypothesis (i.e., alternative model) and the null hypothesis (i.e., null model). A Bayesian ANOVA compares BF's for multiple models; for instance, it provides a BF for a model with only one main effect, a model with two main effects, a full model which includes all the main effects and interactions, etc. The model with the largest BF is the most likely model. In theoretically important instances we will also obtain an odds ratio between the best model and inferior models, as recommended by Rouder et al. (2016). For instance, if the full model is the preferred model, then we can compare the full model to a model without an interaction in order to see whether there is strong evidence for the interaction.

All Bayes factors were judged with Raftery's (1995) guidelines which state that a BF between 1 to 3 is weak evidence, BFs between 3 to 10 is intermediate evidence, and BF >10 is strong evidence. The notation used for the alternative Bayes Factor is $BF_{10}$, whereas the null hypothesis is $BF_{01}$.

## Working Memory

**Distractors.** To analyze distractor strength at the working memory level, we ran a Bayesian paired samples t-test to compare the proportion of distractors (i.e., distractors/all distractors) in the short and long free time conditions. There is very strong evidence ($BF_{10}$ = 151.30) for the alternative hypothesis, meaning there was a difference in the proportion of distractors recognized in short (M=.19) and long (M=.13) free time conditions, supporting the predictions made by the SOB-CS model (see Figure 5). There was no evidence for the null hypothesis ($BF_{01}$ = .007), meaning there was no evidence for the TBRS model.

***Distractors Serial Position.*** We analyzed two different types of serial position curves. However, the overall proportion of distractors was low, thus the following results should be interpreted with caution because there may be floor effects.

*Input curve.* The *input* curve reflects the proportion of distractors encoded at a particular serial position and output in any serial position. This curve is being used to test whether distractors encoded earlier in the list decay more than distractors in later serial positions. If distractors begin to decay once attention has turned away from them, then there should be more distractors recognized from serial position 5 over serial position 1. Thus, the input curve gives an approximate estimate of decay, which allows us test predictions of the TBRS model.

We ran a 2 (free time: short & long) x 5 (serial position: 1-5) Bayesian ANOVA (see Table 1). For the distractor input serial position curve, the preferred model (i.e., the model with the largest BF) was the model with only the main effect of free time ($BF_{10}$=262.68). This finding indicates that there was a difference between the long and short conditions but there were not more distractors intrusions in any particular serial position (see Figure 7). This suggests that the distractors encoded at serial position 1 did not have a higher decay rate as compared to the distractors encoded at serial position 5.

*Input-output curve.* This is a traditional serial position curve which reflects the proportion of distractor intrusions output in the same serial position in which it was encoded. This curve is being used to test predictions of the SOB-CS model, which predicts distractor intrusions to increase steadily across serial position in the short condition whereas distractor intrusions for the long condition should remain negligible across serial position (Oberauer et al., 2012).

We ran a 2 (free time: short & long) x 5 (serial position: 1-5) Bayesian ANOVA (see Table 2). For the distractor input-output serial position (see Figure 9), the best model included both a main effect of free time and a main effect of serial position ($BF_{10}$=41,456.51). To investigate these main effects, we computed an odds ratio that compared the best fitting model (model with both main effects) to other models to evaluate how strong the evidence is for each main effect. A comparison of the models showed that the serial position model was preferred 8,942 to 1, which provides strong evidence in favor of inclusion of serial position in the winning model. Another comparison of models showed that the free time model was only preferred 7.16 to 1, which provides weaker evidence for the inclusion of free time in the model. Overall, this means that there is stronger evidence for a main effect of serial position over free time, which provides evidence of differing amounts of distractors remembered at different serial positions.

To further investigate this serial position curve, we ran a series of post-hoc Bayesian paired samples t-tests by comparing each serial position (1-5) to serial position 1 (i.e., 1 to 2; 1 to 3; 1 to 4; 1 to 5) separately for the long and short conditions. This allowed us to investigate whether there were more distractor intrusions made at later serial positions, known as a recency effect. There was strong evidence in favor of a difference between serial position 1 and serial position 5 for both the long ($BF_{10}$=51.57) and short (short $BF_{10}$=9.46) conditions. For both free time conditions there are more distractors recognized in-place in serial position 5 over serial position 1. There was no evidence of any other differences between serial positions as compared to 1 (see Table 3). These two effects provide conflicting evidence for the SOB-CS model, which predicts this curve for the short condition but not for the long condition. But as Obearuer and Lewandowsky (2016) have noted, "this discrepancy suggests that distractor removal is less efficient in people than in the [SOB-CS] model (p. 111)."

**Targets.** Target strength was analyzed, but is not a primary interest because the models do not make differing predictions regarding the outcome of target memory. We ran a Bayesian paired samples t-test to compare the proportion of targets recognized in the correct position (i.e., targets/all targets) in the short and long free time conditions. There is very strong evidence ($BF_{10}$ = 9014.61) for the alternative hypothesis, with more targets recognized in the long (M=.69) over the short (M=.55) free time condition (see Figure 5). This result confirms the predictions made by both models. The *SOB-CS model* predicts this result because there is a reduction in interference from distractors in the long condition, thus more targets should be remembered. However, the *TBRS model* predicts this result because there is more time to refresh in the long free time condition. Therefore, it is difficult to distinguish the models with this data. To view serial positions for targets, please refer to Figures 8 and 10.

**Lures.** The proportion of lures were very low, long (M=.02) and short (M=.03), hence we did not formally analyze them because of floor effects. This fact does, however, support the notion that distractors are more activated at test as compared to lures.

**Long Term Memory**

**Distractors vs Targets.** We ran a 2 (item: target & distractor) x 2 (free time: short & long) Bayesian ANOVA on the proportion of hits – FA[6] (see Table 4). The best model was the item main effect model ($BF_{10}$= 1426.07). Overall, there were fewer distractors (M= .55) correctly identified in long-term memory as compared targets (M=.61; see Figure 6). This could be interpreted as providing evidence of more decay of distractors than of targets, that were presumably refreshed in working memory creating stronger traces. It could also be interpreted as distractors being more inhibited than targets in long-term memory, but with item inhibition not with the type of inhibition predicted by the SOB-CS model.

***Distractors.*** We followed the ANOVA with a paired samples t-test in order to analyze the strength of distractors (Hits- FA) in long-term memory in the short and long free time conditions. There was positive evidence for the null ($BF_{01}$=4.77) hypothesis. The proportions of distractors recognized in the long condition (M=.55) and in the short condition (M=.55) were very similar (see Figure 6). This result is the opposite of working memory results. It supports the TBRS model, which predicts no difference between the free time conditions. However, this

[6] It should be noted that the average false alarm rate was relatively high at .26.

result could also support the SOB-CS model, which predicts no free time differences because serial position is not being tested.

***Targets.*** To analyze target strength at the long-term memory level, we ran a Bayesian paired samples t-test to compare the strength of targets (Hits– FA) in the short and long free time conditions. There was positive evidence for the null hypothesis ($BF_{01}$=4.91), with a similar number of targets being recognized in the long (M=.61) and short (M=.62) conditions (see Figure 6). This finding is not predicted by the TBRS model, which predicts more targets to be remembered in the long condition over the short condition, because there were more opportunities for the targets to strengthen via refreshing in the long condition. The SOB-CS model makes no explicit predictions.

**LTM Reaction Times.** Reaction times can provide another way to investigate inhibition**.** We analyzed reaction times (RTs) with a 2 (free time: short & long) by 2 (item: distractors & targets) within-subjects Bayesain ANOVA (see Table 5). The preferred model was the main effect of item type ($BF_{10}$= 10.90), with no evidence of a free time difference. Participants were slower at making decisions about distractors (996.33ms) than targets (933.37ms). We also compared overall targets and distractor RTs to lures with a one-way Bayesain ANOVA. There was substantial evidence (BF=8.673E+7) for a difference between distractors, target, and lures, which we followed up with paired samples t-tests. When targets were compared to lures, the alternative hypothesis ($BF_{10}$=30,1162) was preferred. This was the same for the comparison of distractors to lures ($BF_{10}$=1237.62). Overall, participants responded to targets (933.37ms) the fastest, followed by distractors (996.33ms) and lures (1179.27ms). This could mean that there is lingering item inhibition of the distractors because they respond to them more slowly. It could also be due to encoding differences between distractors and targets, confidence differences, etc.

However, the RT data corroborates the LTM accuracy findings that distractors are still in memory because they have not returned to baseline.

### Working Memory vs. Long-term Memory

**Effect sizes.** Results from working memory and long-term memory cannot be compared directly because we used differing types of memory tests. In order to compare these systems we used effect sizes to investigate whether the pattern of findings is consistent across memory systems. The effect sizes in working memory for distractors (d =.67) and targets (d =.76) are very large. Whereas, the effect sizes for long-term memory for distractors (d =0) and targets (d =.05) are very small. Thus, the effect sizes are much larger for working memory vs long-term memory. It is interesting that the difference between the short and long conditions in working memory did not continue into long term memory. This shows that effect of free time is constrained to working memory.

**Inhibited in WM to LTM.** We calculated whether an item that was not chosen in working memory was also not correctly identified in long-term memory. We created a proportion score by dividing the number of not chosen items by the total number of possibly identified items in long-term memory, and then ran a 2 (free time: short & long) x 2 (item: target & distractor) Bayesian within samples ANOVA (see Table 6). The main effect of item (BF= 3.21E+19) was the preferred model. There were more distractors (M=.18) not chosen in both working memory and long-term memory as compared to targets (M=.03). This is not surprising because targets should be chosen in working memory. There was no evidence for the main effect of free time (BF=.21) or an interaction between free time and item (BF=.31). This means free time had no impact on the number of items (distractors nor targets) not chosen across memory systems. This corroborates the other analyses that shows the disappearance of free time differences in long-term memory.  This result provides some evidence for temporary inhibition, an item is inhibited or not chosen in working memory, is then free of inhibition and chosen at long-term memory.  This pattern is predicted by the SOB-CS model because the bindings are not being tested at long-term memory, such that it appears to be temporary inhibition.

## Experiment 1 Discussion

Experiment 1 provides mixed evidence in support of both the SOB-CS and TBRS model.

### Working Memory

In working memory, the weight of the evidence falls in favor of the SOB-CS model. Firstly, there were more distractor intrusions made in the long condition over the short condition in working memory, supporting the SOB-CS model.  This suggests that when participants are given more free time, they remove distractors from working memory space, such that they choose them less frequently at test.  Although, overall distractor intrusions in our experiment were lower than what was reported in Oberauer and Lewandowsky (2016).  It is possible that our participants had fewer distractors in their working memory system as compared to the participants in Oberauer and Lewandowsky’s (2016) study.  This could be due to our modifications to the complex span task, such as going from self-paced to computer paced.  It is also possible that our participants experienced less proactive interference build-up.  We had 20 working memory trials, whereas Oberauer and Lewandowsky had 40 working memory trials. This potentially means there is build-up of proactive interference over the course of trails that increases the probability of choosing a distractor.  Despite this, participants still choose distractors more often than lures, which at least suggests that distractors were encoded into working memory in some way.

The TBRS models' predictions for the *input* serial position curve were not supported. It appears that distractors are remembered equally across serial position (see Figure 7). This suggests that distractors encoded from earlier positions did not decay more than distractors encoded from later serial positions. As for the *input-output* serial position curve, the SOB-CS models' predictions for the input-output serial position curve were partially supported. The input-output serial position curve for the short condition aligned with the model's predictions, but the input-output curve for the long condition was not flat as the SOB-CS model predicts. For both conditions, there were more distractors remembered at serial position 5 that were encoded at serial position 5 (i.e., remembered in place). The SOB-CS model does predict an increase in the number of distractors mistakenly remembered across serial position, with the most distractors remembered at serial position 5. In the graph in Figure 9, it does appear to have a steady increase, especially in the short condition.

**Long-term Memory**

In long-term memory the pattern of results changed; there was no longer a difference between the short and long conditions for distractors. This means the distractors from the long condition, as compared to short condition, were not more inhibited in long-term memory as they were in working memory. But, overall, there were fewer distractors correctly identified as compared to targets. This could mean that distractors on the whole are more inhibited than targets, supporting permanent item inhibition, or it could mean that distractors decayed more than targets, supporting TBRS. In favor of the SOB-CS model, there were a low number of distractors inhibited in working memory that were also inhibited in long-term memory, supporting the notion of binding inhibition.

# CHAPTER 3

# EXPERIMENT 2

For experiment 2, we investigated the nature of individual differences in distractor forgetting with the distractor span task from Experiment 1 and a battery of shortened complex span tasks (i.e., operation span, rotation span, and symmetry span) to measure working memory capacity (Foster et al., 2015). From the working memory battery, a composite working memory score from all the shortened span tasks was derived as an indicator of working memory capacity. A composite working memory score is a better measure of working memory capacity, because it more predictive than a single span score (Foster et al., 2015). Based upon these composite scores, participants were divided into high spans (i.e., the top 33 participants) and low spans (i.e., the bottom 33 participants) in order to investigate the predictions made by the SOB-CS and TBRS model. As a reminder, the SOB-CS model predicts that low spans will perform worse on the task overall, but especially when there is little free time, as compared to high spans. The TBRS model predicts that low spans will have a high rate of decay, which means that they will remember less than high spans, but that span will not interact with free time.

## Participants

One hundred-fifty-six undergraduate students (Male= 58, Female = 99; $M_{age}$= 20.06) from the University of Nevada, Las Vegas were recruited from the undergraduate subject pool. Eleven participants were excluded for skipping more than 20% of the study questions. Sixty-Six participants of the one hundred-thirty-nine students were split into high span (top 33 participants, composite span score of > 41/53; Male =14, Female=19, $M_{age}$ =19.45) and low span (bottom 33 participants, composite span score of < 35/53; Male=8, Female=25, $M_{age}$=20.6) groups for analysis. All had correctly solved at least 84% of processing operations.

## Materials and Procedure

### WMC Measures

All of the complex tasks share the same basic structure; participants are asked to alternate between remembering certain items and performing another task. Shortened complex span tasks (i.e., operation span, rotation span and symmetry span) are used as a measure of participants working memory capacity, which altogether takes about 45 minutes to complete. Each span task had six sets of trials that will contain anywhere from two to seven to-be-remembered items. These sequence lengths do not repeat, which means that participants received each sequence length once in a random order. Each span task began with a practice session in order to familiarize the participants with the various components of the task and to calculate each individual participant's average processing time.

**Operation span.** Operation span (see Figure 4) required participants to remember letters (F, H, J, K, L, N, P, Q, R, S, T Y) and perform simple math problems (i.e., (4*2)/2=). In this task, participants begin by solving a math problem, which they are encouraged to solve them as quickly and as accurately as possible; once solved they are instructed to click the mouse anywhere on the screen. After the mouse click, a screen appeared with a number and two buttons labeled "true" and "false". The participants were asked to determine if the number matched their calculated answer from the previous math equation (true) or did not match the answer (false). Immediately following their response, a letter flashed on the screen for a total of 800 ms and participants were required to remember that letter for a later test. After a sequence of math equations and letters was done, participants were asked to retrieve the letters in order by using the mouse to click on letters displayed in a 4 x 3 matrix. There were six trials and each trial has a sequence length of anywhere from 2 to 7 math operations and letters with each sequence length occurring only once (Foster et al., 2015). This task was scored using a partial score, which is the total number of correctly recalled letters (Turner & Engle, 1989).

**Rotation span.** Rotation span (see Figure 4) required participants to remember the size (i.e., short or long) and the location of an arrow that is pointed in one of eight positions, while judging rotated letters (G, F, J or R; Kane et al, 2004). In this task, participants began by judging whether a rotated letter was presented normally, or whether it is the mirror image of the letter by mentally rotating it. They were encouraged to solve this as quickly and as accurately as possible; once solved they were instructed to click the mouse anywhere on the screen. After the mouse click, participants judged whether a letter was rotated normally(true) or not (false). Immediately following their response, an arrow flashed on the screen and participants were asked to remember the location and size of that arrow for a later test. After a sequence of arrows and letters, participants were asked to retrieve the arrows in the order presented during the trial by using the mouse to click on the displayed arrows. There were six trials and each trial had a sequence length of anywhere from 2 to 7 rotated letters and arrows with each sequence length occurring only once. We used the partial score, which was the total number of arrows correctly recalled.

**Symmetry span.** In symmetry span (see Figure 4), participants are required to remember the location of a red box in a 4 x 4 matrix and judge whether a shape in an 8 x 8 matrix filled with black squares is symmetrical along the vertical axis or not (Kane et al., 2004). Each trial began with a symmetry judgment, where participants were asked to view an image divided along the axis and judge its symmetry (Kane et al, 2004). Immediately following a response, a red box appeared within a matrix which they must remember the location of the square. Participants viewed anywhere from 2 to 7 red boxes and then were asked to recall the sequence of red-square locations in the order that they appeared. There were six trials and each trial had a sequence length of anywhere from 2 to 7 red squares and shapes with each sequence length occurring only once. We used the partial score for symmetry span which is the total number of red square locations correctly recalled.

**Composite score.** Partial scores from all three span measures (rotation, symmetry, and ospan) were combined by adding together each participant's partial score then dividing it by the highest achievable score (53).

### Distractor span task

This experiment used the same distractor span task as Experiment 1, with the exception of including an option of withholding a response in working memory. We instructed participants that if they were confident that they did not remember an item at test, then they should use the button labeled "blank" in place of that item. They were also told that they should use the blank option in place of the word they forgot. For example, if they were confident that they did not remember the second word in the list, then they should use the blank box in the second position at test. To ensure comprehension of the blank option, we had them demonstrate how they would use it.

## Experiment 2 Results

For Experiment 2, we investigated whether there are individual differences (high vs low span) in the ability to forget distractors. This experiment used the same distractor span task as Experiment 1, with the exception of including an option of withholding a response in working memory. The results from Experiment 2 were analyzed with Bayesian ANOVAs using the BayesFactor package (Morey, 2014) for R and/or JASP (2018) with the default settings. The same Bayes Factor criteria, as explained above, are applied here.

**Working Memory**

**Distractors.** A 2 (free time: short & long) x 2 (span: high & low) Bayesian ANOVA was computed on distractors proportions (i.e., distractors/all distractors)**.** The combination of the main effect of span and free time was the preferred model ($BF_{10}$= 2,882,894; see Table 7). To investigate the strength of each main effect, we compared the best fitting model (the model with both main effects) to other models to evaluate how strong the evidence is for each main effect. A comparison of models showed that the free time model was preferred 74, 216.4 to 1, which provides strong evidence in favor of inclusion of free time in the winning model. Another comparison of models showed that the span model was preferred 34.96 to l, which also provides strong evidence for the inclusion of span into the model. This supports the SOB-CS model (see Figure 11) which predicted that low spans (M=.15) would remember more distractors than high spans (M= .09). It also replicates the finding from experiment 1; more distractors were recognized in the short condition (M=.14) over the long condition (M=.10).

***Distractors Serial Position.*** The input and input-output curve were calculated the same way as in Experiment 1.

*Input Curve*. We ran a 2 (free time: short & long) x 5 (serial position: 1-5) x 2 (span: low & high) Bayesian ANOVA (see Table 8). The preferred model includes the main effects of free time and span ($BF_{10}$= 1,031,515). The evidence of these main effects corroborates the above findings of overall distractor accuracy. The lack of evidence for a main effect of serial position provides evidence against low spans having a higher decay rate as compared to high spans, thus not supporting the TBRS model(see Figure 15).

*Input-Output Curve*. We ran a 2 (free time: short & long) x 5 (serial position: 1-5) x 2 (span: low & high) Bayesian ANOVA (see Table 9). The preferred model is the main effect of serial position ($BF_{10}$= 1.82E+17). This means that there were no individual differences in the proportion of distractors remembered in place, but there were differences in the proportion of distractors remembered at different serial positions, supporting the SOB-CS model (see Figure 9). This does not support the TBRS model because it would predict a flat input-output curve (see Figure 17) .

We ran additional post-hoc tests to investigate this curve. We ran the same series of t-tests that we ran for Experiment 1 for low and high spans separately. Both high and low spans had a recency effect, with more distractors remembered in serial position 5 as compared to serial position 1(see Table 10). We also ran a 2 (free-time: short & long) x 2 (span: low & high) ANOVA on the proportion of distractors remembered in serial position 5. The preferred model was the main effect of span ($BF_{10}$=1.96), which did not provide substantial evidence for a difference between low and high spans. Thus, there is a recency effect but this does not differ between high and low spans.

**Targets.** A 2 (free time: short & long) x 2 (span: high & low) mixed model Bayesian ANOVA was computed on the proportion of targets in the correct order (targets/all targets). The model with both main effects (free time and span) was the preferred model ($BF_{10}$= 5.22E+10). This supports the predictions made by both the SOB-CS and TBRS model which predicts both main effects(see Figure 12).

**Long-term Memory**

**Distractors.** A 2 (Free time: short & long) x 2 (span: high & low) mixed model Bayesian ANOVA was computed on distractor strength (Hits - FA). The preferred model is the null model, because all the BFs were below 1(see Table 11). There was only a slight difference between the percent of distractors correctly identified that came from the short (M= .53) and long

(M= .55) conditions (see Figure 13). Low spans (M=.52) remembered about the same number of distractors as high spans (M = .56). This cannot be attributed to higher false alarm rates ($BF_{01}$= 3.92), low spans (FA rate =.28) were not more likely to false alarm than high spans (FA rate=.27). Thus, this lack of difference between high spans and low spans cannot be attributed to low spans having higher rate of endorsing distractors than high spans.

**Targets.** A 2 (free time: short & long) x 2 (span: high & low) mixed model Bayesian ANOVA was computed on target strength (Hits– FA). The preferred model was the main effect of free time ($BF_{10}$=2.36), albeit there is weak evidence for it. There was not a large difference between the number of distractors remembered in the short (M= .60) over the long (M= .63) condition (see Figure 14). This is possibly predicted by the SOB-CS model, but not the TBRS model because it would predict better memory of the targets from the long condition compared to the short condition.

**LTM Reaction Times.** We ran a 2 (free time: short & long) by 2 (item: distractors & targets) by 2 (span: low & high) within-subjects Bayesian ANOVA. The preferred model was the main effect of item ($BF_{10}$= 4.57E+08). Overall, participants were slower at responding to distractors (1030.32 ms) than targets (949.53ms), this replicates Experiment 1. We also compared overall targets and distractor RTs to lures with a two-way Bayesian ANOVA 2 (span: high & low) x 3(item: lures, distractors, targets). This again replicated experiment 1; the preferred model was main effect of item ($BF_{10}$= 1.69e+22). Participants were the slowest at responding to lures (1202.28 ms) as compared to distractors and targets. We followed this up with a paired sample t-tests between targets and lures ($BF_{10}$= 1.489E+14) and, also, distractors and lures ($BF_{10}$= 5.315E+8). All in all, these analyses show that there is an RT difference between targets, distractor, and lures but there were not individual differences in RT performance.

**Working Memory vs. Long-term Memory**

**Effect sizes.** The effect sizes for working memory were much larger than the effect sizes for long-term memory. In working memory, there were large effect sizes for free time, distractors ($\eta$ =.36) and targets ($\eta$ = .49), and span, distractors ($\eta$ =.16) and targets ($\eta$ =.25). However, there were small effect sizes in long term memory for free time, distractors ($\eta$ =.04) and targets ($\eta$ =.08), and span, distractors ($\eta$ =.01) and targets ($\eta$ =. 02). This shows that span differences disappear in long-term memory.

**Inhibited in WM to LTM.** We ran a 2 (span: high & low) by 2 (free time: short & long) by 2 (item: distractor & target) Bayasian ANOVA on the number items not chosen in the working memory and in long-term memory. The most likely model was the main effect of item ($BF_{10}$=1.49E+34). This replicates the findings from experiment 1; there were fewer targets (M=.04) inhibited across memory systems as compared to distractors (M=.17). Again, this is not surprising considering that participants are supposed to remember targets, but it is interesting that there is no evidence of high spans inhibiting more distractors from working memory to long-term memory.

## Experiment 2 Discussion

Overall, experiment 2 replicated the results found in experiment 1 even with a task that had the option to not respond. There were span differences in working memory but not long-term memory.

**Working Memory**

Low spans mistakenly chose distractors in working memory more often than high spans, which suggest that they have more trouble actively removing distractors from working memory. This supports the SOB-CS model, which views forgetting as an active process that low spans are deficient in. This does not support the TBRS model, which predicts that low spans will remember fewer distractors than high spans because they have a faster decay rate.

**Long-Term Memory**

In long-term memory there were no span differences; not in the number of distractors chosen, of targets remembered, in reaction times, or in the number of items inhibited across memory systems. This is not surprising given that span differences are not usually found in long-term memory recognition tests (Unsworth & Brewer, 2009). Span differences in long-term memory are typically found in recall tests, because they rely more on the effortful process of recollection.

# CHAPTER 4

# GENERAL DISCUSSION

Our primary goal was to test the claims made by the SOB-CS and TBRS model with a modified distractor span task that incorporated methods from both of their primary papers.

## Working Memory

The SOB-CS model was supported at the working memory level, and our results, both overall distractor intrusions and the input-output serial position curve, mirror the results found in Experiment 1 of Oberauer and Lewandowsky's (2016) study. These results could also be explained by tagging of distractors and targets during encoding, such that at retrieval participants choose distractors less often because they have tagged the item as a distractor; thus, it is possible that free time is being used to tag items. A future study would first to identify if participants maintain source memory for distractors at test, and then ask them to put those distractors in serial order on surprise trials. If they are able to place distractor's correctly, then they are not unbinding the item, rather they are tagging the item. This could provide an alternative explanation for results.

There was an increase in item errors across serial position, which is predicted by the SOB-CS model. This increase in item errors has been found in a modified complex span task (Oberauer & Lewandowsky, 2016) and with short-term verbal memory tasks (Guerard & Tremblay, 2008; Henson, 1996). The SOB-CS model predicts the increase, but the model does not specify a reason for the increase. It is possible that the last encoded item (a distractor) in our span task has remained in the focus of attention and is more accessible than other items (McElree, 2006). This seems plausible considering that there was no difference between free-time conditions on serial position 5, meaning even when there was time to remove a distractor, the last seen item is still the most accessible. This claim could be further investigated by switching the order of items in a trial such that a target is the last item encoded in the list, to see whether the targets have a larger recency effect than distractors. There is reason to believe that there would be a recency effect for the targets in such an experiment. In traditional complex span tasks the last item viewed is a target and there is usually a recency effect found with targets in complex span tasks.

**Long-term Memory**

Distractors from working memory were still accessible on a long-term memory test. Overall distractor memory was worse than target memory, although recognition rates for distractors were still relatively high, replicating Dagry et al. (2017). This could be indicative of distractors decaying faster than the targets. However, this finding could also be explained by lasting inhibition of the distractors, such that memory is worse for the distractors because they are still inhibited. This is not type of inhibition used in the SOB-CS model though, which makes no explicit predictions regarding long-term memory. It is possible that the SOB-CS model would predict no overall differences between distractor and target memory on a long-term memory recognition test, because the most important element of their model are serial position-item bindings. These bindings are not needed in long-term memory, thus the representations for both targets and distractors could be equally accessible.

There was also no difference in distractor memory between the long and short free time conditions. Proponents of the TBRS model would take this evidence as support for their model, and evidence against the SOB-CS. These results are similar to the findings in Dagry, Vergauwe, and Barrouillet's (2017) paper, except for their unexpected free time difference (more distractors in long condition over the short condition) which we did not replicate with our study. We suspect the consistency of this finding (e.g., Dagry, Vergauewe, & Barrouillet, 2017; Dagry & Barrouillet, 2017) could be due to increased encoding time for distractors in the slow condition, which is something we controlled for. Thus, encoding time is an important element of the task that should be controlled.

While the TBRS model takes the evidence of no free time differences as support for their model, the SOB-CS model could also predict no free time differences in long-term memory. The removal of distractors in working memory is the breaking of context-item bindings and not the inhibition of the item itself. Thus, distractors could still be accessible in long-term memory with no difference between free time conditions because removal in working memory would only remove the bindings of a distractor to a particular serial position.

**Difference between working memory and long-term memory**

The high accessibility of distractors in long-term memory as opposed to working memory, combined with the fact that only a small number of distractors inhibited in the working memory were also inhibited in the long-term memory, provides support for the hypothesis that forgetting in working memory is not the inhibition of the item itself. However, participants had slower reaction times to distractors in long-term memory. This could mean that the distractors were less accessible in long-term memory, such that their traces are not as strong as the traces for targets. If this were the case, it would be indicative of lasting inhibition of an item from working memory, thus supporting item inhibition (Healey, Campbell, Hasher, & Ossher, 2010).

The difference between working memory and long-term memory could also be due to different demands of the differing tasks. In working memory, recollection is needed to match serial position to an item, whereas recollection is needed much less in long-term memory. To test whether the differences in the demands account for the different results in working memory and long-term memory, a future study could use free-recall or a source memory test in long-term memory to equate the working memory test to the long-term memory test.  Overall, these results from long-term memory cannot adjudicate between the models.

**WM Individual Differences**

There are individual differences in distractor removal; low spans mistakenly choose distractors more often than high spans. This suggests that low spans have more trouble removing distractors as compared to low spans.  However, there was no difference between the span groups on the distractor input-output curve.  Recency effects were found on the distractor input-output serial position curve for both low and high spans.  This suggests that both groups are more likely to remember a distractor in place at later serial positions, particularly serial position 5.

The reason low spans have more trouble removing distractors could be a difference in removal speed between spans, as predicted by the SOB-CS model.  But, as mentioned in the introduction, Ecker, Lewandowsky and Oberauer (2014) found no correlation between removal speed and span in a modified updating task, which presents a challenge to this assumption.  It, however, remains possible that removal speed differs between spans in a complex span task, a question for future research.

It seems unlikely that low spans have a faster decay rate as compared to high spans given that they remember more distractors and that they did not have a more pronounced input serial position curve as compared to high spans.  To rule out this possibility, future research would need to calculate decay rate, as in Keller and Cowan (1994), and correlate it with distractor span performance.  It is also possible that low spans do not take advantage of the free time, by either removing distractors or refreshing, and have a higher level of confusion between items, similar to older adults (see Hoareau, Lemaire, Portrat, & Plancher, 2016).

**LTM Individual differences**

Similar to Carretti, Cornoldi, De Beni, and Palladion (2004), we found individual differences in distractor memory in working memory, but not in long-term memory. Carretti et al., (2004) used a categorization span task in working memory and a near-identical long-term memory recognition test. Thus, we have extended these findings to a distractor working memory task. These results could suggest that inhibitory processes used by high spans are temporary; that is, the items' activation is temporarily inhibited in working memory in service of ongoing goals.

The lack of individual differences on the long-term memory recognition task could also be due to the reliance on familiarity, and typically no individual differences are found in such tasks (e.g., Unsworth & Brewer, 2009). The use of a recall test at long-term memory would be an interesting further study because it relies more on recollection and may be a better measure of accessibility of distractors in long-term memory between low and high spans. It may be that high spans cannot recollect as many distractors as low spans in long-term memory, suggesting that they have less access to them. Another study could look at ROC curves to determine if there are span differences in how much they rely on familiarity or recollection in this task.

These results are in line with the SOB-CS model, which predicts no span differences in long-term memory because individual differences arise in the bindings. This goes against the TBRS model because low spans should have had less accessibility to distractors than high spans, because their distractors should have decayed faster. The fact that they have similar accessibility, even if it is from a familiarity signal, suggests that the distractors have not decayed at a higher rate for low spans than high spans.

**Limitations**

There is concern about a dependency between the targets and distractors in the test of working memory (Dagry & Barrouillet, 2017). The TBRS model proposes that more targets will be remembered when there is more free time because there is more time to refresh, but the reconstruction test constrains responses. If more targets are chosen, then fewer distractors can be chosen because of how the task is set up. Therefore, if fewer distractors are remembered in the long condition, it could be due to stronger target representations that were refreshed more often, rather than better removal of distractors.

For example, in the working memory test, participants are limited in the number of items they can choose per trial (5 items) and thus the number of distractors they can choose is constrained by the number of targets they have already chosen. For instance, if they choose 5 targets then they would not be able to choose any distractors for that trial even if those distractors are still in memory. However, participants do have the option of choosing a lure, which breaks the dependency a little bit. The problem is that participants do not choose lures very often (between 2% and 3 %). Therefore, in Experiment 2, we tried to break this dependency by allowing participants to withhold responding, like the blank option in Engle and colleagues' complex span tasks. They used this option quite often; on average, participants used the blank 6 % of the time with a standard deviation of 7 %. Numerically, low spans used the blank option more often (M = 8%) than high spans (M = 5%). Even with low spans on average using the blank option 8% of the time, they still choose more distractors than high spans.

Another limitation is the difference in the demands between the working memory test and the long-term memory test. They may differ in difficulty level, with the working memory test being more difficult than the long-term memory test, because it required participants to not only remember the difference between items but also their serial position. Whereas the long-term memory test only required participants to remember whether they had seen an item or not. It is possible that the working memory test relies more upon recollection processes than the long-term memory test, thus making it difficult to compare results across memory systems. In future studies, researchers would ideally try to equate both the working memory and long-term memory tests, such as using a recall test for both.

**Conclusions**

Overall, we found mixed evidence in favor of both models. Distractors appear to be forgotten through a removal mechanism in working memory, as predicted by the SOB-CS model. There were differences in the number of distractors remembered in the short over the long free time condition, suggesting that people use free time to remove distractors. Moreover, low spans, with less attentional and inhibition abilities, remembered more distractors from the short than long conditions as compared to high spans, which provides more evidence that forgetting in working memory is a type of active process, like the removal mechanism in the SOB-CS model.

The results from long-term memory were less clear-cut than the results from working memory. There was no difference in the number of distractors recognized in the different free time conditions, but overall fewer distractors were recognized in long-term memory than targets. These results could be support for a decay mechanism, as proposed by the TBRS model, because there were no free time differences, thus suggesting that distractors from both conditions decayed at the same rate. However, these results could also support the SOB-CS model, which proposes that distractors are unbound from serial position representations in working memory, but serial position representations are not needed in long-term memory; meaning that free time differences would not remain in long-term memory. Therefore, it is more difficult to distinguish the models at long-term memory. Further research needs develop a better way to distinguish these two models at long-term memory. Therefore, we believe that distractor forgetting for working memory is best tested in working memory rather than with a long-term memory recognition test.

One point that appears to be missing in the literature is that the two models appear to talk past each other. TBRS proponents, Dagry et al. (2017) and Dagry and Barrouillet (2017), have assumed that the SOB-CS model defined inhibition as a type of item inhibition; however, the SOB-CS model proposes that inhibition removes content-context bindings leaving the item representation intact. Therefore, their method of free-recall and LTM recognition are appropriate to test the accessibility of a distractor representations but not the accessibility of the bindings between a distractor and serial position marker. SOB-CS proponents, Obearuer and Lewandowsky (2017), used a reconstruction test that assesses the distractor-position bindings, but that includes a dependency between the targets and distractors at test, as noted in the limitations section. Overall then, the discrepancy between the findings stemming from the two models may simply be a result of differing definitions of inhibition.

# TABLES

Table 1

*Exp 1- Distractor Input Bayes Factors*

| Models | BF |
|---|---|
| [1] SP | 0.10 |
| [2] FT | **262.68** |
| [3] SP:FT | 0.08 |
| [4] SP + FT | 30.00 |
| [5] SP + SP:FT | 0.01 |
| [6] FT + SP:FT | 23.77 |
| [7] SP + FT + SP:FT | 2.77 |

*Note.* SP = Serial Position; FT= Free Time

Table 2

*Exp 1- Distractor Input-Output Bayes Factors*

| Models | BF |
|---|---|
| [1]SP | 5792.76 |
| [2]FT | 4.64 |
| [3]SP:FT | 0.04 |
| [4]SP + FT | **41456.51** |
| [5]SP + SP:FT | 269.13 |
| [6]FT + SP:FT | 0.21 |
| [7]SP + FT + SP:FT | 1965.76 |

*Note. SP = Serial Position; FT= Free Time*

Table 3

*Exp 1- Distractor Input-Output T-tests Bayes Factors*

| Long Free time | | | | |
|---|---|---|---|---|
| | 1 to 2 | 1 to 3 | 1 to 4 | 1 to 5 |
| Alt | 0.42 | 0.2 | 2.82 | **51.57** |
| Null | 2.39 | 4.99 | 0.35 | 0.02 |
| Short Free time | | | | |
| | 1 to 2 | 1 to 3 | 1 to 4 | 1 to 5 |
| Alt | 0.71 | 0.43 | 1.03 | **9.46** |
| Null | 2.54 | 2.31 | 0.96 | 0.12 |

Table 4

*Exp 1- Distractor vs Targets in LTM Bayes Factors*

| Models | BF |
|---|---|
| [1] FT | 0.20 |
| [2] Item | **1426.07** |
| [3] FT: Item | 0.27 |
| [4] FT + Item | 304.86 |
| [5] FT + FT:Item | 0.05 |
| [6] Item + FT:Item | 371.24 |
| [7] FT + Item + FT:Item | 78.33 |

*Note.* FT= Free Time

Table 5

*Exp 1- LTM RT's Bayes Factors*

| Models | BF |
|---|---|
| [1] FT | 0.22 |
| [2] Item | **10.90** |
| [3] FT:Item | 0.51 |
| [4] FT + Item | 2.35 |
| [5] FT + FT:Item | 0.11 |
| [6] Item + FT:Item | 5.72 |
| [7] FT + Item + FT:Item | 1.24 |

*Note.* FT= Free Time

Table 6

*Exp 1- Inhibit WM to LTM Bayes Factors*

| Models | BF |
|---|---|
| [1] FT | 0.21 |
| [2] Item | **3.21E+19** |
| [3] FT:Item | 0.31 |
| [4] FT + Item | 7.35E+18 |
| [5] FT + FT:Item | 0.06 |
| [6] Item + FT:Item | 1.14E+19 |
| [7] FT + Item + FT:Item | 2.50E+18 |

*Note*. FT= Free Time

Table 7

*Exp 2- WM Distractors Bayes Factors*

| | Models | BF |
|---|---|---|
| [1] | WM | 38.84 |
| [2] | FT | 82473.31 |
| [3] | WM:FT | 0.32 |
| [4] | WM + FT | **2882894.00** |
| [5] | WM + WM:FT | 11.89 |
| [6] | FT + WM:FT | 30578.19 |
| [7] | WM + FT + WM:FT | 1037520.00 |

*Note*. WM= Working Memory Span; FT= Free Time

Table 8

*Exp 2- Distractor Input Bayes Factors*

| | Models | BF |
|---|---|---|
| [1] | FT | 29407.46 |
| [2] | SP | 0.02 |
| [3] | FT + SP | 700.93 |
| [4] | FT + SP + FT:SP | 20.17 |
| [5] | WM | 36.04 |
| [6] | FT + WM | **1031515.00** |
| [7] | SP + WM | 0.83 |
| [8] | FT + SP + WM | 30759.25 |
| [9] | FT + SP + FT:SP + WM | 755.46 |
| [10] | FT + WM + FT:WM | 185685.40 |
| [11] | FT + SP + WM + FT:WM | 4318.21 |
| [12] | FT + SP + FT:SP + WM + FT:WM | 132.93 |
| [13] | SP + WM + SP:WM | 0.01 |
| [14] | FT + SP + WM + SP:WM | 213.39 |
| [15] | FT + SP + FT:SP + WM + SP:WM | 6.49 |
| [16] | FT + SP + WM + FT:WM + SP:WM | 34.08 |
| [17] | FT + SP + FT:SP + WM + FT:WM + SP:WM | 0.99 |
| [18] | FT + SP + FT:SP + WM + FT:WM + SP:WM + FT:SP:WM | 0.08 |

*Note*. WM= Working Memory Span; FT= Free Time; SP= Serial Position

Table 9

*Exp 2- Distractor Input-Output Bayes Factors*

| | Models | BF |
|---|---|---|
| [1] | FT | 0.210636 |
| [2] | SP | **1.82E+17** |
| [3] | FT + SP | 4.50E+16 |
| [4] | FT + SP + FT:SP | 3.32E+15 |
| [5] | WM | 0.8152212 |
| [6] | FT + WM | 0.1693182 |
| [7] | SP + WM | 1.75E+17 |
| [8] | FT + SP + WM | 3.94E+16 |
| [9] | FT + SP + FT:SP + WM | 3.26E+15 |
| [10] | FT + WM + FT:WM | 0.0351064 |
| [11] | FT + SP + WM + FT:WM | 9.78E+15 |
| [12] | FT + SP + FT:SP + WM + FT:WM | 7.46E+14 |
| [13] | SP + WM + SP:WM | 1.37E+16 |
| [14] | FT + SP + WM + SP:WM | 4.03E+15 |
| [15] | FT + SP + FT:SP + WM + SP:WM | 2.62E+14 |
| [16] | FT + SP + WM + FT:WM + SP:WM | 8.30E+14 |
| [17] | FT + SP + FT:SP + WM + FT:WM + SP:WM | 6.57E+13 |
| [18] | FT + SP + FT:SP + WM + FT:WM + SP:WM + FT:SP:WM | 2.78E+12 |

*Note.* WM= Working Memory Span; FT= Free Time; SP= Serial Position

Table 10

*Exp 2- Distractor Input-Output T-tests Bayes Factors*

| Low span | | | | |
|---|---|---|---|---|
| | 1 to 2 | 1 to 3 | 1 to 4 | 1 to 5 |
| Long | 0.26 | 0.47 | 1.99 | **453.65** |
| Short | 0.19 | 2.51 | 2.70 | **143.11** |
| High Span | | | | |
| | 1 to 2 | 1 to 3 | 1 to 4 | 1 to 5 |
| Long | | | | |
| Short | 0.25 | 4.28 | 0.39 | **7509.48** |

*Note:* High span Long t-test could not be run there 0 variance in

| |
|---|
| serial position 1. |

Table 11

*Exp 2- LTM Distractors Bayes Factors*

| | Models | BF |
|---|---|---|
| [1] | WM | 0.63 |
| [2] | FT | 0.57 |
| [3] | WM:FT | 0.26 |
| [4] | WM + FT | 0.35 |
| [5] | WM + WM:FT | 0.16 |
| [6] | FT + WM:FT | 0.15 |
| [7] | WM + FT + WM:FT | 0.09 |

*Note.* WM = Working Memory; FT = Free Time

**FIGURES**

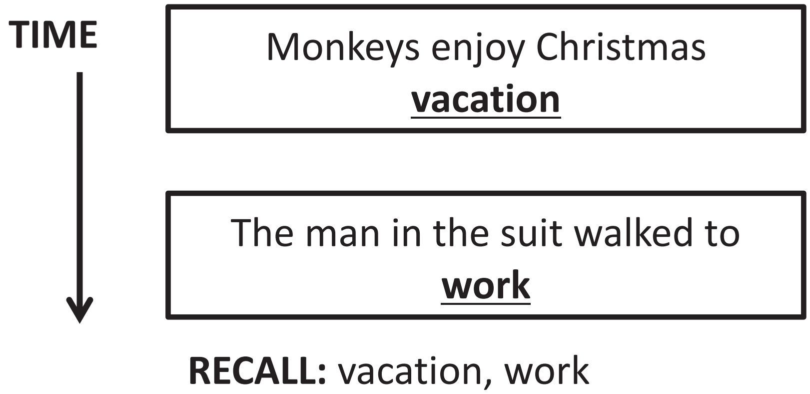


*Figure 1.* This demonstrates Daneman and Carpenter's (1980) version of reading span. Participants are asked to read the sentences, remember the last word of the sentences (in bold) and judge the truthfulness of the sentences. For example, participants would read, "Monkeys enjoy…", and are asked to judge whether that is true or not while remembering the word vacation for later recall.

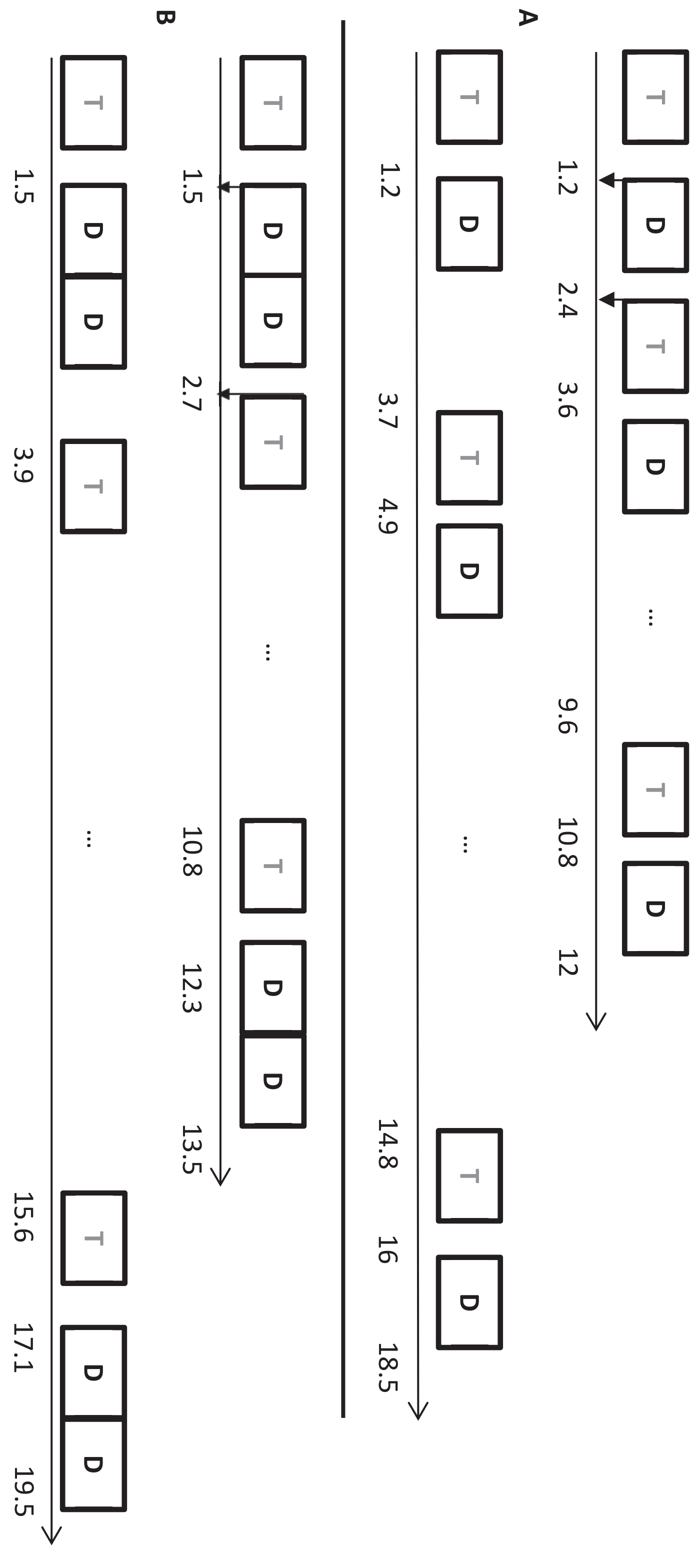


*Figure 2.* (A) This demonstrates the time-line of events for the short free time (first row) and the long free time (second row) for Oberauer & Lewandowsky's (2016) study. (B) This demonstrates the fast paced (first line) and slow paced (second line) condition's in Dagry et al. (2017) study. The letter T represents target items and distractors are represented by the letter D.

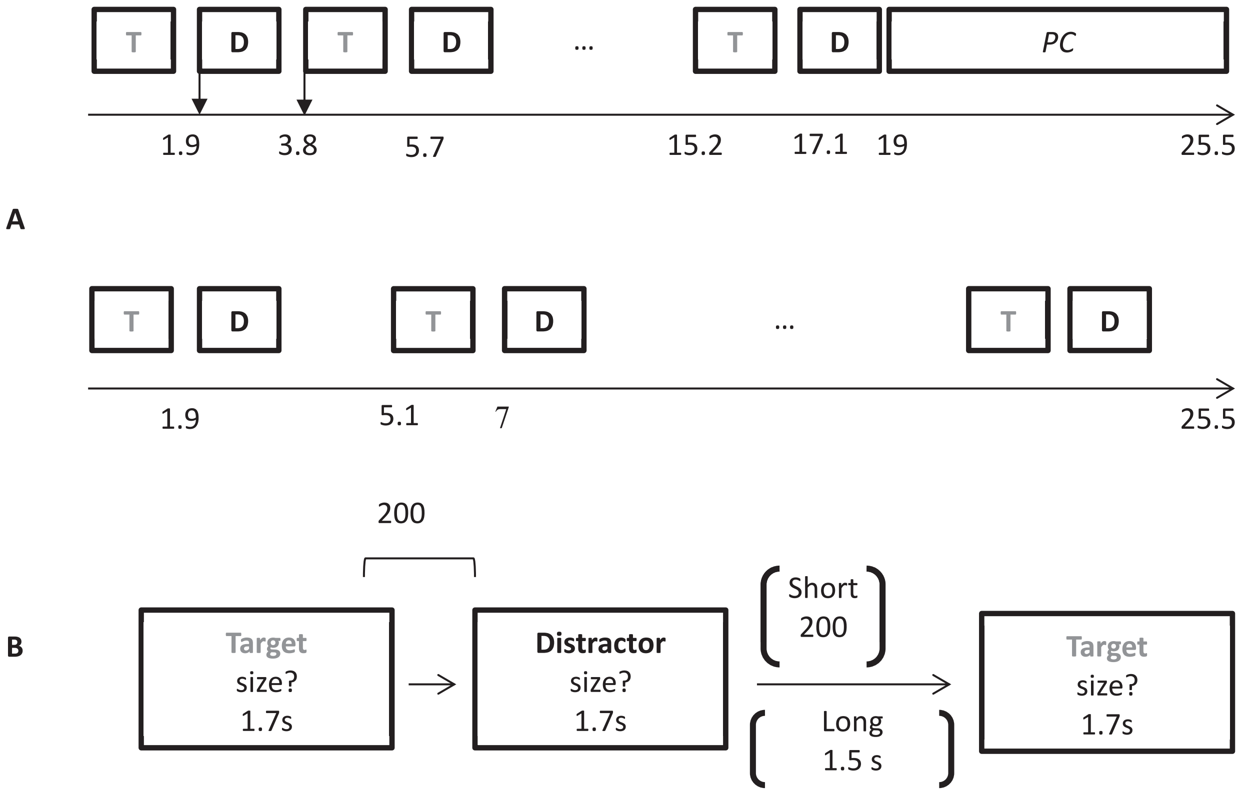


*Figure 3.* (A) Demonstrates the cumulative time line of one trial of distractor span for both the short (first row) and long (second row) free time conditions in seconds. The short free time condition also had a filled retention interval where participants will be completing a pattern comparison task (PC). Targets are represented by a "T" and distractors are represented by a "D". (B) Displays the timing between the target and distractors in the distractor span. The main manipulation is the free time interval, either short (200ms) or long (1.5s) after the distractor word.

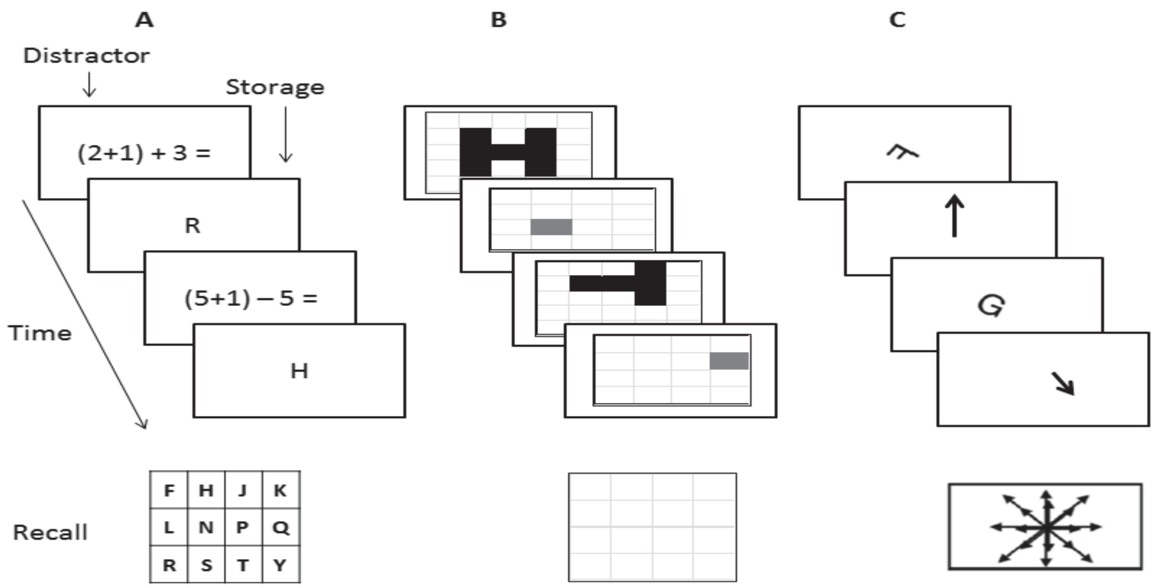


*Figure 4.* Is an illustration of operation span (A) operation span, (B) rotation span, and (C) symmetry span  (Foster et al., 2015).

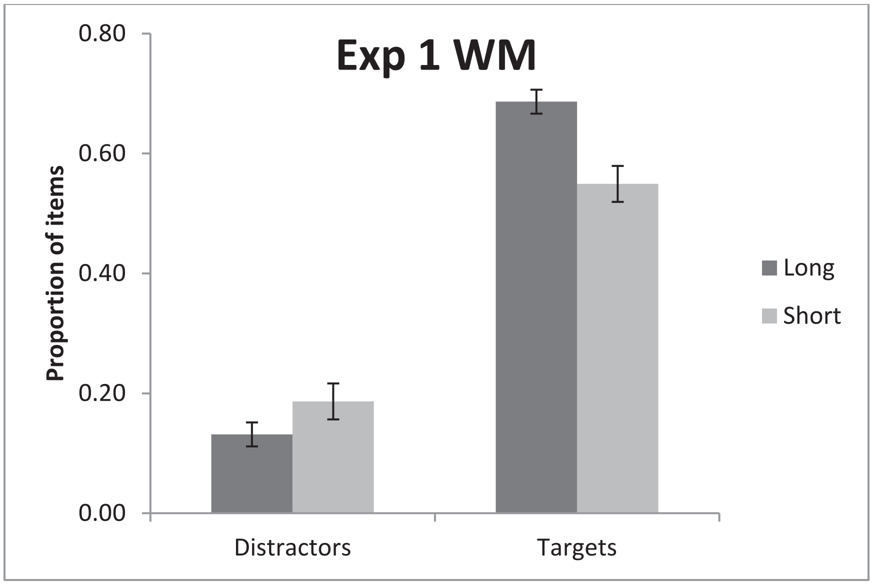


*Figure 5.* Working memory results from Experiment 1. There was evidence of difference between free time conditions for both distractors and targets.

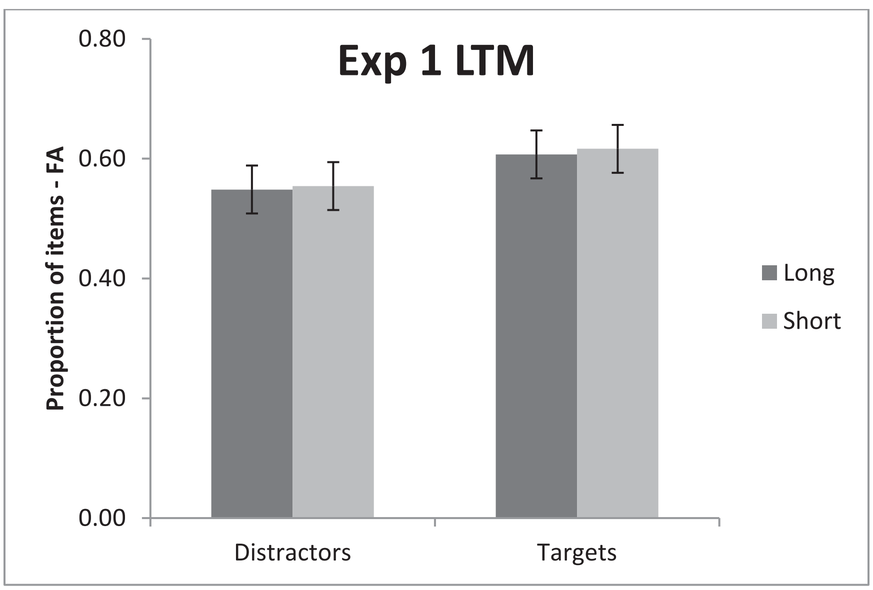


*Figure 6.* Long-term memory results from Experiment 1. There were no free time differences in targets or distractors.

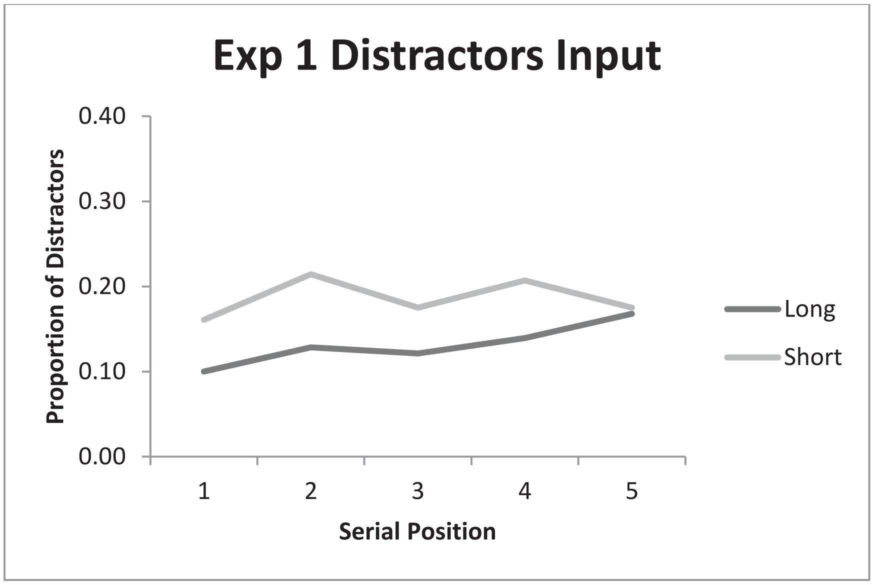


*Figure 7.* The distractor input serial position curve for Experiment 1. There was a free time difference between short and long, but no differences in serial position.

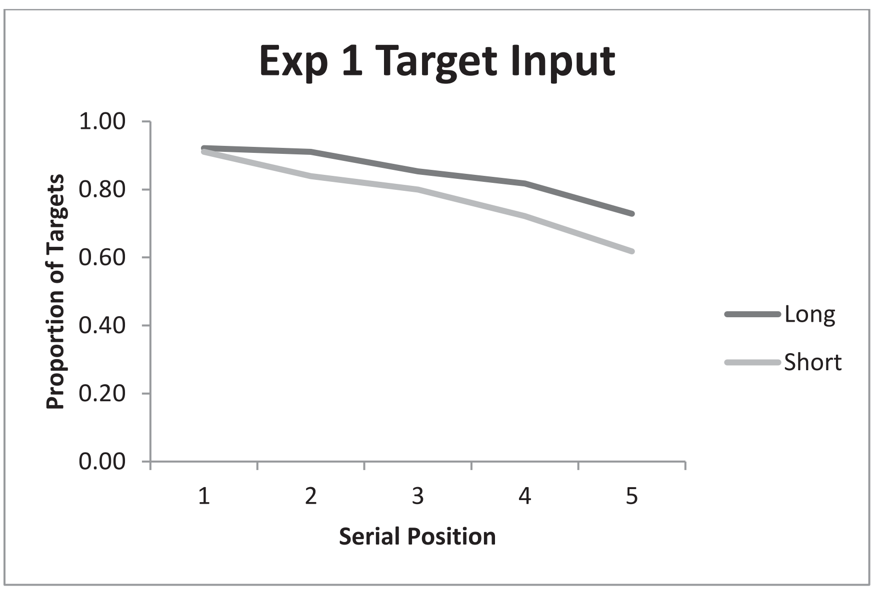


*Figure 8.* The target input serial position curve for Experiment 1.

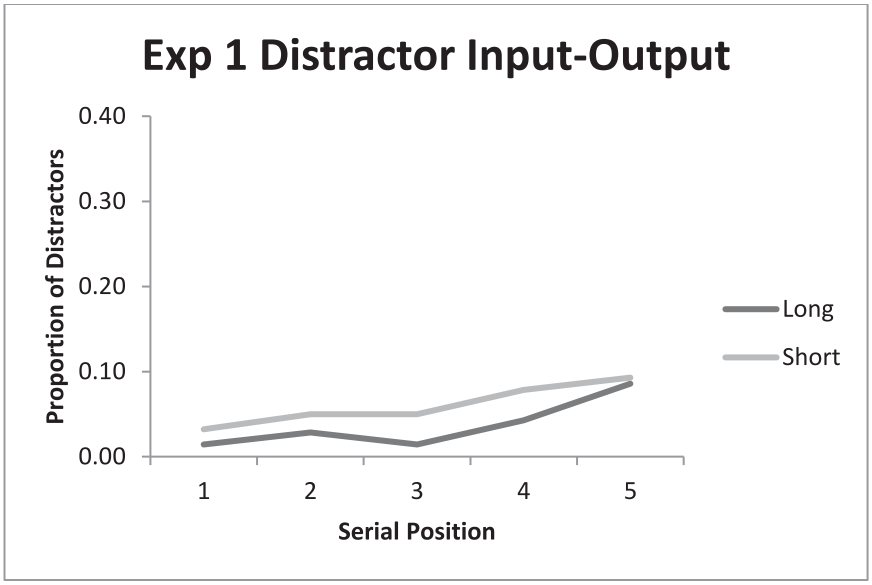


*Figure 9.* The distractor input-output curve from Experiment 1. There was a small recency effect.

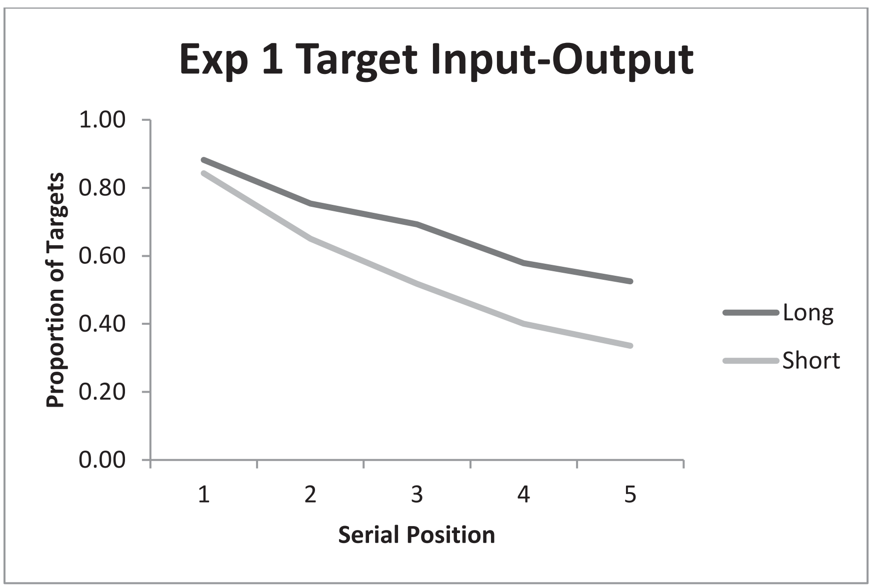


*Figure 10*. The target input-output curve from Experiment 1.

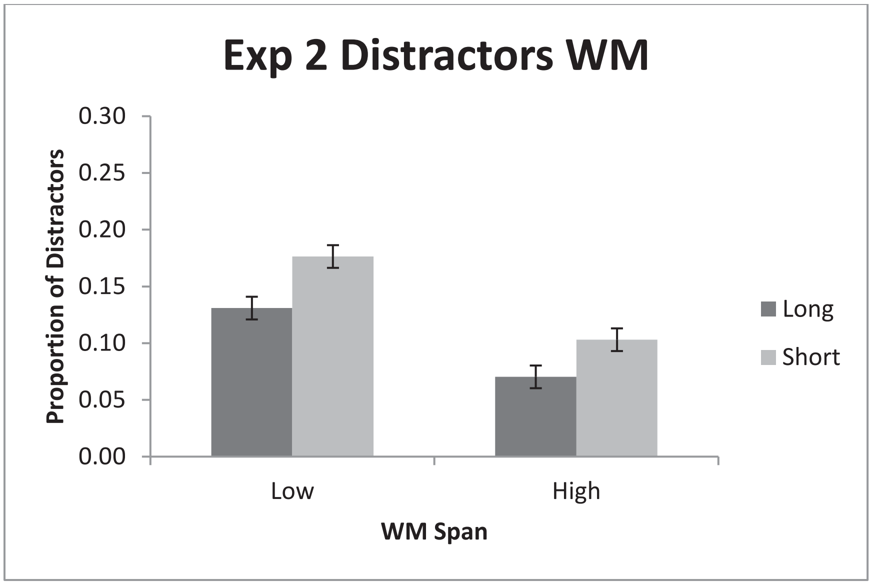


*Figure 11.* Distractors found in working memory (WM) in Experiment 2. Low spans mistakenly recognized more distractors that high spans.


*Figure 12.* Target memory scored with a strict criteria in Experiment 2. Low spans remembered fewer targets then high spans.

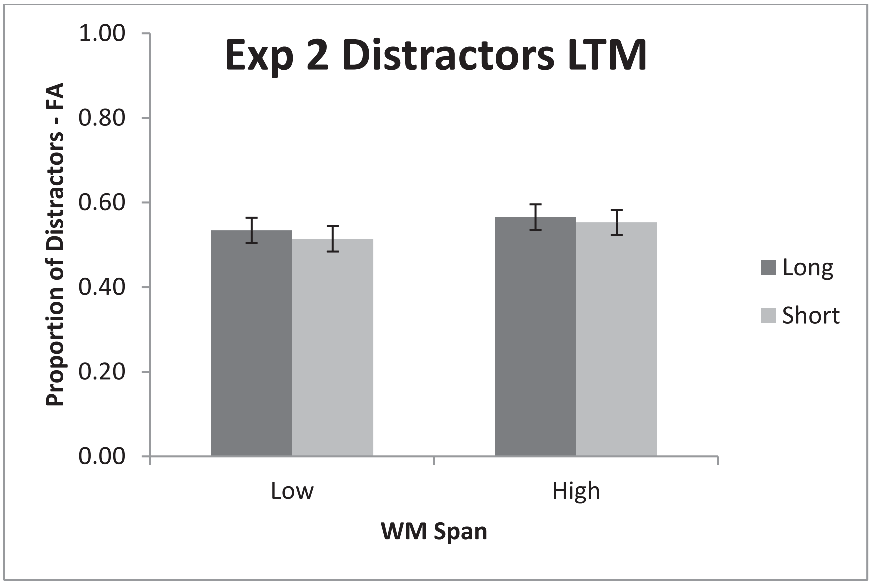


*Figure 13.* Long-term distractor memory in Experiment 2. There is no difference in distractor memory between spans.

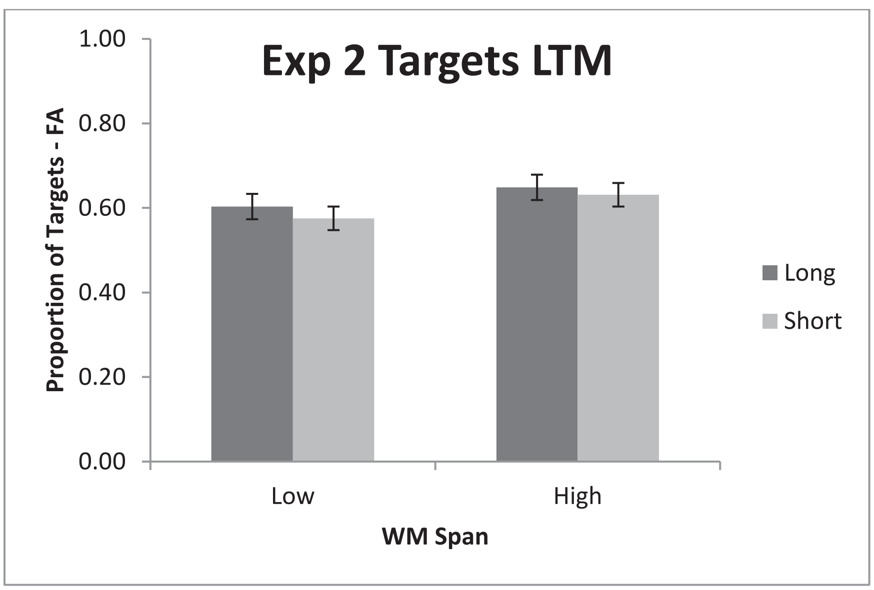


*Figure 14.* Long-term target memory in Experiment 2.

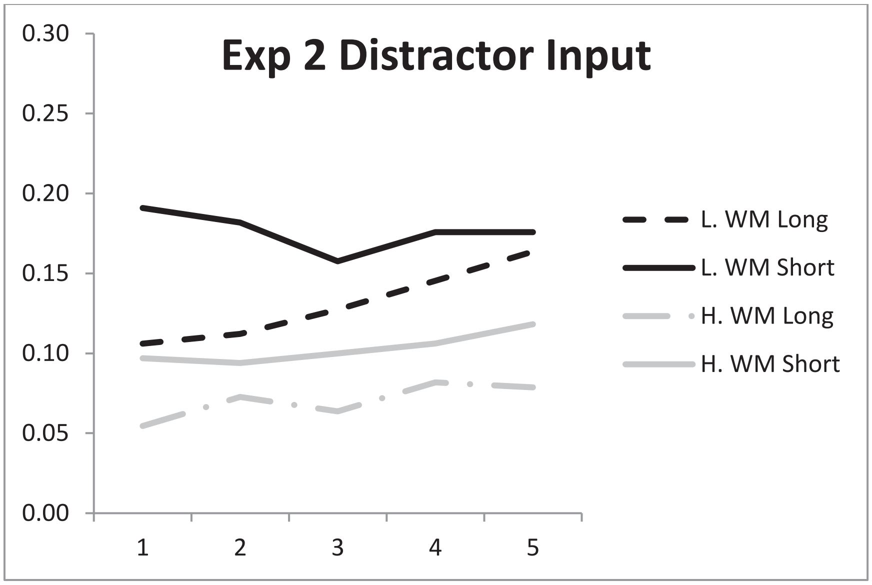


*Figure 15.* The distractor input curve for Experiment 2. There was a difference between spans and free-time, but no serial position differences.

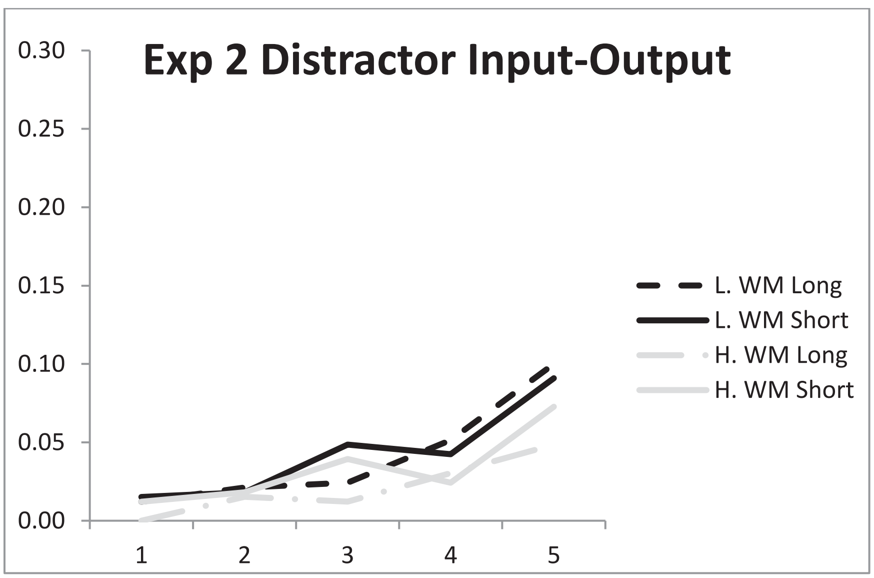


*Figure 16.* The distractor input-output curve for Experiment 2. There was no difference between spans or free time, but there was a difference in serial position.

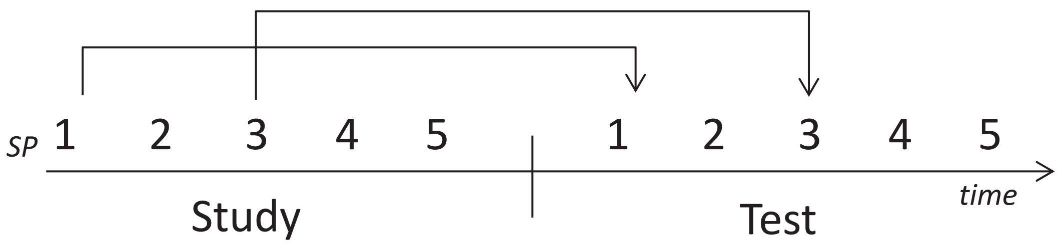


Figure 17. This demonstrates the reason that TBRS model predicts a flat input-output curve. The item from serial position 1 will experience the same amount of decay as the item in all the other serial positions, like serial position 3.

## REFERENCES


Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working Memory and Intelligence: The Same or Different Constructs?. *Psychological Bulletin*, *131*(1), 30-60. doi:10.1037/0033-2909.131.1.30

Anderson, J. A. (1991). Why, having so many neurons, do we have so few thoughts?. In W. E. Hockley, S. Lewandowsky, W. E. Hockley, S. Lewandowsky (Eds.), *Relating theory and data: Essays on human memory in honor of Bennet B. Murdock* (pp. 477-507). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc.

Anderson, J. A. (1995).An Introduction to Neural Networks. Cambridge, MA: MIT Press; 1995.

Anderson, M. C., & Levy, B. (2002). Repression can (and should) be studied empirically. *Trends in Cognitive Sciences*, *6*(12), 502-503. doi:10.1016/S1364-6613(02)02025-9

Barrouillet, P., & Camos, V. (2012). As time goes by: Temporal constraints in working memory. *Current Directions in Psychological Science*, *21*(6), 413-419. doi:10.1177/0963721412459513

Barrouillet, P., & Camos, V. (2015). *Working memory: Loss and reconstruction*. New York, NY, US: Psychology Press.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time Constraints and Resource Sharing in Adults' Working Memory Spans. *Journal of Experimental Psychology: General*, *133*(1), 83-100. doi:10.1037/0096-3445.133.1.83

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(3), 570-585. doi:10.1037/0278-7393.33.3.570

Barrouillet, P., Gavens, N., Vergauwe, E., Gaillard, V., & Camos, V. (2009). Working memory span development: A time-based resource-sharing model account. *Developmental Psychology*, *45*(2), 477-490. doi:10.1037/a0014615

Barrouillet, P., Lépine, R., & Camos, V. (2008). Is the influence of working memory capacity on high-level cognition mediated by complexity or resource-dependent elementary processes?. *Psychonomic Bulletin & Review*, *15*(3), 528-534. doi:10.3758/PBR.15.3.528

Barrouillet, P., Portrat, S., & Camos, V. (2011). On the law relating processing to storage in working memory. *Psychological Review*, *118*(2), 175-192. doi:10.1037/a0022324

Barrouillet, P., Portrat, S., Vergauwe, E., Diependaele, K., & Camos, V. (2011). Further evidence for temporal decay in working memory: Reply to Lewandowsky and Oberauer (2009). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1302-1317. doi:10.1037/a0022933

Brown, J. (1958). Some tests of the decay theory of immediate memory. *The Quarterly Journal of Experimental Psychology*, *10*12-21. doi:10.1080/17470215808416249

Camos, V., & Portrat, S. (2015). The impact of cognitive load on delayed recall. *Psychonomic Bulletin & Review*, *22*(4), 1029-1034. doi:10.3758/s13423-014-0772-5

Camos, V., Lagner, P., & Barrouillet, P. (2009). Two maintenance mechanisms of verbal information in working memory. *Journal of Memory and Language*, *61*(3), 457-469. doi:10.1016/j.jml.2009.06.002

Cantor, J., Engle, R. W., & Hamilton, G. (1991). Short-term memory, working memory, and verbal abilities: How do they relate?. *Intelligence*, *15*(2), 229-246. doi:10.1016/0160-2896(91)90032-9

Carretti, B., Cornoldi, C., De Beni, R., & Palladino, P. (2004). What happens to information to be suppressed in working-memory tasks? Short and long term effects. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *57A*(6), 1059-1084. doi:10.1080/02724980343000684

Coltheart, M. (1981). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *33A*(4), 497-505. doi:10.1080/14640748108400805

Conway, A. A., Jarrold, C., Kane, M. J., Miyake, A., & Towse, J. N. (2007). Variation in working memory: An introduction. In A. A. Conway, C. Jarrold, M. J. Kane, J. N. Towse, A. A. Conway, C. Jarrold, ... J. N. Towse (Eds.) , *Variation in working memory* (pp. 3-17). New York, NY, US: Oxford University Press.

Conway, A. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7*(12), 547-552. doi:10.1016/j.tics.2003.10.005

Conway, A. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769-786. doi:10.3758/BF03196772

Cowan, N. (1992). Verbal memory span and the timing of spoken recall. *Journal of Memory and Language*, *31*(5), 668-684. doi:10.1016/0749-596X(92)90034-U

Cowan, N. (2000). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*(1), 87-185. doi:10.1017/S0140525X01003922

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*(1), 87-185. doi:10.1017/S0140525X01003922

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science*, *19*(1), 51-57. doi:10.1177/0963721409359277

Cowan, N. (2016). The many faces of working memory and short-term storage. *Psychonomic Bulletin & Review*, doi:10.3758/s13423-016-1191-6

Dagry, I., & Barrouillet, P. (2017). The fate of distractors in working memory: No evidence for their active removal. *Cognition*, *169*, 129–138. https://doi.org/10.1016/j.cognition.2017.08.011

Dagry, I., Vergauwe, E., & Barrouillet, P. (2017). Cleaning working memory: The fate of distractors. *Journal of Memory and Language*, *92*327-342. doi:10.1016/j.jml.2016.08.002

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning & Verbal Behavior, 19*(4), 450-466. doi:10.1016/S0022-5371(80)90312-6

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review*, *3*(4), 422-433. doi:10.3758/BF03214546

De Beni, R., Palladino, P., Pazzaglia, F., & Cornoldi, C. (1998). Increases in intrusion errors and working memory deficit of poor comprehenders. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *51A*(2), 305-320. doi:10.1080/027249898391648

Ecker, U. H., Lewandowsky, S., & Oberauer, K. (2014). Removal of information from working memory: A specific updating process. *Journal of Memory and Language*, *74*77-90. doi:10.1016/j.jml.2013.09.003

Ecker, U. H., Lewandowsky, S., Oberauer, K., & Chee, A. H. (2010). The components of working memory updating: An experimental decomposition and individual differences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(1), 170-189. doi:10.1037/a0017891

Ecker, U. H., Oberauer, K., & Lewandowsky, S. (2014). Working memory updating involves item-specific removal. *Journal of Memory and Language*, *74*1-15. doi:10.1016/j.jml.2014.03.006

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science*, *11*(1), 19-23. doi:10.1111/1467-8721.00160

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*(3), 309-331. doi:10.1037/0096-3445.128.3.309

Farrell, S. (2012). Temporal clustering and sequencing in short-term memory and episodic memory. *Psychological Review*, *119*(2), 223-271. doi:10.1037/a0027371

Festini, S. B., & Reuter-Lorenz, P. A. (2013). The short- and long-term consequences of directed forgetting in a working memory task. *Memory*, *21*(7), 763-777. doi:10.1080/09658211.2012.754900

Gaillard, V., Barrouillet, P., Jarrold, C., & Camos, V. (2011). Developmental differences in working memory: Where do they come from?. *Journal of Experimental Child Psychology*, *110*(3), 469-479. doi:10.1016/j.jecp.2011.05.004

Garavan, H. (1998). Serial attention within working memory. *Memory & Cognition*, *26*(2), 263-276. doi:10.3758/BF03201138

Guérard, K., & Tremblay, S. (2008). Revisiting evidence for modularity and functional equivalence across verbal and spatial domains in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(3), 556–569. https://doi.org/10.1037/0278-7393.34.3.556

Healey, M. K., Campbell, K. L., Hasher, L., & Ossher, L. (2010). Direct evidence for the role of inhibition in resolving interference in memory. *Psychological Science*, *21*(10), 1464-1470. doi:10.1177/0956797610382120

Henson, R. N. A., Norris, D. G., Page, M. P. A., & Baddeley, A. D. (1996). Unchained memory: Error patterns rule out chaining models of immediate serial recall. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *49A*(1), 80–115. https://doi.org/10.1080/027249896392810

JASP Team (2018). JASP (Version 0.10.0)[Computer software].

Kail, R., & Hall, L. K. (2001). Distinguishing short-term memory from working memory. *Memory & Cognition*, *29*(1), 1-9. doi:10.3758/BF03195735

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The Generality of Working Memory Capacity: A Latent-Variable Approach to Verbal and Visuospatial Memory Span and Reasoning. *Journal of Experimental Psychology: General*, *133*(2), 189-217. doi:10.1037/0096-3445.133.2.189

Keller, T. A., & Cowan, N. (1994). Developmental increase in the duration of memory for tone pitch. *Developmental Psychology*, *30*(6), 855-863. doi:10.1037/0012-1649.30.6.855

Kuhl, B. A., Dudukovic, N. M., Kahn, I., & Wagner, A. D. (2007). Decreased demands on cognitive control reveal the neural processing benefits of forgetting. *Nature Neuroscience*, *10*(7), 908-914. doi:10.1038/nn1918

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?!. *Intelligence*, *14*(4), 389-433. doi:10.1016/S0160-2896(05)80012-1

Lewandowsky, S., & Farrell, S. (2008). Phonological similarity in serial recall: Constraints on theories of memory. *Journal of Memory and Language*, *58*(2), 429-448. doi:10.1016/j.jml.2007.01.005

Lewandowsky, S., & Farrell, S. (2008). Short-term memory: New data and a model. In B. H. Ross, B. H. Ross (Eds.) , *The psychology of learning and motivation: Advances in research and theory, Vol. 49* (pp. 1-48). San Diego, CA, US: Elsevier Academic Press. doi:10.1016/S0079-7421(08)00001-7

Lewandowsky, S., Geiger, S. M., & Oberauer, K. (2008). Interference-based forgetting in verbal short-term memory. *Journal of Memory and Language*, *59*(2), 200-222. doi:10.1016/j.jml.2008.04.004

Lewandowsky, S., Geiger, S. M., Morrell, D. B., & Oberauer, K. (2010). Turning simple span into complex span: Time for decay or interference from distractors?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(4), 958-978. doi:10.1037/a0019764

Lewis-Peacock, J. A.,  Kessler, Y. & Oberauer, K. (2018). The removal of information from working memory. *Annals of the New York Academy of Sciences, 1424*, 33-44. doi: 10.1111/nyas.13714

Loaiza, V. M., & McCabe, D. P. (2012). Temporal–contextual processing in working memory: Evidence from delayed cued recall and delayed free recall tests. *Memory & Cognition*, *40*(2), 191-203. doi:10.3758/s13421-011-0148-2

Loaiza, V. M., & McCabe, D. P. (2013). The influence of aging on attentional refreshing and articulatory rehearsal during working memory on later episodic memory performance. *Aging, Neuropsychology, and Cognition*, *20*(4), 471-493. doi:10.1080/13825585.2012.738289

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*(4), 492-527. doi:10.1037/0033-295X.95.4.492

McCabe, D. P. (2008). The role of covert retrieval in working memory span tasks: Evidence from delayed recall tests. *Journal of Memory and Language*, *58*(2), 480-494. doi:10.1016/j.jml.2007.04.004

McElree, B. (2006). Accessing recent events. In B. H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory., Vol. 46.* (Vol. 46, pp. 155–200). San Diego, CA: Elsevier Academic Press. https://doi.org/10.1016/S0079-7421(06)46005-9

Morey, R. D. (2015). Using the BayesFactor package version 0.9.2+. From: <http://bayesfactorpcl.r-forge.r-project.org/>.

Morey, R. D., & Rouder, J. N. (2015). BayesFactor (Version 0.9.2). Retrieved from: <http://cran.at.r-project.org/web/packages/BayesFactor/index.html>.

Oberauer, K. (2005). Control of the Contents of Working Memory--A Comparison of Two Paradigms and Two Age Groups. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(4), 714–728. https://doi.org/10.1037/0278-7393.31.4.714

Oberauer, K. (2009). Interference between storage and processing in working memory: Feature overwriting, not similarity-based competition. *Memory & Cognition*, *37*(3), 346-357. doi:10.3758/MC.37.3.346

Oberauer, K., & Lewandowsky, S. (2008). Forgetting in immediate serial recall: Decay, temporal distinctiveness, or interference?. *Psychological Review*, *115*(3), 544-576. doi:10.1037/0033-295X.115.3.544

Oberauer, K., & Lewandowsky, S. (2011). Modeling working memory: A computational implementation of the Time-Based Resource-Sharing theory. *Psychonomic Bulletin & Review*, *18*(1), 10-45. doi:10.3758/s13423-010-0020-6

Oberauer, K., & Lewandowsky, S. (2013). Evidence against decay in verbal working memory. *Journal of Experimental Psychology: General*, *142*(2), 380-411. doi:10.1037/a0029588

Oberauer, K., & Lewandowsky, S. (2016). Control of information in working memory: Encoding and removal of distractors in the complex-span paradigm. *Cognition*, *156*106-128. doi:10.1016/j.cognition.2016.08.007

Oberauer, K., Farrell, S., Jarrold, C., Pasiecznik, K., & Greaves, M. (2012). Interference between maintenance and processing in working memory: The effect of item–distractor similarity in complex span. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(3), 665-685. doi:10.1037/a0026337

Oberauer, K., Lewandowsky, S., Farrell, S., Jarrold, C., & Greaves, M. (2012). Modeling working memory: An interference model of complex span. *Psychonomic Bulletin & Review*, *19*(5), 779-819. doi:10.3758/s13423-012-0272-4

Öztekin, I., Davachi, L., & McElree, B. (2010). Are representations in working memory distinct from representations in long-term memory? Neural evidence in support of a single store. *Psychological Science*, *21*(8), 1123–1133. https://doi.org/10.1177/0956797610376651

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, *58*(3), 193-198. doi:10.1037/h0049234

Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M. R. (2007). Refreshing: A minimal executive function. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, *43*(1), 135-145. doi:10.1016/S0010-9452(08)70451-9

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*, *28*(3), 164-171. doi:10.1027/1015-5759/a000123

Robert, C., Borella, E., Fagot, D., Lecerf, T., & De Ribaupierre, A. (2009). Working memory and inhibitory control across the life span: Intrusion errors in the Reading Span Test. *Memory & Cognition, 37*(3), 336-345. doi:10.3758/MC.37.3.336

Rohrer, D., Pashler, H., & Etchegaray, J. (1998). When two memories can and cannot be retrieved concurrently. *Memory & Cognition*, *26*(4), 731-739. doi:10.3758/BF03211393

Raftery, A. E. (1995). Bayesian model selection in social research. *Sociological Methodology, 25,* 11-163.

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science*, *2*(3), 179-183. doi:10.1111/j.1467-9280.1991.tb00127.x4

Saults, J. S., & Cowan, N. (1996). The development of memory for ignored speech. *Journal of Experimental Child Psychology*, *63*(1), 239-261. doi:10.1006/jecp.1996.0049

Towse, J. N., & Hitch, G. J. (1995).Is there a relationship between task demand and storage space in tests of working memory capacity? *Quarterly Journal of Experimental Psychology, 48,* 108-124.1995-32672-001

Towse, J. N., Hitch, G. J., & Hutton, U. (2000). On the interpretation of working memory span in adults. *Memory & Cognition*, *28*(3), 341-348. doi:10.3758/BF03198549

Unsworth, N. (2007). Individual differences in working memory capacity and episodic retrieval: Examining the dynamics of delayed and continuous distractor free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(6), 1020-1034. doi:10.1037/0278-7393.33.6.1020

Unsworth, N. (2016). Working memory capacity and recall from long-term memory: Examining the influences of encoding strategies, study time allocation, search efficiency, and monitoring abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(1), 50-61. doi:10.1037/xlm0000148

Unsworth, N., & Brewer, G. A. (2009). Examining the relationships among item recognition, source recognition, and recall from an individual differences perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(6), 1578–1585. https://doi.org/10.1037/a0017255

Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: An examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin, 133*, 1038–1066. doi:10.1037/0033- 2909.133.6.1038

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*(3), 498-505. doi:10.3758/BF03192720

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory*, *17*(6), 635-654. doi:10.1080/09658210902998047

**CURRICULUM VITAE**

# Laura Lucille Sarah Werner

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## EDUCATION

### University of Nevada, Las Vegas

Ph. D Experimental Psychology (Current)
Qualifying Activity: The Aging of Working Memory
Dissertation: Forgetting distractors: Inhibition or decay?
Advisor: Dr. Colleen Parks

### University of North Carolina Wilmington

M.A. Experimental Psychology (2014)
Thesis: The Role of Working Memory in Preventing the Cognitive Depletion Caused by Decisions
Advisor: Dr. Karen Daniels

### University of North Carolina Greensboro

B.A. Psychology (2010)

## AWARDS

### 2019

- UNLV College of Liberal Arts (COLA) Ph.D. Student Summer Research Stipend
- UNLV Graduate and Professional Student Sponsorship- Spring & Fall

### 2018

- American Psychological Association(APA) Psychological Science Student Research Grant
- Psychonomic Society Graduate Travel Award
- Patricia Sastaunik Scholarship
- UNLV College of Liberal Arts (COLA) Ph.D. Student Summer Research Stipend
- UNLV Graduate and Professional Student Sponsorship – Spring & Summer

### 2016

- Association for Psychological Science Campus Representative Spotlight

**2015**

- UNLV College of Liberal Arts (COLA) PhD Student Summer Faculty Research Stipend

**2014**

- UNLV Graduate and Professional Student Sponsorship

## PUBLICATIONS

Parks, C.M., & **Werner, L.L.S** (under review). Repetition Effects in Auditory and Visual Recognition. *Acta Psychologia.*

Parks, C.M., Mohawk, K. D., **Werner, L.L.S.**, & Kiley, C. (registered replication). The Time Window of Reconsolidation: A Replication. *Psychonomic Bulletin & Review.*

## PRESENTATIONS

**Werner, L.L.S**., & Parks, C.M. (2019). Inhibition vs. Decay: Using Individual Differences to Test Working Memory Models. Poster presented at the 60th Annual Meeting of the Psychonomic Society, Montreal, Quebec, Canada.

**Werner, L.L.S**., & Parks, C.M. (2018). Forgetting Distractors: Evidence of inhibition and decay in working memory depends on test type. Poster presented at the 59th Annual Meeting of the Psychonomic Society, New Orleans, LA.

**Werner, L.L.S**., & Parks, C.M. (2018). Forgetting distractors: An investigation of competing theories of inhibition and decay in working memory. Poster presented at 98th Annual Convention of the Western Psychological Association, Portland, OR.

**Werner, L.L.S**., & Parks, C.M. (2018). What is the fate of distractors in a working memory span task? Poster presented at Graduate & Professional Student Research Forum at the University of Nevada, Las Vegas ,Las Vegas, NV.

**Werner, L.L.S.** (2017). How do distractors get removed from memory? Presented at UNLV Rebel Grand Slam: 3 minute thesis competition, Las Vegas, NV.

**Werner, L.L.S.** (2016). Do mindful people have better working memory ability? Presented at UNLV Rebel Grand Slam: 3 minute thesis competition, Las Vegas, NV.

**Werner, L.L.S.,** & Daniels, K. A. (2015). Cognitive depletion: Exploring the consequences of having too many options. Poster presented at Graduate & Professional Student Research Forum at the University of Nevada, Las Vegas, Las Vegas, NV.

**Werner. L.L.S.**, Hartman. E. S., Daniels, K. A., & Toth. J. P. (2014). The role of working memory in preventing the cognitive depletion caused by decisions. Poster presented at North Carolina Cognition Conference(NCCC) at Duke University, Durham, NC.

## ONGOING PROJECTS

Werner, L.L.S., & Parks, C.M. Decay and inhibition in working memory
Werner, L.L.S., & Parks, C.M. Source monitoring of distractor information
Werner, L.L.S., & Parks, C.M. Search set size and inhibition in directed forgetting

Werner, L.L.S., & Parks, C.M. Individual differences in distractor memory

## TEACHING EXPERIENCE

**Instructor**, General Psychology (Psy 101), University of Nevada, Las Vegas, Fall 2016- Present.

- I have prepared and taught several Psychology 101 courses both in person and online that cover the treatment of psychological disorders, sensation-perception, cognition, physiological psychology, learning, personality, development, social psychology, and history.

**Teaching Assistant**, Foundations of Cognitive Psychology (Psy 316), University of Nevada, Las Vegas, Fall 2017- Spring 2018. I worked under the supervision of Dr. Colleen Parks.

- This course provides an introduction to the major phenomena, methods, concepts, and theories that make-up the field of cognitive psychology. My main responsibility was providing feedback on article summaries and grading short-answers on tests.

**Teaching Assistant**, Introduction to the Psychology Major (Psy 200), University of Nevada, Las Vegas, Fall 2014. I worked under the supervision of Dr. David Copeland.

- This is an online course that provides students with knowledge regarding psychology major requirements, how to write in APA style, the different types of jobs available to psychology graduates, the requirements for graduate school, etc. I primarily provided detailed feedback for online assignments.

## SERVICE

**American Psychological Association (APA) Student Grant Competition, Reviewer,** 2018

- Reviewed submissions for the APA student grant award.

**American Psychological Science (APS) Student Coordinator,** 2016- 2019

- My main responsibility was to keep UNLV students informed of all the opportunities at APS, like available grants etc.

**Undergraduate Mentor for the Outreach Undergraduate Mentoring Program (OUMP),** University of Nevada, Las Vegas, 2014- 2018

- I mentored underrepresented undergraduates, who were interested in pursuing graduate school. I helped them with their application materials for graduate school. For example, I helped them prepare for the GRE, write personal statements, find schools that fit their interests, etc.

**Association for Psychological Science Student Grant Competition (APSSC),** 2015- present

- Reviewed submissions for the APS student grant award.

**Cognitive Emphasis Representative,** University of Nevada, Las Vegas- Experimental Student Committee, 2015

- It was my job to be a liaison between the faculty cognitive coordinator and the students in order to keep the students informed about any changes in requirements and upcoming classes.

## PROFESSIONAL AFFILIATIONS

- American Psychological Science(APS): Student Member
- Psychonomic Society: Student Member