ATTENTION TO AND MEMORY REACTIVATION OF LONG-TERM MEMORIES WHEN ANTICIPATING UPCOMING INTERFERENCE

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ABSTRACT

ATTENTION TO AND MEMORY REACTIVATION OF LONG-TERM MEMORIES WHEN ANTICIPATING UPCOMING INTERFERENCE

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PSYCHOLOGY M.A. THESIS, JULY 2023

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Although the effects of interference on working memory and long-term memory retrieval are well-studied, the effects of anticipating interference on working memory maintenance of long-term memories are yet to be explored. In this thesis, I aimed to explore whether anticipating upcoming interference would modulate the extent to which long-term memories are reactivated in working memory. In Chapter 2, participants were presented with a previously studied item, and after an interval, they reported the item they were presented with. Half of the blocks, the retention period contained a perceptual interference screen which they were instructed to ignore. In Chapter 3, we added a baseline condition that probed the participants with novel items. We manipulated the memory load by implementing a condition in which participants were presented with three items. Lastly, we replaced the perceptual interference with an interference task to increase the cost of interference. Overall, the findings from these chapters suggest that there is no WM reactivation difference when anticipating interference or not. Moreover, when the interference can be ignored (i.e., perceptual interference), participants stop attending to the memory item location, probably to inhibit future distractor encoding. When interference cannot be ignored (i.e., interference task), participants attended the memory items later in the retention interval.

ÖZET

ÇELDİRİCİ BEKLERKEN UZUN SÜRELİ BELLEKTEKİ BİLGİYE YÖNELİK DİKKAT VE BİLGİNİN KISA SÜRELİ BELLEKTE YENİDEN AKTİVE EDİLMESİ

NURSENA ATASEVEN ÖZDEMİR

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Anahtar Kelimeler: çalışan bellek, uzun süreli bellek, çeldirici, dikkat, kontralateral tutulma aktivitesi

Çeldiricilerin çalışan bellek ve uzun süreli bellekten bilgi alma üzerindeki etkileri iyi çalışılmış olmasına rağmen, çeldiricilerin öngörülmesinin uzun süreli belleklerin çalışma belleğinde tutulmasına etkisi henüz araştırılmamıştır. Bu tezde, öngörülmekte olan çeldiricileri önceden tahmin etmenin, çalışan bellekte uzun süreli bilgilerin yeniden etkinleştirilme derecesini değiştirip değiştirmeyeceğini araştırmayı amaçladım. 2. Bölümde, katılımcılara daha önce öğrendikleri bir öğe sunuldu ve bir aradan sonra kendilerine sunulan öğrenilmiş öğeyi bildirdiler. Bekleme aralığında blokların yarısı göz ardı etmeleri talimatı verilen bir algısal çeldirici ekranı içeriyordu. Bölüm 3'te, katılımcıları yeni öğelerden test eden bir temel durum ekledik. Katılımcılara üç öğenin sunulduğu bir koşul ekleyerek bellek yükünü manipüle ettik. Son olarak, çeldiricilerin bellek üzerindeki etkisini artırmak için algısal çeldiricileri ikincil çeldirici göreviyle değiştirdik. Genel olarak, bu bölümlerden elde edilen bulgular, çeldiricilerin öngörülüp öngörülmediği durumlarda çalışan bellekte yeniden etkinleştirme farkı olmadığını göstermektedir. Ayrıca, çeldiriciler göz ardı edilebildiğinde (yani, algısal çeldiriciler), katılımcılar, muhtemelen gelecekteki çeldiricileri kodlamayı engellemek için bellek öğesinin konumuna dikkat etmeyi bıraktı. Çeldiriciler göz ardı edilemediğinde (yani, ikincil çeldirici görevi), katılımcılar bekleme aralığının geç kısımlarında bellek öğelerine dikkat etmeye başladı.

ACKNOWLEDGEMENTS

Dedication page
Dedicated to my late uncle Ahmet Rıfkı Ataseven

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1.   GENERAL INTRODUCTION

Everyday tasks require humans to constantly rely on their previous memories, quickly form new memories or actively represent existing memories. For example, when walking into a supermarket, you see that your favorite chocolate bar is on sale. You need to memorize that you will buy that chocolate bar when you reach the chocolate aisle. Long-term memory (LTM) passively stores previous memories (Atkinson and Shiffrin 1968; Cowan 2008; James 1890; Rubin and Wenzel 1996), such as your favorite chocolate bar. On the other hand, working memory (WM) represents new memories or retrieved LTMs (Cowan 1999; Oberauer 2002) in an active mental workspace (but see Liu et al. 2022) which might involve relevant behavioral goals (Carlisle et al. 2011) such as buying your favorite chocolate. Therefore, interplays between LTM and WM systems are crucial to aid future everyday behavior.

1.1 The Role of Prospective Memories in Everyday Goal-directed Behavior

Memory systems not only function to remember the past but also serve the future (Brandimonte, Einstein, and McDaniel 2014; Cona et al. 2015). Planning future behavior using previous memories and executing the future behavior correctly is an important aspect of memories, which is referred to as prospective memories (PM, Brandimonte, Einstein, and McDaniel 2014; Kliegel et al. 2002; McDaniel and Einstein 2000). For instance, if you planned a family trip for next week, you need to remember to talk to your boss to take a week off for the trip. Some studies suggest that prospective memories might necessitate the maintenance of information related to future goals in WM and top-down attentional control to scan the environment for the anticipated memory cues (Burgess, Quayle, and Frith 2001; Smith 2003 but see McDaniel and Einstein 2000). The anticipation of upcoming PM cues can

allow for the strategic allocation of cognitive resources to remember the related memories (Smith 2003). Therefore, the prospective aspect of memories can aid memory performance by preparing cognitive mechanisms to execute according to the anticipated events. One might suggest that if high attentional demands are anticipated in an upcoming memory task, then the cognitive mechanisms that are related to memory maintenance (e.g., WM and attention) could prepare to protect memories.

1.2 Predictive Coding Perspective

A growing body of research suggests that the brain is a prediction machine (Friston 2010; for review see Clark 2013; Mendonça, Curado, and Gouveia 2020). It is argued that the brain constantly tracks the environment to produce predictions that regulate how the environment is processed (Friston 2010). Accordingly, all systems adapt to the current predictions to minimize energy consumption by modulating the perceptual input, referred to as the free-energy principle (Friston and Stephan 2007). The benefits of temporally predicting interference to behavioral performance are previously shown (Appelbaum et al. 2012; Gresch et al. 2021; Hakim et al. 2020). For instance, Appelbaum et al. (2012) found that in a Stroop task, participants were better (shown in error rates) and faster (shown in RTs) in resolving the interference (Stroop incongruency) effect when the stimulus onset asynchrony was held constant. The findings of the study suggest that predictable stimuli are better perceived and encoded to WM, therefore, allowing better performance. Moreover, Gresch et al. (2021) found that information maintained in WM is better protected (shown in higher accuracy rates) from temporally predictable interference compared to unpredictable performance.

Alink et al. (2010) found attenuated cortical activity for predictable visual stimuli compared to unpredictable stimuli, which suggests that predicting upcoming input allows for minimizing energy consumption. Moreover, Schevernels et al. (2014) found enhanced P2 response, an event-related potential (ERP) index that is commonly argued to reflect visual processing that is modulated by attention (see Luck and Hillyard 1994), when predicting reward compared to no reward. This might suggest that energy is directed strategically to enhance the processing of stimuli with more benefit. Based on research on this perspective, we can argue that the anticipated demands of a memory task can help the strategic allocation of the necessary cognitive resources to aid memory performance while minimizing unnecessary functions.

1.3 Attention and Memory Performance: The Effect of Divided Attention on Working Memory and Long-term Memory

Attention and memory are highly related cognitive mechanisms and memories are recalled better if they are attended (for a review see Awh and Jonides 2001; Gazzaley and Nobre 2012). Allocation of selective attention to predicted locations (e.g., via spatial cues) of upcoming memory items enhances their encoding into WM (Murray, Nobre, and Stokes 2011). For instance, in Murray, Nobre, and Stokes (2011)'s study, the participants were either cued to a spatial location and were instructed to memorize the items appearing in that location or were not cued. They found that participants were more accurate when the spatial location is cued prior to memory presentation and memory accuracy correlated with electroencephalogram (EEG) indices of anticipatory attention.

In contrast, dividing attention may lead to memory impairments or complete forgetting (Craik 1983; Craik and Byrd 1982; Jennings and Jacoby 1993; Kilb and Naveh-Benjamin 2007; Rabinowitz, Craik, and Ackerman 1982). Perceptual interference and dual-task interference are two widely used methods when studying the effects of divided attention (e.g., Bennett and Cortese 1996; Magnussen and Greenlee 1992; Magnussen et al. 1991; McLeod 1977; Moscovitch 1994; Pashler 1990). Perceptual interference is simply done by interrupting a memory task with visual stimuli that the participants are instructed to ignore. For instance, Vredeveldt, Hitch, and Baddeley (2011) presented participants with a video clip, and before the participants were interviewed, they were either presented with distractors (visual or auditory interference) or not (instructed to close their eyes or were presented with a blank screen). Recall accuracies revealed that memory performance was better when no interference was present. Moreover, Blalock (2013) studied the effect of the similarity of the perceptual interference to the target memory in a change detection task. The results suggested that perceptual interference that is similar to the WM item deteriorated consolidation of the memory and led to memory failures. Moreover, this effect is larger when more items are memorized. On the other hand, dual-task interference interrupts a memory task by requiring participants to make a judgment (Clapp, Rubens, and Gazzaley 2010; Irwin and Thomas 2008; Moscovitch 1994; Pinto et al. 2013). For example, Moscovitch (1994) instructed participants to do a secondary task, a finger-tapping task, while doing a California Verbal Learning task and found that words recalled were decreased in dual-task interference condition compared to no interference.

LTM retrieval is also impaired by divided attention. Though the extent of the

divided attention cost is smaller compared to the divided attention during memory encoding and novel information in WM, divided attention can distort LTM retrieval by its effects on different stages of retrieval (for a review see Ataseven, Ünver, and Günseli 2023). Attentional lapses before processing retrieval cues (e.g., retrieval goal cues) are found to disrupt retrieval performance (Madore et al. 2020). Moreover, (Moscovitch 1994) suggested that impairing retrieval mode, a maintained state that prioritizes attention to internal representations (Tulving 1983), by presenting the participants with a dual task that depends on similar brain regions as retrieval mode impairs recall accuracy.

Given its predictive functioning, the human nervous system can be expected to prepare for anticipated interference to minimize the aforementioned costs of interference on memory. It is likely that an adaptive approach can be held to free energy while protecting memories against the effects of divided attention. This thesis proposed and investigated two possible strategies that the human memory systems might use when preparing for anticipated interference, as explained below in the *Current studies* section.

1.4 Current Studies

This thesis investigates whether the interplay between WM and lLTM is adaptively modulated when perceptual (Chapter 2) and dual-task (Chapter 3) interference is anticipated. Previous studies have provided conflicting findings regarding the effects of internal prioritization in WM on the costs of interference. While some studies found that information prioritized in WM is protected from interference (Matsukura, Luck, and Vecera 2007; Oberauer and Lin 2017; van Moorselaar et al. 2015), others have found that prioritized items rather become more vulnerable to interference (Allen and Ueno 2018; Hitch et al. 2018). Previous studies investigated these effects of interference on novel items, however, we mostly navigate our daily life interacting with familiar items. This thesis investigates the effect of interference on previously studied information by proposing two possible directions that are supported by the literature. First, there will be more WM reactivation when attentional demands are anticipated because reactivation in WM and focus of attention (FoA) is found to protect the information against interference (Matsukura, Luck, and Vecera 2007; Oberauer and Lin 2017; van Moorselaar et al. 2015). Second, there will be less WM reactivation and more reliance on LTM when attentional demands are anticipated because some studies suggest that information in WM is vulnerable to interference

(Allen and Ueno 2018; Hitch et al. 2018).

Chapter 2 investigated the effect of anticipating perceptual interference on WM for previously studied information to increase the detrimental effect of interference on memory. **Chapter 3** investigated the effect of anticipating dual-task interference on WM. Additionally, this study manipulated the memory load and included a previous unstudied (pure WM) control condition.

2. EQUAL REACTIVATION OF BUT REDUCED INTERNAL ATTENTION TO MEMORIES WHEN ANTICIPATING PERCEPTUAL INTERFERENCE

2.1 Introduction

Humans constantly cope with distractors while carrying out daily tasks. For example, while you are taking an online test that requires you to memorize visual information, a pop-up advertisement appearing on the website can interfere with the information you memorize. Perceptual distractors have detrimental effects on our active mental workspace, working memory (WM; Bennett and Cortese 1996; Blalock 2013; Magnussen and Greenlee 1992; Magnussen et al. 1991; van Moorselaar et al. 2015). Likewise, LTM has been shown to be affected by interference, particularly during encoding (Craik et al. 1996; Naveh-Benjamin and Guez 2000; Naveh-Benjamin et al. 2000) and, to a smaller degree, at retrieval (Atkins and Reuter-Lorenz 2008; Hupbach et al. 2007; Moscovitch 1994). While factors that affect the extent to which distractors interfere with WM and LTM have been explored, an interesting question is how individuals prepare for anticipated interference in terms of the interplays between these memory systems.

We propose that there are two possible memory strategies to prepare for interference for information available in LTM as hinted by the literature. The first possible preparation strategy is to rely on LTM. WM actively maintains information via extended neural activity (Goldman-Rakic 1995). Such activity co-occurring with representing novel information (e.g., distractors) has been suggested to underline some of the

disruptive effects of interference specifically when the distractors are similar to the memory item (Blalock 2013). Moreover, this neural activity is metabolically costly compared to holding information offline in LTM (Goldman-Rakic 1995). Thus, individuals may rely on passive LTM traces to cope with anticipated interference.

The second possible preparation strategy could be to rely on WM. Attentional focus within WM has been suggested to protect information against perceptual interference (Barth and Schneider 2018; Oberauer and Lin 2017). For example, when selective attention is directed to a particular item by using cues that retrospectively indicate the location or color of that item, i.e., retro-cues, performance is not affected by the presence of perceptual distractors (Astle et al. 2012; Griffin and Nobre 2003; Makovski and Pertzov 2015; van Moorselaar et al. 2015). Thus, reactivating WM to store information available in LTM could be an effective strategy to protect it against interference particularly if attention can be directed at them. However, the studies that found the role of attention to protect memories used novel information that necessitated WM involvement. Therefore, it is unclear whether individuals would reactivate information in WM if it can be kept passively in LTM instead.

Here, to test the interplay between WM and LTM, participants first studied pictures of real-world objects in Phase 1 (Figure 2.1A). Later, in Phase 2, we ensured that these objects were learned by testing participants' memory until they were accurate four times in a row for each object (Figure 2.1B). As a result, later in the main experimental session (Phase 3), participants were able to rely on existing LTMs if they chose to do so (Figure 2.1C). At the beginning of each trial, they were shown a previously studied object on the cued side of the screen and an irrelevant object on the other side to match the perceptual input, which is important given that we are interested in lateral indices of WM (see below). After a brief retention interval, they performed a two-alternative forced-choice task. Importantly, on some blocks, the retention interval contained perceptual distractors. Given the blocked design, participants had accurate predictions regarding when to face interference.

Figure 2.1 The experimental procedure
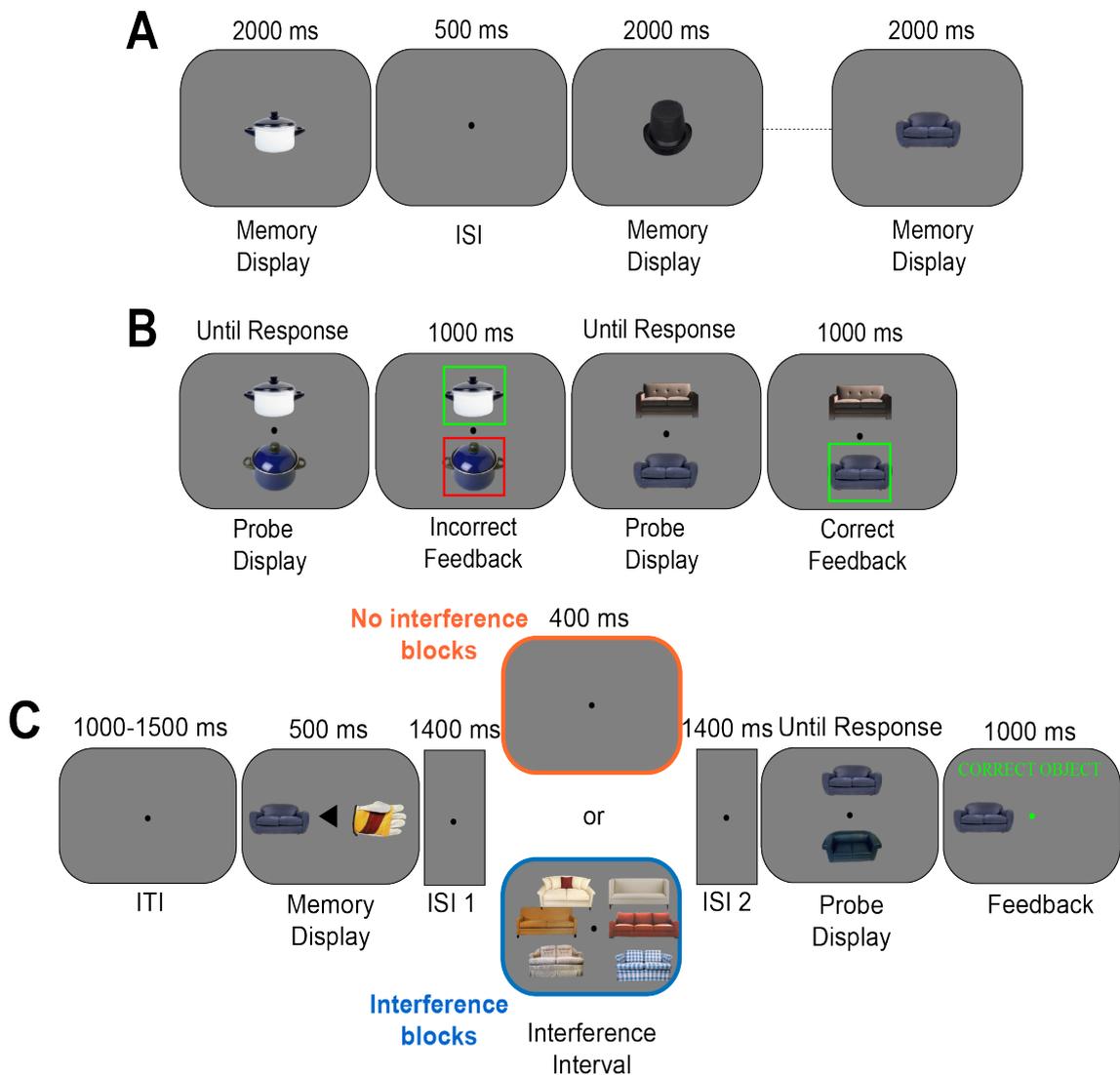
(A) In Phase 1, participants studied pictures of real-world objects. (B) In Phase 2, their memory for the objects was tested until they responded correctly four times in a row for each object. (C) In Phase 3, during which EEG was recorded, participants were given a previously studied object and performed a two-alternative forced-choice task. On some blocks, there were perceptual distractors before the probe. At the end, participants received feedback regarding their responses.

To test the degree of reliance on WM in preparation for interference, we used the contralateral delay activity (CDA) in the EEG. The CDA is sustained negativity over posterior-occipital channels contralateral to memory items. It is a well-studied measure of the number of items kept in WM (e.g., Feldmann-Wüstefeld, Vogel, and Awh 2018; Gunseli et al. 2018; Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Hakim et al. 2019; Vogel and Machizawa 2004). Moreover, it is

sensitive to the number of items and not to other aspects such as task difficulty (Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Ikkai, Mc-Collough, and Vogel 2010). Thus, it is a reliable index of WM storage. Accordingly, if participants prepare against interference by deploying WM to store information available in LTM, then the CDA should be larger in interference vs. no interference blocks. On the other hand, if participants rely on passive LTMs to prepare against interference, the CDA should be smaller in interference vs. no interference blocks. We also calculated the contralateral alpha-band (8-12 Hz) power suppression, an index of spatial selective attention during perception, or important to our purposes, also within WM (Foster et al. 2016; Gould, Rushworth, and Nobre 2011; Gunseli et al. 2018; Hakim et al. 2019; Kelly et al. 2006; Myers et al. 2015; Thut, Nietzel, A., Brandt, S. A., and Pascual-Leone, A. 2006). This allowed us to track the degree to which individuals maintain spatial positions of memory items in mind in anticipation of interference. To sum, by using previously learned information in a typical WM paradigm and manipulating anticipated interference, we tested the degree to which information available in LTM is reactivated in WM when anticipating perceptual interference.

2.2 Results

Incorrect trials were removed from the RT and neuroimaging data analyses. Bayes factor (BF) greater than 6 was considered evidence in favor of a meaningful difference between the comparison groups (alternative hypothesis) and BF less than 0.166 was considered evidence in favor of a meaningful non-difference (null hypothesis). Moreover, BF between 3-6 or 0.333-0.166 was considered moderate evidence, and BF between 1-3 and 0.333-1 was considered anecdotal evidence.

2.2.1 Behavior

Accuracy was high in both interference (M=0.94, SD = 0.04) and no interference (M=0.95, SD=0.03) conditions, and was above chance, as tested using Bayesian one-sample t-tests for interference ($BF_{10}=8.88852 \times 10^{32}$) and no interference blocks ($BF_{10}=4.38138 \times 10^{35}$; Figure 2.2A). To test the effects of perceptual interference on accuracy, we compared the accuracy scores between the interference and no interference conditions by using a Bayesian paired samples t-test. This comparison provided only anecdotal evidence ($BF_{10}=1.23$). Thus, on average, interference did

not result in major detriments in accuracy. However, there were individual differ-
ences in preparing for interference via WM vs. LTM that resulted in differences
in vulnerability to interference, which is described below. Responses were also rel-
atively fast in both the interference condition (M=0.73 s, SD=0.17) and the no
interference condition (M=0.75 s, SD=0.16; Figure 2.2B). To see whether exposure
to perceptual interference affected reaction times (RTs), we compared RTs across
interference conditions with a Bayesian paired samples t-test, which also only pro-
vided anecdotal evidence (BF_{10}=0.50). Thus, we conclude that interference did not
result in major costs in behavioral performance.

Figure 2.2 Behavioral performance
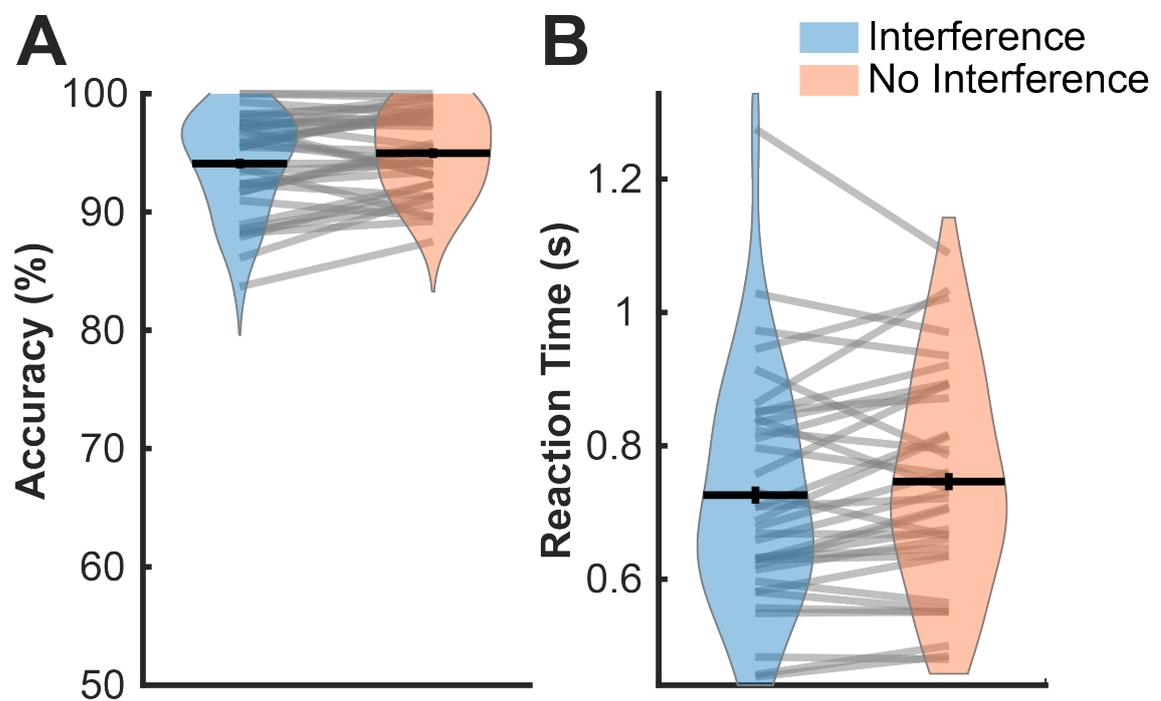
The violin plots show (A) accuracy and (B) reaction time for each condition in
different colors. Solid lines show average values across individuals. Each gray line
shows data from one participant. The error bars indicate the standard error of the
mean for the within-participant interference condition differences (i.e., interference
– no interference).

2.2.2 EEG

We grouped all the EEG analyses below based on the time period relative to the
interference as pre-interference and post-interference.

2.2.2.1 The pre-interference period

2.2.2.1.1 WM involvement in storing previously learned LTMs in anticipation of interference

To examine the WM reactivation of the information available in LTM, we tested the CDA (Figure 2.3A), averaged across 700 ms to 1700 ms after the memory display, against zero using a Bayesian one sample t-test for each condition. The CDA was prominent in both the interference (M =-0.418, SD = 0.479, BF_{10}=1971.48) and no interference (M =-0.424, SD = 0.529, BF_{10}=622.04) conditions (Figure 2.3B). Notably, the CDA observed in this experiment was about half of what has been observed when participants had to represent novel information on each trial (Gunseli et al. 2018; Gunseli, Meeter, and Olivers 2014; Gunseli, Olivers, and Meeter 2014). This suggests that in the present experiment, participants were able to rely on existing LTM without fully representing the information in VWM.

Figure 2.3 CDA results
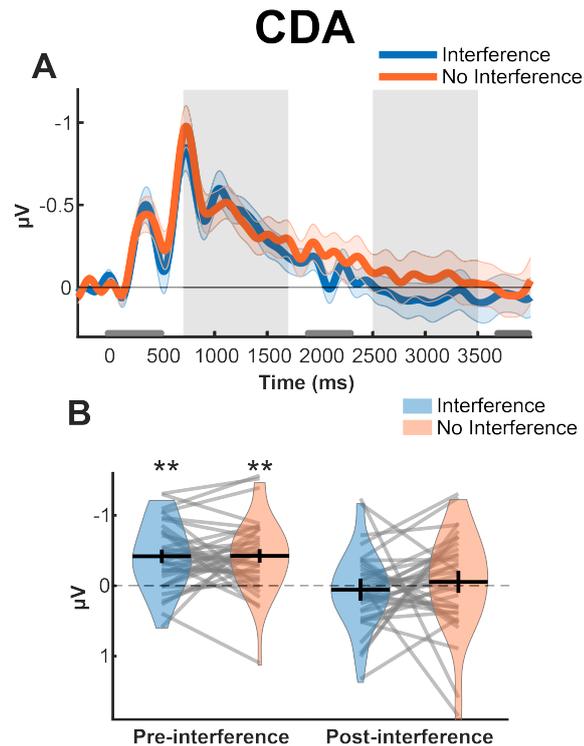
(A) The waveforms for the CDA are shown in different colors for interference and no interference conditions. The dark gray areas on the x-axis show the timing of the memory, interference, and probe displays, respectively. The shaded light gray areas show the time intervals used for computing average CDAs in pre-interference (left) and post-interference (right) time windows. (B) Violin plots that show the CDA averaged across pre-interference and post-interference intervals. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference). * and ** refer to BF>3 and BF>6, respectively.

Our main research question was to test whether anticipating upcoming perceptual interference results in preparatory differences in the degree of reactivating existing LTMs in WM. To this end, we compared the CDA amplitude in the interference and no interference conditions using a Bayesian paired samples t-test. If individuals rely on passive LTMs in anticipation of perceptual interference to prevent interfering input to intervene with the active mental representations in WM, the CDA should be smaller in the interference blocks. On the other hand, if individuals reactivate LTMs in WM more to protect them against interference, then the CDA should be larger in the interference condition. Contrary to each hypothesis, we obtained strong evidence for the null hypothesis (BF_{10}=0.162) supporting the absence of

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a meaningful difference between conditions (Figure 2.3B). Thus, on average, the degree to which LTMs are reactivated in WM did not depend on the anticipated perceptual interference. Given the large participant number, we explored individual differences in reactivating WM when preparing for interference, as described next.

2.2.2.1.2 Individual differences in WM reactivation of LTMs to prepare for anticipated interference

Although there was no difference across conditions in the level of reactivating LTMs in WM on average, there might be individual differences in the degree of reactivating LTMs. To test for different trends in the data, first, we checked for bimodality. The bimodality analysis ran on the CDA difference between the conditions (interference - no interference) did not produce a significant bimodality (Bimodality Coefficient = 0.3003). Given that a bimodality test could fail to identify two distributions with means close to each other, we divided the participants into two groups according to their relative CDA in interference and no interference conditions. There were 17 participants who had larger CDA in the interference condition (i.e., those who prepared against interference using WM) and there were 18 participants who had larger CDA in the no interference condition (i.e., those who prepared against interference using LTM). For the rest of the text, we will refer to these groups as WM preparers (Figure 2.4A&B) and LTM preparers (Figure 2.4C&D), respectively.

Figure 2.4 Individual differences in the CDA difference between interference conditions
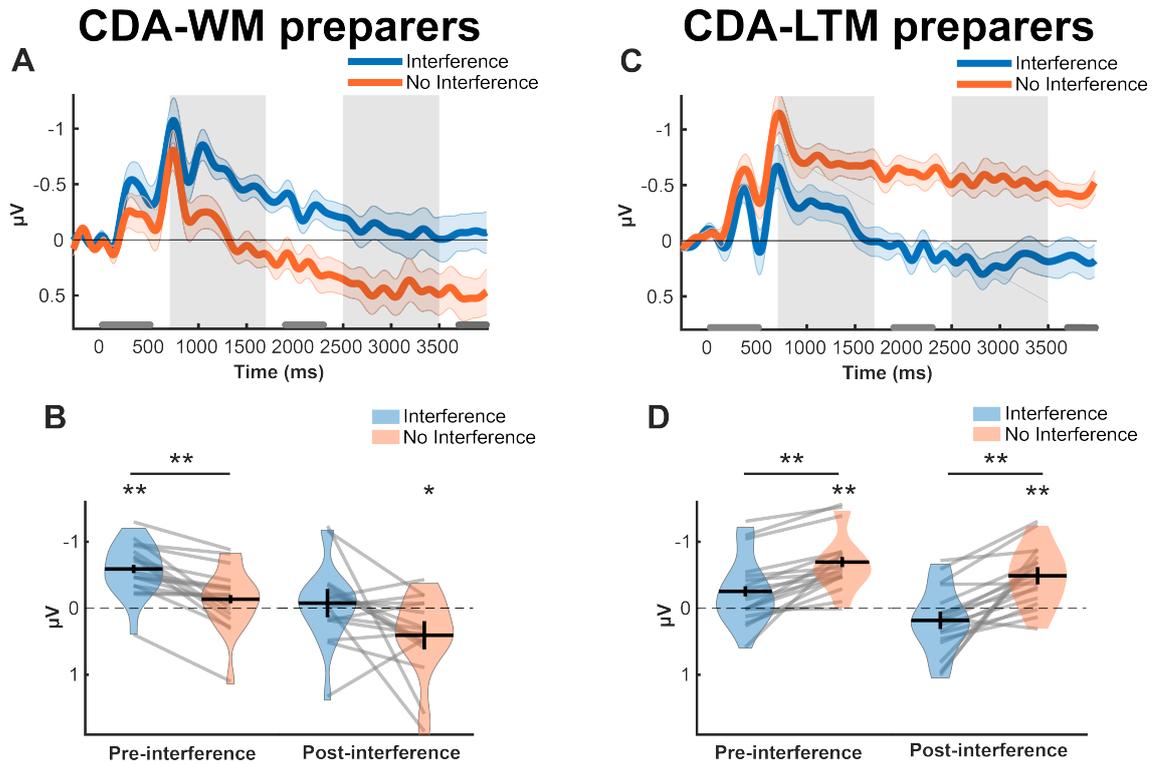
(A) The waveforms for the CDA are shown in different colors for interference and no interference conditions for WM preparers (i.e., those with larger CDA in the interference vs. no interference condition, N=17) and (C) for LTM preparers (i.e., those with smaller CDA in the interference vs. no interference condition, N=18). The dark gray areas on the x-axis show the timing of the memory, interference, and probe displays, respectively. The shaded light gray areas show the time intervals used for computing average CDAs in pre-interference (left) and post-interference (right) time windows. (B) Violin plots that show the CDA averaged across pre-interference and post-interference intervals for WM preparers and (D) LTM preparers. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference). * and ** refer to BF>3 and BF>6, respectively.

A Bayesian independent samples t-test confirmed that the groups we created are significantly different from each other (BF$_{10}$=941986; Figure 2.4BD). Two Bayesian paired samples t-tests comparing the CDA across interference and no interference conditions for each group confirmed that there was strong evidence for a larger CDA in the interference (M=-0.591 SD=0.399) vs. no interference (M=-0.137, SD=0.471)

condition for WM preparers (BF_{10} = 285.43), and there was strong evidence for a smaller CDA in interference (M=-0.255, SD=0.501) vs. no interference (M=-0.695, SD=0.437) condition for LTM preparers (BF_{10}=1026). Thus, we were able to divide the participants into two groups based on whether they show more or less WM involvement in anticipation of interference. Lastly, we conducted two Bayesian independent samples t-tests to compare the groups separately for each condition. These tests revealed that the group differences mainly stemmed from the no interference condition. Specifically, in the no interference condition there was strong evidence for a larger CDA for LTM preparers than WM preparers (BF_{10}=34.08). On the other hand, in the interference condition, there was only anecdotal evidence for a larger CDA for WM preparers than LTM preparers (BF_{10}=1.91). Thus, the two groups differed mainly in the no interference but not in the interference condition.

Having established meaningful strategy differences between the conditions across the two groups, we wanted to assess the WM involvement in storing LTMs for each group and condition. For this, we tested the WM involvement against zero for each group x condition combination using four Bayesian one-sample t-tests (Figure 2.4BD). The evidence for the CDA was anecdotal for WM preparers in the no interference condition (BF_{10}=0.46) and for LTM preparers in the interference condition (BF_{10}=1.55). On the other hand, there was strong evidence for the CDA for WM preparers in the interference condition (BF_{10}=1532.48) and LTM preparers in the no interference condition (BF_{10}=5888.32). Thus, we conclude that WM preparers did not meaningfully recruit WM in the no interference condition and LTM preparers did not meaningfully recruit WM in the interference condition. These results suggest that metabolically costly WM can be avoided when information is available in LTM. However, there may be individual differences in the conditions in which WM recruitment is considered beneficial, as some deploy, and others withdraw WM to prepare for interference.

Next, we wanted to test the effectiveness of these different preparation types for protection against interference. First, we tested whether each group's performance was negatively impacted by interference by comparing the average accuracy cost (i.e., accuracy difference in no interference and interference conditions) against zero using Bayesian one-sample t-tests. There was strong evidence for interference cost for LTM preparers (M=0.017, SD=0.019, BF_{10}=27.25), whereas there was moderate evidence for the absence of interference costs for WM preparers (M=-0.0002, SD=0.027, BF_{10}=0.24; Figure 2.5A). Thus, interference mainly harmed the performance of LTM preparers and not WM preparers, though there was only anecdotal evidence for interference costs being different across groups as tested by a Bayesian independent samples t-test (BF_{10}=2.05). It is important to note that the division

of groups based on CDA differences across interference conditions was established using trials with correct responses only. Thus, a reduction in the CDA cannot be attributed to a complete loss of memories but rather to individuals relying on passive LTMs to complete the task. With this in mind, the interference cost being present only for LTM preparers suggests that preparing against interference with WM might be an effective strategy to deal with interference.

Lastly, to test whether the accuracy cost pattern described above might reflect differences in speed-accuracy tradeoff across group x condition combinations, we performed the same analyses for accuracy also for the RT (Figure 2.5B). The evidence for the absence of interference cost (i.e., the difference in RT between interference and no interference conditions) was anecdotal for WM preparers ($BF_{10} = 0.52$) and moderate for LTM preparers ($BF_{10} = 0.27$). We also checked the difference between the RT cost (interference no interference) between WM preparers and LTM preparers using a Bayesian independent samples t-test. There was anecdotal evidence for the absence of a condition difference ($BF_{10} = 0.39$) between WM preparers (M=-0.031, SD=0.093) and LTM preparers (M=-0.009, SD=0.056). Thus, we conclude that the interference cost on accuracy for LTM preparers was not due to a speed-accuracy tradeoff. Together, these results suggest that individuals who prepare for perceptual interference by deploying WM to reactivate LTMs did not suffer interference costs while individuals who prepare for interference by relying on passive LTM traces do.

Figure 2.5 Individual differences in the behavioral effects of interference
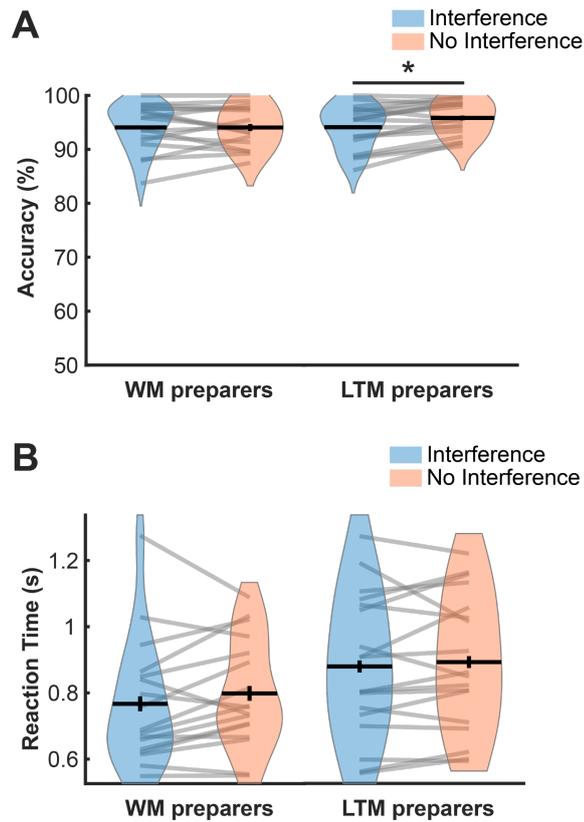
The (A) average accuracy and (B) average RT are shown separately for interference and no interference conditions in different colors and for WM preparers and LTM preparers on the left and right sides of each plot. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference - no interference). * and ** refer to BF>3 and BF>6, respectively.

2.2.2.1.3 Allocation of spatial attention to memory locations before interference

Working memory and attention are closely related to each other, such that attending to WM items is associated with benefits for their storage. Thus, we also explored preparatory attention when anticipating interference. The role of attention in protecting information against interference is inconsistent in the literature. Some studies suggest that selective attention protects information (Barth and Schneider 2018; Matsukura, Luck, and Vecera 2007; Oberauer and Lin 2017; van Moorselaar et al. 2015), whereas others suggest that it makes the information more vulnerable (e.g. high priority items Allen and Ueno 2018; Hitch et al. 2018; when congruent

perceptual interference is anticipated Sreenivasan and Jha 2007; for a review see Lorenc, Mallett, and Lewis-Peacock 2021). Accordingly, there are two contrasting possibilities regarding selective attention in anticipation of interference in an attempt to protect it. Attention can either be directed to the memory item or withdrawn away from it.

To test these possibilities, we used the contralateral alpha suppression, i.e., relative negativity in alpha-band (8-12 Hz) power at contralateral vs. ipsilateral side at posterior-occipital electrodes to measure whether attention is allocated to the memory item (Figure 2.6A) (Foster et al. 2016; Gould, Rushworth, and Nobre 2011; Gunseli et al. 2018; Hakim et al. 2019; Kelly et al. 2006; Myers et al. 2015; Thut, Nietzel, A., Brandt, S. A., and Pascual-Leone, A. 2006). We compared the contralateral alpha in both interference and no interference conditions against 0 by using two Bayesian one-sample t-tests. There was strong evidence for contralateral alpha power suppression for the interference (M=-0.124, SD=0.237, BF_{10}=9.799) and no interference conditions (M =-0.159, SD=0.233, BF_{10}=93.829, Figure 2.6B). Moreover, there was moderate evidence for the lack of a difference in contralateral alpha power suppression between interference conditions on average as tested by a Bayesian paired samples t-test (BF_{10}=0.251). These results suggest that participants attended the position of the memory item regardless of anticipated interference.

In the present study, the positions of perceptual distractors could overlap with the memory item's position. As a result, continuing to attend to the position of the memory item during interference could result in the involuntary processing of the distractors in the interference condition (Hillyard, Vogel, and Luck 1998; Rees, Frith, and Lavie 1997). To prevent such distractor processing, participants might have stopped attending to the memory position (Luck et al. 1997) prior to the interference in the interference condition. This was particularly plausible given that the timing of the interference onset was fixed. To test whether the contralateral alpha power changes over time before interference, first, we divided the pre-interference time interval into two time windows based on visual inspection: 700-1000 ms (early) and 1000-1700 ms (late). Then, we tested whether there was a significant change in the contralateral alpha power suppression from early to late pre-interference period separately for each condition using two Bayesian paired-sample t-tests. There was strong evidence for a reduction in contralateral alpha band power suppression in the interference condition (BF_{10} = 17.253), while there was moderate evidence for the absence of a such reduction in the no interference condition (BF_{10}= 0.173; Figure 2.6C). To examine whether the difference between the contralateral alpha power differences in the early and late pre-interference period varied across inter-

ference conditions, we conducted a paired-samples t-test that compared the decline in alpha-band power suppression (early – late) in interference vs. no interference conditions. There was strong evidence for a larger reduction in alpha power suppression in the interference condition from early to late pre-interference period (BF_{10} = 6.468). Together, these results suggest that participants attended to the memory item in both conditions though they stopped attending to it later in anticipation of interference in the interference condition.

Lastly, we tested whether this trend we observed between the early and late pre-interference intervals for contralateral alpha power is present in the CDA findings. First, we tested whether there is a change in the CDA from early to late pre-interference period by running two Bayesian paired-samples t-tests separately for each condition. There was a reduction in the CDA in both conditions, in the interference condition with moderate evidence (BF_{10} =3.89) and in the no interference condition with strong evidence (BF_{10} =375.97). We compared the CDA reduction between the interference conditions using a Bayesian paired samples t-test to test whether the CDA reduction is different across conditions as in the contralateral alpha power findings, however, there was not a conclusive result (BF_{10} =1.10). These findings are in line with the previous studies suggesting that CDA declines over time (e.g., Balaban, Drew, and Luria 2019; Feldmann-Wüstefeld 2021; Günseli et al. 2019; Hakim et al. 2019; for a review see Roy and Faubert 2023). Lastly, the Bayesian correlation between the contralateral alpha power and CDA for the difference between early and late pre-interference periods suggested that there was no correlation, r= -0.11, BF_{10} =0.25. Thus, we found that WM reactivation and attentional allocation acted differently when preparing for perceptual interference which is in line with the literature suggesting that WM reactivation and attention are different cognitive mechanisms.

Figure 2.6 Contralateral alpha power suppression results

Contralateral alpha power(8-12 Hz)

(A) Contralateral alpha power suppression over time is shown in different colors for interference and no interference conditions. The dark gray areas on the x-axis show the timing of the memory, interference, and probe displays, respectively. The shaded light gray areas show the time intervals used for computing average contralateral alpha power in pre-interference (left) and post-interference (right) time windows. (B) Violin plots that show the contralateral alpha suppression averaged across pre-interference and post-interference intervals, and (C) early (700-1000 ms) and late (1000-1700 ms) pre-interference time window. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference). * and ** refer to BF>3 and BF>6, respectively.

2.2.2.1.4 Allocation of spatial attention to memory locations before interference separately for WM preparers and LTM preparers

We explored the patterns of attending to the memory item across individuals who deployed WM in preparation for interference (WM preparers) and those who relied on LTM (LTM preparers). To check whether the decline in attention differed across the preparation groups, we compared WM preparers and LTM preparers in

their differences in the contralateral alpha power in the early and late (late – early) pre-interference period using a Bayesian independent samples t-test. The groups' attentional decline differed in the interference condition with moderate evidence ($BF_{10} = 3.602$), but there was anecdotal evidence in the no interference condition ($BF_{10} = 1.376$). To assess the direction of the difference in the interference condition, we computed two Bayesian paired samples t-tests to compare the attentional allocation in the early (Figure 2.7A) and late (Figure 2.7B) pre-interference period for both WM and LTM preparers. There was strong evidence suggesting that WM preparers decreased attention to the memory item in the late pre-interference period compared to early when they anticipated interference ($BF_{10} = 24.187$) whereas there was only anecdotal evidence for LTM preparers ($BF_{10} = 0.565$). Lastly, we wanted to explore WM preparers' and LTM preparers' attentional suppression in the late pre-interference period between conditions using Bayesian paired samples t-tests comparing the interference conditions for each group. There was moderate evidence for smaller contralateral alpha suppression for WM preparers allocated in the interference vs. no interference condition ($BF_{10} = 4.460$), whereas moderate evidence for equal contralateral alpha suppression for LTM preparers ($BF_{10} = 0.245$). These results suggest that WM preparers stopped attending to the memory item prior to the interference while LTM preparers did not. Together with the presence of interference costs selectively for LTM preparers, these results suggest that withdrawing attention from locations of anticipated distractors may help protect memories against interference.

Figure 2.7 Contralateral alpha power suppression separately for WM preparers and LTM preparers

Contralateral alpha power(8-12 Hz)

(A) Contralateral alpha suppression over time is shown in different colors for interference and no interference conditions. The dark gray areas on the x-axis show the timing of the memory, interference, and probe displays, respectively. The shaded light gray areas show the time intervals used for computing average contralateral alpha power in pre-interference (left) and post-interference (right) time windows. (B) Violin plots that show the contralateral alpha suppression averaged across pre-interference and post-interference intervals, and (C) early (700-1000 ms) and late (1000-1700 ms) pre-interference time window. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference). * and ** refer to BF>3 and BF>6, respectively.

2.2.2.2 The post-interference period

2.2.2.2.1 How does the interference affect WM involvement to store LTMs after the interference?

We tested whether the reactivation of the information available in LTM was still prominent in the post-interference interval (i.e., 2500 ms 3500 ms after the memory display onset, which corresponds to 600 and 1600 after the interference display onset) by comparing the CDA to zero for either condition using Bayesian one-sample

t-tests (Figure 2.3B). There was moderate evidence for the absence of the CDA both in the interference condition (M=0.056, SD=0.548, BF_{10}=0.215) and the no interference condition (M=-0.55, SD=0.690, BF_{10}=0.201). Moreover, there was moderate evidence to suggest that the CDA did not differ across conditions, as tested by a Bayesian paired samples t-test (BF_{10}=0.205). Lastly, there was strong evidence that the CDA declined over time (pre-post interference intervals), as reflected in the outcome of Bayesian paired-samples t-tests for both the no interference (BF_{10} =1920.21, pre-interference M=-0.424 SD=0.529, post-interference M=-0.55 SD=0.690) and interference conditions (BF_{10} = 938.51, pre-interference M=-0.418 SD=0.479, post-interference M=0.056, SD=548).

2.2.2.2.2 Individual differences in the interference effects on WM involvement after the interference

To test whether the WM involvement after interference differed across WM preparers and LTM preparers, we used Bayesian independent samples t-tests to compare the CDA between the two groups for each condition. There was strong/moderate evidence for larger CDA for LTM preparers vs. WM preparers in the no interference condition (BF_{10}=1019.253), while anecdotal evidence for equal CDA in the interference condition (BF_{10}=1.513). To assess whether the rate of decline in WM involvement differed across WM preparers and LTM preparers, we used a Bayesian independent samples t-test to compare the CDA difference between pre- and post-interference period between groups for each condition. In the interference condition, there was moderate evidence for an equal CDA decline (BF_{10}=0.315) for WM preparers (M=0.513, SD=0.698) and the LTM preparers (M=0.436, SD=0.441; Figure 2.4D). On the other hand, in the no interference condition, there was moderate evidence for a larger CDA (BF_{10}=3.412) for WM preparers (M=0.543, SD=0.431) than for LTM preparers (M=0.206, SD=0.356).

2.2.2.2.3 Allocation of spatial attention to memory locations after interference

Lastly, we tested whether the memory item was attended after interference by comparing the contralateral alpha suppression against 0 using a Bayesian one sample t-test. There was anecdotal evidence in the interference condition (BF_{10}=1.095, M=-0.063, SD=0.186), and moderate evidence for the absence of contralateral alpha power suppression in the no interference condition (BF_{10}=0.210, M=-0.016, SD=0.168; Figure 2.6C). Comparing the lateralized alpha power across interference

conditions by using a Bayesian paired samples t-test provided only anecdotal evidence (BF_{10}=0.365). Thus, we conclude that participants did not attend to the memory locations in the post-interference period in either the interference or the no interference condition.

2.3 Discussion

Here, we tested the effects of anticipated interference on reactivating LTMs in WM. WM reactivation was measured using the CDA, a widely studied index of storage in WM (Günseli et al. 2019; Hakim et al. 2019; Ikkai, McCollough, and Vogel 2010; Luria et al. 2010; McCollough, Machizawa, and Vogel 2007; Vogel and Machizawa 2004). The CDA was equal across interference and no interference blocks suggesting that the anticipation of interference did not have an impact on the level of recruiting WM to represent information available in LTM. Likewise, there was no effect of interference on accuracy, in line with the previous research on the effect of perceptual interference being fairly weak or absent (Clapp, Rubens, and Gazzaley 2010; Moscovitch 1994; Pinto et al. 2013) for memory performance. Interestingly, contralateral alpha-band power suppression, an index of spatial attention (Foster et al. 2016; Gould, Rushworth, and Nobre 2011; Gunseli et al. 2018; Kelly et al. 2006; Myers et al. 2015; Thut, Nietzel, A., Brandt, S. A., and Pascual-Leone, A. 2006), showed that the time course of the attentional allocation was different across conditions. When anticipating interference, participants attended to the memory item more early on and they stopped attending later before the interference screen appeared, probably in an attempt to inhibit distractor encoding on the attended spatial location (Luck et al. 1997; Sreenivasan and Jha 2007).

Traditionally, WM studies intentionally prevent LTM contributions. While this approach has been fruitful to explore the unique properties of WM such as its limited capacity, it does not allow forming a more complete and ecologically valid understanding of how these two memory systems interact with each other. Recently, attempts have been made to overcome this limitation. For example, using information available in LTM, WM has been suggested to be more involved under high proactive interference conditions (Mızrak and Oberauer 2022; Schurgin et al. 2018). However, these differences in recruiting WM were the outcomes of similarities between the current memory with existing memories. Here, we tested the effects of an external factor: perceptual interference. Moreover, we were mainly interested in the effects of anticipating it as opposed to experiencing it. This distinction between the current

study and previous ones may suggest that control over WM reactivation of LTMs may not be possible in a proactive manner. Rather, differences in WM recruitment may only take place reactively, in response to existing conditions. On the other hand, proactive flexible control may be possible but not prominent in anticipation of interference. The fact that there were individual differences in deploying WM in our study provides indirect support for the second possibility. Future research is needed to explore the anticipated task settings that may encourage different rates of WM reactivation in a more consistent way across individuals.

While there was a robust CDA in both conditions, its amplitude was about half of what was observed in the literature for novel items (cf. Brady, Störmer, and Alvarez 2016; Carlisle et al. 2011; Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Miuccio, Zelinsky, and Schmidt 2022; Schmidt and Zelinsky 2017; but see Hakim et al. 2019). Rather the amplitude we obtained is more similar to conditions that have been suggested to benefit from LTM aid such as the same information being stored repeatedly or after a study session as in the present study (Carlisle et al. 2011; Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Schurgin et al. 2018). Therefore, we argue that WM was only partially recruited in both conditions. This finding highlights the role of LTM traces being relied on when available instead of fully recruiting metabolically costly WM. It is unclear from the current study whether this partial reliance on each memory system reflects the average of an all-or-none reactivation across trials (e.g., fully reactivate in WM in one trial, fully use LTM in another trial) or partial reactivation in a given moment. It may be possible that intermittent bursts of neural activity associated with storage in WM (Lundqvist et al. 2016, 2018) occur less frequently when information is available in LTM. This possibility can be explored using techniques with a higher signal-to-noise ratio that can obtain more reliable single-trial measures.

In the present study, we explored WM-LTM interplays when information is presented again. While accessing LTMs is also possible via re-experiencing the same information, this recognition-type reactivation may be easier than recalling information via retrieval cues. Indeed, previous studies have suggested that accessing LTMs requires a mental search of the memory space (Cabeza 2008; Cabeza et al. 2011). This additional demand suggests that, in the face of anticipated interference, individuals may be less likely to retrieve LTM and recruit WM when provided with a retrieval cue compared to accessing information via re-experiencing, as done in the present study. We claim that it is an interesting venue to compare WM-LTM interplays depending on the type of accessing LTMs.

The effects of anticipated interference on EEG indices of WM and attention have

been explored before. Hakim et al. (2020) also studied the effects of anticipation of perceptual interference and found no effects of anticipation on the CDA. However, they provided novel information on each trial, necessitating WM involvement. We replicated the absence of CDA differences on average, suggesting that WM involvement does not differ with interference expectations when being able to rely on LTM either. However, looking into the individual differences, we found that half of the participants prepared for upcoming interference with smaller CDAs (i.e., LTM preparers) and the other half with larger CDAs (i.e., WM preparers). We found that interference costs on accuracy were present only for LTM preparers and not for WM preparers. These results suggest averaging out the CDA across participants might result in finding no preparation differences and that there may be two opposite strategies to prepare for interference in terms of the interplay between WM and LTM; deploying WM and relying on passive LTMs. Moreover, our results demonstrate that deploying WM to represent LTMs might be an effective way to cope with anticipated interference.

A possible reason the current study did not find a difference between the interference conditions in the CDA and in the behavioral accuracy on average could be due to the perceptual interference being ineffective. Previous studies showed that perceptual interference has a mild or no effect on memory for low memory loads (Clapp, Rubens, and Gazzaley 2010; Irwin and Thomas 2008; Pinto et al. 2013). Since the effect of anticipated interference was subtle, the participants might have not engaged in strong preparation strategies. Future studies can compare the WM involvement in storing LTMs when more disruptive interference is anticipated.

In addition to the CDA, an index of WM storage, we also explored selective spatial attention, as measured by contralateral alpha suppression (Foster et al. 2016; Gould, Rushworth, and Nobre 2011; Gunseli et al. 2018; Hakim et al. 2019; Kelly et al. 2006; Myers et al. 2015; Thut, Nietzel, A., Brandt, S. A., and Pascual-Leone, A. 2006). We obtained equal levels of contralateral alpha suppression, particularly early in the retention interval. However, later in the retention, prior to anticipated interference, contralateral alpha suppression disappeared in the interference condition. Moreover, this effect was driven by WM preparers. We argue that continuing to attend to the memory item, which has been found to be beneficial in previous WM studies (Griffin and Nobre 2003; Gunseli et al. 2015; Günseli et al. 2019), can be harmful here because the location of the distractors could overlap with the location of memory items on some trials. Since participants had the chance of relying on passive LTM traces, they had a stronger incentive to stop attending to the location of the memory item, which could have resulted in an involuntary encoding of the interfering irrelevant objects. In fact, in a previous study that used novel items on

each trial, anticipating interference did not result in withdrawing attention from memory items (Hakim et al. 2020). This difference across studies highlights the usefulness of enabling LTM contributions to understand WM functioning in a way that more closely resembles daily life where WM and LTM often exchange information.

The similarities and differences between WM and selective attention have been under debate. Some studies suggest that WM is nothing more than selective attention directed to memories (Curtis and D'Esposito 2003; Kane et al. 2001; LaBar et al. 1999) whereas some other studies, including our own, suggest that attention and storage in WM can be dissociated (Günseli et al. 2019; Hakim et al. 2019). Here, we found that while CDA did not differ across conditions, contralateral alpha power showed a difference over time when anticipating interference. Moreover, to check whether the change in alpha power for the pre-interference interval is also evident in the CDA, we ran the correlation between the two and did not have significant results. Therefore, the current study is supportive of the view of attention is different from WM activation. Moreover, the fact that withdrawing attention from memory positions at which distractors may appear was evident in WM preparers but not LTM preparers and that only LTM preparers were subject to costs of interference. These results suggest that the attention withdrawal strategy may have been beneficial for protection against interference. Future studies with a larger sample size can explore the role of such a strategy in the protection of memories.

We observed no CDA later in the retention interval, in the post-interference period. This was the case also in the no interference condition suggesting that it was not due to the disruptive effects of perceptual interference. We believe there are at least three possible interpretations of the absence of CDA in the post-interference period in the present experiment. First, individuals might have lost all memory traces, which is extremely unlikely given almost perfect behavioral performance. Second, the CDA might not be a suitable index to measure WM over such long intervals, as most studies find such declines over extended periods (Wang, Rajsic, and Woodman 2019; Williams and Drew 2021). Third, individuals in the present experiment might have started relying on previously established LTM traces to complete the task. We claim that while the CDA may not be the most suitable tool to track long-term retentions in WM given the declining trend in experiments over 1-second intervals (Wang, Rajsic, and Woodman 2019; Williams and Drew 2021), the contribution of LTM in the present study must have played a role, as there are studies with above zero CDA at similar time intervals as the present study (e.g., Wang, Rajsic, and Woodman 2019). In line with this argument, these studies provided novel information on each trial, thus minimizing the LTM contributions that were available in the present experiment.

Despite the lack of active object storage during the first retention interval for LTM preparers, as evident in the absence of a CDA, the position of the memory item was attended, as indexed by a contralateral alpha suppression. There is now growing evidence for a dissociation between these two markers (De Vries, Van Driel, and Olivers 2017; Günseli et al. 2019; Hakim et al. 2019). Together, these findings highlight a dissociation between these indices such that the CDA tracks the number of objects while contralateral alpha suppression tracks selective attention to their locations. If so, why do individuals continue attending to the position of an object no longer available in WM? We believe there are two possible explanations. First, locations have longer lingering traces in WM than objects, which would be in line with the special status of location in WM (e.g., Foster et al. 2017). Second, and as a possible consequence of the first, locations in WM can be used to point to objects in LTM. This explanation is consistent with the presence of contralateral alpha suppression in the absence of CDA when there is a relatively higher potential of a given memory item to be relevant in the future (Günseli et al. 2019). Although, in Günseli et al. (2019), the memory items were harder to benefit from LTMs due to being semantically meaningless and not being studied in advance, an attempt similar to the present paper might have been in place: Future-relevant information handed off to LTM can be accessed easier by using its location as a pointer. This would be in line with the use of pointers for more accessible LTMs in expert behavior as suggested in the influential working long-term memory model (Ericsson and Kintsch 1995).

To sum, there was no difference in WM reactivation of LTMs when anticipating perceptual interference vs not. However, internal attention is reduced specifically when anticipating perceptual interference, probably to inhibit the encoding of the upcoming perceptual distractors. We further identified two approaches of recruiting WM to represent information available in LTM. Individuals who recruited WM in preparation for interference (WM preparers) suffered no interference costs on behavioral performance. On the other hand, individuals who relied on LTM (LTM preparers) did experience costs. Moreover, we show that WM preparers stopped attending to memories in anticipation of interference, which may reflect a protection strategy against the involuntary processing of task-irrelevant distractors. Overall, these findings highlight different preparatory operations in WM reactivation of LTMs and reallocation of internal attention when anticipating interference. Thus, they provide an important novel direction in the study of the interplays between WM and LTM.

2.4 Materials and Methods

2.4.1 Participants

52 participants from Sabancı University participated in exchange for course credit. This study is performed according to the Declaration of Helsinki principles and the ethics approval was granted by the Sabancı University (SUREC) ethics committee. All participants signed an informed consent form prior to participating in the study. Data from 17 subjects were excluded due to ocular and recording artifacts, leaving 35 participants (24 female; all normal or corrected-to-normal vision; no reported history of neuropsychological disorders; 18-28 years old, M=23.4, SD=2.3).

To calculate the minimum number of participants needed, we estimated the effect size by averaging the effect sizes across five studies that analyzed the CDA for WM maintenance (Adam, Robison, and Vogel 2018; Gunseli, Olivers, and Meeter 2014; Hakim et al. 2019; Miuccio, Zelinsky, and Schmidt 2022). We carried out a sequential design approach by following the guidelines of Dienes (2021) and Schönbrodt and Wagenmakers (2018) with the associated R package made available by Schönbrodt and Stefan (2019) (github.com/nicebread/BFDA). The number of participants needed for a .90 power and a .02 false positive rate under the estimated effect size d=1.61 was calculated as 20. After collecting data from 20 participants, BF is calculated after every 5 subjects.

2.4.2 Stimuli

The stimulus set, freely accessible at http://cvcl.mit.edu/MM, contained 204 daily life object images from 12 categories (backpack, bucket, camera, mug, cooking pot, drawer, glows, hat, microwave, radio, sofa, and suitcase; Konkle et al. 2010). All the object images were resized to equalize the number of non-transparent pixels across object images (1.5° x 1.5°). The stimuli set was divided into two sets: target and nontarget stimuli. 24 objects were selected from 12 categories as target stimuli. The rest of the 180 objects were used as nontarget stimuli. The viewing distance to the screen was approximately 85 cm. The background color was gray (RGB: [128 128 128]). The triangle cue (0.5° x 1.1°) and the fixation dots (0.3° x 0.3°) were black (RGB: [0 0 0]). Red (RGB: [256 0 0]) and green (RGB: [0 256 0]) fixation dots were used for giving feedback.

2.4.3 Design and Procedure

2.4.3.1 Trial design

Figure 2.1 illustrates the trial structure for the experiment. The experiment consisted of 3 phases. In Phase 1 (the learning phase), each object was randomly presented at the center of the screen for two seconds with a 500 ms interstimulus interval and repeated three times, which summed up to 72 trials, taking approximately three minutes. In Phase 2 (the testing phase), participants were tested for the objects they have learned in Phase 1. Two objects were shown vertically at the midline of the screen, one object positioned 2.8° above the fixation point and the other object positioned 2.8° below the fixation point. One of these two objects was previously studied, and the other one was a novel object from the same category. Participants were instructed to indicate the previously learned object by pressing the up or down arrow keys. The objects stayed on the screen until response. After the response, participants received feedback. If the response was correct, then a green frame (1.7° x 1.7°; RGB: [0 256 0]) appeared around the correct object. If the response was incorrect, then a red frame (1.7° x 1.7°; RGB: [256 0 0]) appeared around the incorrect object while a green frame appeared around the correct object to support participants' learning of the correct objects. Each attempt in this phase contained 96 trials and continued until participants gave a correct response four times in a row for each object.

In Phase 3 (the experimental phase) each trial started with the participant pressing the space key. At the beginning of the trial, a fixation dot was presented for an interval that is randomly jittered between 1000 and 1500 ms. Next, two objects were laterally presented on the screen for 500 ms: one object is a target object that is previously learned, and the other object is a novel random one that is irrelevant to the task and presented only with the purpose of balancing the visual input. The target object was pointed with a triangle cue. The participants were instructed to memorize the cued object. After an interstimulus interval of 1400 ms, during which a fixation dot was shown, on half of the blocks, participants were presented with six randomly selected novel objects, three on each side of the screen, from the target object category (interference condition) for 400 ms. The area within which the interference objects can appear was restricted to 0.9 and 2.7° to the left and the right from the fixation, and 2.7° above and below the fixation. There were no other restrictions for positions of interference objects within the aforementioned ranges. As a result, on some trials, the interference objects partially overlapped with each other. On the other half of the blocks, the fixation dot remained on the screen

for 400 ms without any interference objects (no interference condition). Following another interstimulus interval of 1400 ms, a probe screen where two objects were shown vertically at the midline of the screen, one object positioned 2.8° above the fixation point and the other object positioned 2.8° below the fixation point. Both of the presented objects were previously learned objects in Phase 1, however, only one of them was cued at the beginning of the particular trial. Participants were instructed to indicate the target item for the trial by pressing the up or down arrow keys. The probe stayed on the screen until response. After the response, for the correct answer, the correct object was presented on either the right or left side of the screen with a green fixation dot and a green "CORRECT OBJECT" text. For the incorrect answer, the correct object was presented on either the right or left side of the screen with a red fixation dot, red "INCORRECT OBJECT" text, and a black "THIS WAS THE CORRECT OBJECT:" text for 1000 ms.

2.4.3.2 Trial distributions & block design

The experimental phase consisted of 576 trials and two interference conditions (Interference and No Interference). The interference conditions were blocked, consisting of 48 trials, and the condition of the block changed after every two blocks. In total, there were 12 blocks. The order of conditions was counterbalanced across participants. Each target memory object was probed 24 times. Target object location in the memory display (left vs right) was equally and randomly distributed within each block.

The experimental phase began with a training session of 16 trials for both block types. During the experimental phase, the interference condition changed five times overall. Prior to each block change, participants completed four practice trials, which resulted in 20 practice trials in total. The experiment was self-paced and each trial started with the participant pressing the space key. At the end of each block, the participants were informed about their accuracy for that block and were provided with a motivational sentence that was selected according to their accuracy percentage. For the accuracy percentage that was smaller than 70% "Please focus and try as hard as you can!"; between 70-80% "You are doing okay, but there is room for improvement!"; between 80-95% "You are doing pretty well!" and larger than 95% "Wow! You are doing amazingly well. Keep it up!" text was presented on the screen. The experimental phase lasted approximately 57 minutes.

2.4.4 EEG Recording

The EEG and horizontal electrooculogram (HEOG) were recorded from 32 sintered - AG/AgCI electrodes positioned at International 10/20 System sites, attached to an elastic cap (actiCAP, Brain Products). The EEG signal was amplified with the actiCHamp amplifier (ActiCHamp Plus, Brain Products GmbH, Gilching, Germany) and digitized at a sampling rate of 1000 Hz. The HEOG was recorded via the BrainVision Recorder (Vers. 1.24.0001, Brain Products GmbH, Gilching, Germany) from electrodes that were located approximately 1 cm lateral to the external canthi. The vertical electrooculogram (VEOG) was recorded from two external electrodes that were located approximately 2 cm above and below the right eye. Two electrodes (TP9 and TP10) attached to the two mastoids were used as reference electrodes while the left mastoid (TP9) was used as the online reference. Two external VEOGs were used to detect vertical eye movements and blinks. Two electrodes (F7 and F8) were used as HEOGs to detect horizontal eye movements. Since the amplification of EEG and external electrooculogram channels differ, we applied a scaling factor of 0.1 µV (Brain Vision Recorder | User Manual, 2018) to VEOGs to make the magnitude of the VEOG and HEOG recordings compatible with other EEG channels for both online visualization and offline analysis. The EEG data were collected from the following electrodes with a custom layout optimized for collecting data mainly from the parietal and occipital regions: Fp1, Fp2, F3, F4, Fz, FC5, FC6, FC1, FC2, C3, C4, Cz, CP5, CP6, CP1, CP2, P7, P8, P3, P4, Pz, PO7, PO8, PO3, PO4, O1, O2, and Oz. We kept the impedance for the electrodes below 20 kΩ.

The EEG analyses were carried out using MATLAB R2020b (Mathworks, Natick, MA), the EEGLAB toolbox (version 2021.1; Delorme and Makeig 2004), the ERPLAB toolbox (Version 8.30; Lopez-Calderon and Luck 2014), and custom scripts. Recording artifacts (muscle noise, slow drifts, saturation, and blocking) and ocular artifacts (eye movements and blinks) were detected manually by visual inspection. Rejection of the artifacts was performed blind to the experimental conditions and only before hypothesis testing. Trials containing such artifacts and incorrect behavioral responses were excluded from the analysis. After artifact rejection, datasets with less than 144 trials per interference condition were excluded from the analyses.

The data were filtered by an IIR Butterworth filter with a band-pass of .01-40 Hz using the pop_basicfilter.m function of ERPLAB. The data were re-referenced offline to the average of the right (TP10) and left (TP9) mastoids. The data was epoched between -2.5 and 5.7 ms where time 0 is the memory display. An additional epoching was performed between -0.5 and 3.7 ms for artifact rejection. Both types of epoching were done using the pop_epoch.m function of EEGLAB.

2.4.5 CDA Analysis

The CDA analysis was computed with a 300 ms baseline period prior to the stimulus onset, between 500 and 1900 ms, which is the time interval prior to the interference display. The CDA was calculated from the PO3/4, P3/4, P7/8, PO7/8, and O1/2 channels as the voltage difference between electrode sites contralateral versus ipsilateral to the location of the target object (Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Hakim et al. 2019; Vogel and Machizawa 2004). Bayesian paired samples t-test was used to compare the CDA amplitudes averaged within the time of interest before (700-1700ms) and after (2500-3500ms) interference for interference and no interference conditions. For the Bayesian statistical analyses, we used the uninformed and objective Cauchy distribution as prior with half of the estimated effect size, d/2=0.8 as the scaling parameter (Dienes 2021).

2.4.6 Lateralized Alpha-band (8-14 Hz) Power Suppression Analysis

Power analysis was performed using the same trials as in the CDA analysis. The epoched EEG time series were decomposed into time-frequency representations via a custom script. 20 logarithmically spaced complex Morlet wavelets ranging from 4 to 50 Hz were created by multiplying perfect sine waves (for each, $e^{i2 \pi ft}$; i represents the complex operator, f represents the frequency, and t represents the time) with a Gaussian ($e^{-t2/2s2}$; t represents time and s represents the width of the Gaussian). The width of the Gaussian was set according to s = δ /(2 π f), δ representing the number of cycles of each Morlet wavelet, logarithmically spaced between 3 and 10 cycles to have a good tradeoff between temporal and frequency precision.

The convolution was applied in the frequency domain. The Fast Fourier Transform (FFT) was applied to both the EEG data and the Morlet wavelets, then, the outcome was multiplied in the frequency domain. Taking its inverse FFT resulted in a complex signal. We estimated the frequency-specific total power at each time point by taking the square of the length of this complex signal (in Matlab: $abs(X)^2$, X representing the signal length). Power data was baseline normalized separately for each condition (interference and no interference) with decibel (dB) conversion according to 10*log10(power/baseline), using 500 to 200 ms prior to the memory display.

For the lateralized power calculations, the dB normalized data was averaged separately for contralateral and ipsilateral according to the side of the memory item at the same electrode pairs of interest that were used for the CDA analysis. The

lateralized power suppression was calculated as the difference between contralateral vs. ipsilateral dB normalized power values. The power values were averaged across alpha-band frequencies between 8 and 12 Hz. Lateralized alpha-band power was averaged across electrodes and within the same time of interest as in the CDA analysis. Bayesian paired samples t-test was used to compare the suppression across interference conditions (interference vs no interference) by using the same prior and the scaling parameter as in the CDA analysis.

2.4.7 Behavioral Analysis

Average reaction times (RTs) and accuracies were compared across interference and no interference conditions with a Bayesian paired samples t-test by using the same prior and the scaling parameter as in the CDA analysis.

2.5 Acknowledgments

3. EFFECTS OF ANTICIPATING AN INTERFERING TASK AND MEMORY LOAD ON WORKING MEMORY REACTIVATION OF LONG-TERM MEMORIES

Ataseven, N., Fukuda, K., Günseli, E. (in prep). Effects of anticipating an interfering task and memory load on working memory reactivation of long-term memories.

3.1 Introduction

Chapter 3 differed from Chapter 2 in three main aspects. First, in Chapter 3, we aimed to explore the effect of a stronger interference on the reactivation of LTMs in WM. Previous studies stated that passively viewing an interference screen had a weak or no effect on memory performance (Clapp, Rubens, and Gazzaley 2010; Irwin and Thomas 2008; Pinto et al. 2013). In line with these studies, in Chapter 2 there was no accuracy or RT cost of seeing an interference screen. Since there was no cost of the perceptual interference, the participants might not have needed to engage in preparatory memory reactivation strategies. On the other hand, the literature suggests that there is a significant cost of doing a secondary task on memory performance (Hakim et al. 2021; McLeod 1977; Moscovitch 1994; Pashler 1990) and this effect is higher than the effect of perceptual interference (Clapp and Gazzaley 2012; Hakim et al. 2021). For example, Clapp and Gazzaley (2012) tested participants' memory performance (accuracy and reaction times) in a delayed recognition task when the participants expected to be presented with a perceptual interference (stimulus-to-be-ignored) vs an interfering secondary task (stimulus-to-be-judged). They found that completing an interfering task had a more detrimental effect on memory performance than viewing a perceptual interference. Accordingly, in Chapter 3, we replaced the perceptual interference screen in Chapter 2 with a secondary task in which participants were instructed to find a target within a visual display.

Second, in Chapter 2, the participants were given one item to remember. However, one item can be stored in the FoA in WM and be protected from interference (Makovski and Jiang 2007; Makovski, Sussman, and Jiang 2008; Oberauer and Bialkova 2011; van Moorselaar et al. 2015; but see Allen and Ueno 2018; Hitch et al. 2018). Therefore, being able to protect the information in the FoA in WM could be another factor that inhibited the participants from engaging in preparatory memory mechanisms. In contrast, remembering more than one item exceeds the FoA capacity, which was shown to be one item (Garavan 1998; Makovski and Jiang 2007; McElree 1998; Oberauer 2002). When maintaining multiple items in WM, attentional resources are distributed among these items (Duncan 1980; Emrich, Lockhart, and Al-Aidroos 2017). This leaves fewer attentional resources available for each item and makes the memory items more vulnerable to the detrimental effects of interference (Allen and Ueno 2018; Hu et al. 2014). In this case, remembering multiple items could be another factor that encourages preparatory behavior for upcoming interference. In Experiment 2, we tested this by including a memory load 3 condition.

These two changes aimed to increase the costs of interference. The third main revision was the inclusion of a baseline WM condition: in half of the blocks, participants were given unstudied memory objects. This way, we were able to test the level of WM involvement for previously studied vs. unstudied information.

3.2 Materials and Methods

3.2.1 Participants

38 participants from Sabancı University participated in the experiment, 36 for course credit and 2 for monetary compensation (300 Turkish Liras). The study was performed according to the Declaration of Helsinki principles and the ethics approval was granted by the Sabancı University (SUREC) ethics committee. All participants signed an informed consent form prior to participating in the study. 3 participants did not complete the experiment. Data from 7 subjects were excluded from the analysis. 6 participants were excluded due to ocular and recording artifacts, 1 due to poor behavioral performance, leaving 28 participants (17 female; all normal or corrected-to-normal vision; no reported history of neuropsychological disorders; 18-29 years old, M=22.4, SD=2.8).

To calculate the minimum number of participants needed, we estimated the ef-

fect size by averaging the effect sizes across 7 experiments from 5 studies that analyzed the CDA for anticipating task difficulty and anticipating interruption (Feldmann-Wüstefeld, Vogel, and Awh 2018; Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Hakim et al. 2019; Schmidt and Zelinsky 2017). We carried out a sequential design approach by following the guidelines of Dienes (2021) and Schönbrodt and Wagenmakers (2018) with the associated R package made available by Schönbrodt and Stefan (2019) (github.com/nicebread/BFDA). The number of participants needed for a .90 power and a .02 false positive rate under the estimated effect size d=1.1 was calculated as 20. The stopping rule was determined as follows. After collecting data from 20 participants, BF was calculated after every 5 subjects. If the BF for the 2 (interference) x 2 (study) x 2 (memory load) Bayesian Repeated Measures ANOVA remained within and 6, data collection was going to end at 80 usable datasets.

3.2.2 Stimuli

We created a stimulus set that contained 1620 animal images (animate) from 54 categories and 1620 daily-life object images (inanimate) from 54 categories. The images were collected via a search on Google Images. The background of the images was removed using remove.bg website. All the images were then resized to equalize the number of non-transparent pixels across object images with a custom code using MATLAB R2020b (Mathworks, Natick, MA). The stimuli set was divided into three sets: target stimuli (22 items from 30 categories per animacy), interference stimuli (a separate dataset of 16 different version items from the 30 target categories), and nontarget stimuli (20 objects from 24 categories per animacy). The viewing distance to the screen was approximately 85 cm. The background color was gray (RGB: [128 128 128]). The cue (0.36° x 0.36°) contained blue (RGB: [0 0 256]) and orange (RGB: [256 128 0]) colors. The fixation dots (0.36° x 0.36°) were black (RGB: [0 0 0]). Red (RGB: [256 0 0]) and green (RGB: [0 256 0]) fixation dots were used for giving feedback.

3.2.3 Design and Procedure

3.2.3.1 Trial design

Figure 3.1 illustrates the trial structure for the experiment. The experiment consisted of 3 phases. Phase 1 and Phase 2 were almost identical to those in Experiment

1. The only difference was that in Experiment 2, 10 real-life objects and 10 animals were randomly shown 4 times, summing up to 80 trials for Phase 1 and also a minimum of 80 trials for Phase 2 compared to 72 trials for Phase 1 and 96 trials for Phase 2 in Experiment 1.

In Phase 3 (the experimental phase) each trial started with the participant pressing the space key. At the beginning of the trial, a fixation dot was presented for an interval that is randomly jittered between 500 and 650 ms. Next, a memory display of one or three memory items was laterally presented on the screen for 1250 ms. On the other lateral side of the screen, one or three nontargets appeared to balance the perceptual input. The blue or orange end of a central cue indicated the target lateral side and the cue color that indicated the target side was counterbalanced across participants. The participants were instructed to memorize the cued item/s. After an interstimulus interval of 1000 ms, during which a fixation dot was shown, on half of the blocks (as an interference block), participants were presented with four novel items for 1600 ms, two on each lateral side of the screen. One item belonged to the same category as one of the memorized items and the other three items belonged to one randomly selected category. Participants were instructed to report the lateral side that contains the item from the memorized item category by pressing the right or left arrow keys until the probe of the main task appeared. The visual area within which the interference objects can appear was restricted to 1.2° - 1.09° to the left and the right from the fixation, and 0.52° - 0.63° above and below the fixation. There were no other restrictions for positions of interference objects within the aforementioned ranges. As a result, in some trials, the interference objects partially overlapped with each other. On the other half of the blocks, the fixation dot remained on the screen for 1600 ms with 4 dots (0.36° x 0.36° each), two on each side of the screen, instead of the interference items (no interference condition). This was done to balance the perceptual input expectation between the conditions and keep the participants engaged throughout the retention interval.

Following another interstimulus interval of 400 ms, a probe screen contained two objects shown vertically at the midline of the screen, one item positioned above and one item below the fixation point with a 1.72° distance to the fixation point. If the current block probed the participants from studied objects, both of the presented objects were previously learned objects in Phase 1, however, only one of them was cued at the beginning of the particular trial. If the current block probed the participants from novel objects, one object was cued at the beginning of the particular trial and the other was never seen before. Participants were instructed to indicate the target item for the trial by pressing the up or down arrow keys. The probe stayed on the screen until response. After the response, for the correct answer, the cor-

rect object was presented on either the right or left side of the screen with a green fixation dot and a green "CORRECT OBJECT" text. For the incorrect answer, the correct object was presented on either the right or left side of the screen with a red fixation dot, red "INCORRECT OBJECT" text, and a black "THIS WAS THE CORRECT OBJECT:" text for 300 ms. If the current block contained an interfering task, the fixation dot after the interfering task was either green or red according to the accuracy of the response. If participants failed to give a response to the interfering task until the main task probe, they were warned with a black "PLEASE GIVE A RESPONSE TO THE INTERFERENCE TASK!" text for 1000 ms at the end of the trial after the feedback.

Figure 3.1 The experimental procedure
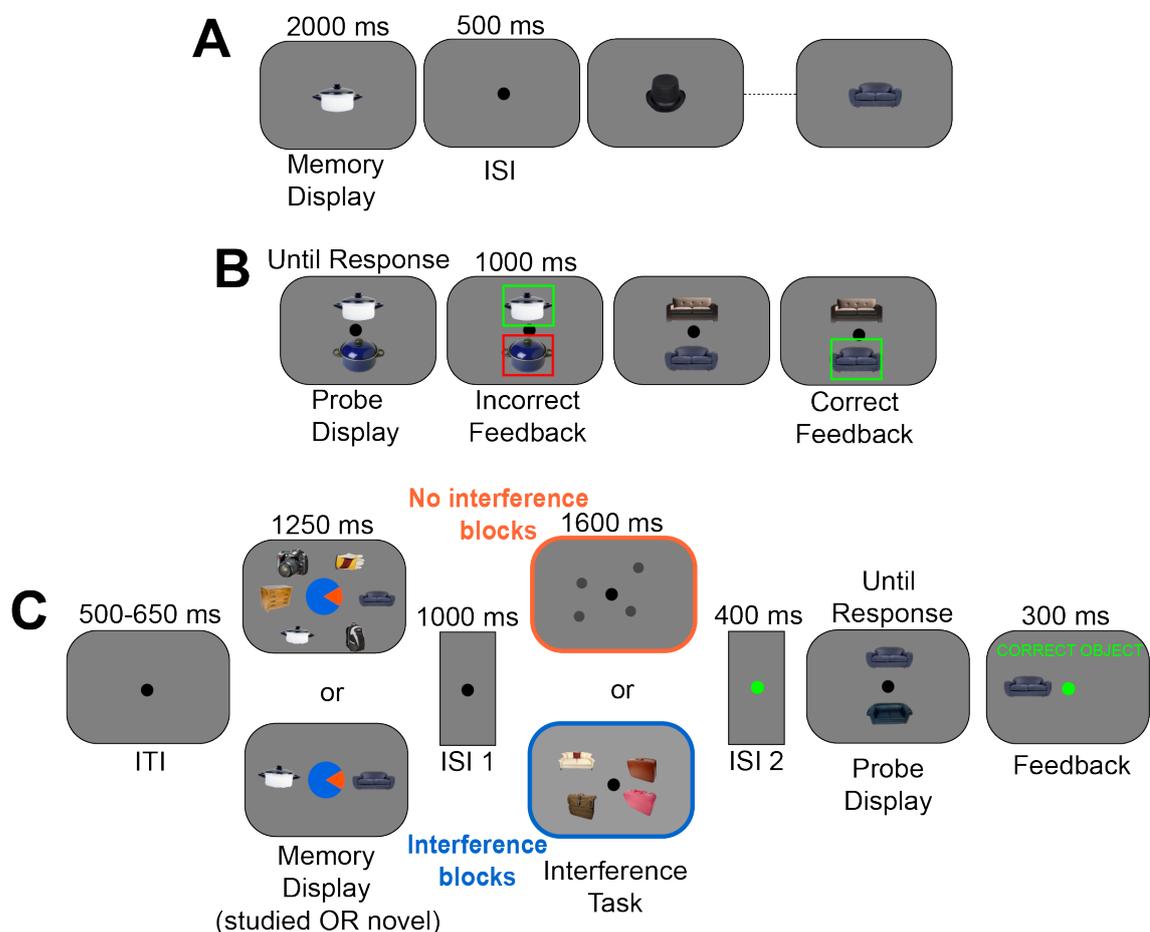
(A) In Phase 1, participants studied pictures of real-world objects or animals. (B) In Phase 2, their memory for the items was tested until they responded correctly four times in a row for each item. (C) In Phase 3, during which EEG was recorded, participants were given one or three previously studied or novel items and performed a two-alternative forced-choice task. On some blocks, there was an interfering task before the probe. At the end, participants received feedback regarding their responses.

3.2.3.2 Trial distributions & block design

The experimental phase consisted of 1280 trials and the trials were equally distributed among two interference conditions (Interference vs No Interference) two memory load conditions (load 1 vs load 3), and 2 study conditions (studied vs novel). The interference and study conditions were blocked, each block consisting of 80 trials, and the memory load conditions were intermixed. The study condition changed after every two blocks and the interference condition changed after every four blocks. In total, there were 16 blocks. The order of conditions was counterbalanced across participants. Each target memory item in the studied condition was presented as a target 64 times throughout the experiment. Each target memory item in the novel condition was presented as a target 2 times throughout the experiment and there were 8 blocks in between the two appearances. Target item location in the memory display (left vs right) was equally and randomly distributed within each block.

The experimental phase began with an information text regarding the upcoming block type and a training session of 8 trials when a new block type was introduced for the first time. During the experimental phase, the interference condition changed five times overall. The experiment was self-paced, and each trial started with the participant pressing the space key. At the end of each block, the participants were informed about their accuracy for that block and were provided with a motivational sentence that was selected according to their accuracy percentage. If the current block was an interference block, they additionally received feedback for the interfering task performance. For the accuracy percentage that was smaller than 65% "Please focus and try as hard as you can!"; between 65-75% "You are doing okay, but there is room for improvement!"; between 75-90% "You are doing pretty well!" and larger than 90% "Wow! You are doing amazingly well. Keep it up!" text was presented on the screen for both task types. The experimental phase lasted approximately 180 minutes (SD = 17.8 minutes).

3.2.4 EEG Recording

The EEG recording procedure in Experiment 2 was almost identical to Experiment 1 except for the epoch period was from -500 to 4550 ms for both EEG analysis and artifact rejection.

3.2.5 CDA Analysis

The CDA analysis was computed with a 300 ms baseline period prior to the memory display onset, between 1350 and 2150 ms, which is the time interval prior to the interference display. The CDA was calculated from the PO3/4, P3/4, P7/8, PO7/8, and O1/2 channels as the voltage difference between electrode sites contralateral versus ipsilateral to the location of the target object (Gunseli et al. 2018; Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Hakim et al. 2019, 2020; Vogel and Machizawa 2004). We computed a 2 (interference) x 2 (study) x 2 (memory load) Bayesian Repeated Measures ANOVA to analyze the main effects of the conditions and their interactions following the guidelines of Van den Bergh and Stefan (2023). For the Bayesian statistical analyses, we used the uninformed and objective Cauchy distribution as prior with half of the estimated effect size, d/2=0.55 as the scaling parameter (Dienes 2021).

3.2.6 Lateralized Alpha-band (8-14 Hz) Power Suppression Analysis

The alpha power analysis in Experiment 2 was almost identical to Experiment 1 except for the time period used for baseline normalization was from -400 to -100 ms prior to memory display onset. Similarly, Bayesian paired-samples t-tests were computed to compare the lateral alpha power suppression averaged before interference within the same time interval as the CDA analysis for the interference, study, and memory load conditions by using the same prior and scaling parameter as in the CDA analysis.

3.2.7 Behavioral Analysis

Average reaction times (RTs) and accuracies were compared across interference, study, and memory load conditions with Bayesian paired samples t-tests by using the same prior and the scaling parameter as in the CDA analysis.

3.3 Results

Trials with RTs faster than 200 ms and slower than 5000 ms were removed from the following analyses. BF greater than 6 was considered evidence in favor of a

meaningful difference between the comparison groups (alternative hypothesis); BF less than 0.166 was considered evidence in favor of a meaningful non-difference (null hypothesis); and BF between 3-6 or 0.166-0.333 was considered moderate evidence, and BF between 1-3 and 0.333-1 was considered anecdotal evidence. Means (M), standard deviations (SD), and 95% credible intervals (CI) are provided in parentheses when necessary. When calculating repeated measures ANOVA, we checked the effects across matched models as instructed by Van den Bergh and Stefan (2023) and Mathôt (2017).

3.3.1 Behavior

The average accuracy for each condition is shown in Figure 3.2A (violin plots). 6 Bayesian one-sample t-tests comparing the accuracy in the interference, no interference, novel item, studied item, memory load 1, and memory load 3 conditions against the chance level (50) showed that participants performed significantly above chance in all conditions with strong evidence ($BFs_{10} = 9.964 \times 10^{+19}$, $9.617 \times 10^{+22}$, $1.351 \times 10^{+22}$, $4.542 \times 10^{+20}$, $1.535 \times 10^{+27}$, $1.265 \times 10^{+14}$, respectively). Next, we computed a 2 (interference) x 2 (study) x 2 (memory load) Bayesian Repeated Measures ANOVA. There was strong evidence for all the main effects. Participants were more accurate in (i) no interference (M=85.133, SD=4.291) vs interference (M = 78.308, SD = 4.528) conditions, (ii) studied (M = 83.649, SD = 5.071) vs novel (M = 79.793, SD = 3.930) conditions ($BF_{inclusion} = 15203.370$), (iii) in load 1 (M = 92.529, SD = 3.566) vs load 3 (M = 70.912, SD = 5.780) conditions ($BF_{inclusion} = 5.297 \times 10^{+17}$). The interference x load ($BF_{inclusion} = 0.710$, anecdotal evidence), study x load ($BF_{inclusion} = 0.266$, moderate evidence) two-way interactions, and the interference x study x load three-way interaction ($BF_{inclusion} = 0.442$, anecdotal evidence) suggested no effect on accuracy. However, there was strong evidence for a significant interference x study two-way interaction on accuracy ($BF_{inclusion} = 9.320$). We then analyzed this interference x study interaction by comparing the interference cost (interference - no interference) on accuracy across the study conditions by computing a Bayesian paired-samples t-test. The results suggested that the interference cost on accuracy was more prominent for the novel item condition (M = -8.613, SD = 3.801, CI = [-10.086 -7.139]) compared to the studied item condition (M = -5.038, SD = 3.935, CI = [-6.564 -3.512]) with strong evidence ($BF_{10} = 9.353$).

Figure 3.2 Behavioral performance results
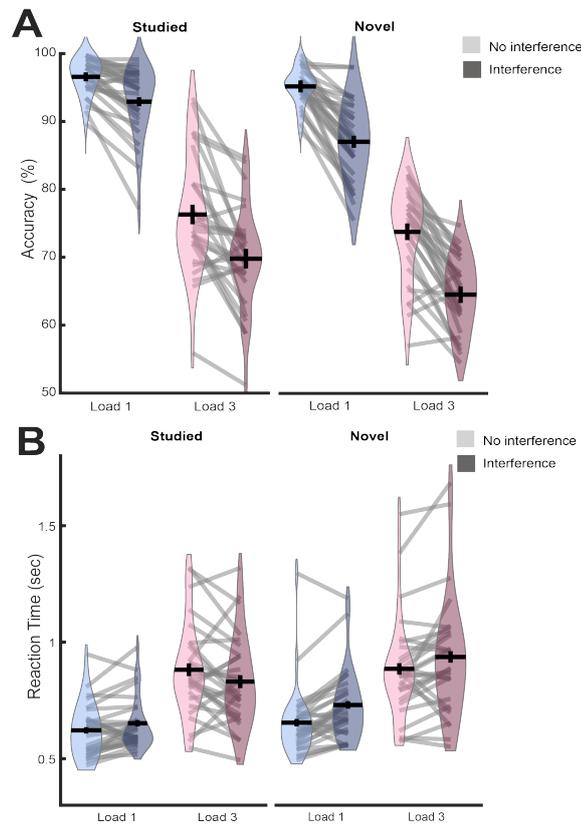
The violin plots show (A) accuracy and (B) reaction time for each condition. Lighter colors indicate the no interference condition and darker colors indicate the interference condition. The left columns show the studied item condition and the right columns show the novel item condition. Blue colors indicate memory load 1 condition and pink colors indicate memory load 3 condition. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference).

Reaction time (RT) averages for each condition are shown in Figure 3.2B (violin plots). The Bayesian repeated measures ANOVA suggested no significant effect of interference ($BF_{inclusion} = 0.909$) on RT with anecdotal evidence. On the other hand, the study ($BF_{inclusion} = 11.396$) and memory load conditions ($BF_{inclusion} = 1.795 \times 10^{+9}$) had an effect on RT with strong evidence. Participants were overall faster in studied (M = 0.746, SD = 0.142) vs novel (M = 0.802, SD = 0.189) conditions and in load 1 (M = 0.664, SD = 0.124) vs load 3 (M = 0.884, SD = 0.203) conditions. Moreover, the interference x study ($BF_{inclusion} = 59.686$) and interference x load ($BF_{inclusion} = 11.715$) interactions had significant effects on RT with strong evidence and interference x study x load ($BF_{inclusion} = 2.277$) interaction

with moderate evidence. Only the study x load interaction showed no effect on RT with moderate evidence ($BF_{inclusion} = 0.249$).

Next, to analyze the interference x study interaction we compared the interference cost (interference-no interference) on RT between the study conditions using a Bayesian paired-samples t-test. The results suggested that the interference cost on RT was more prominent for the novel item condition (M = -0.064, SD = 0.098, CI = [0.026 0.101]) compared to the studied item condition (M = -0.010, SD = 0.101, CI = [-0.049 0.029]) with strong evidence ($BF_{10} = 56.874$).

Then, we analyzed the interference x load interaction by comparing the interference cost (interference-no interference) on RT between load conditions using a Bayesian paired-samples t-test which suggested anecdotal evidence for no difference ($BF_{10} = 0.445$). Therefore, we further analyzed the memory load cost (load 3-load 1) on RT between the interference conditions using a Bayesian paired-samples t-test. Interestingly, the results suggested that the memory load cost on RT was more prominent for the no interference condition (M = 0.246, SD = 0.106, CI = [0.205 0.287]) compared to the interference condition (M = 0.193, SD = 0.110, CI = [0.150 0.235]) with strong evidence ($BF_{10} = 27.947$).

Lastly, we compared the memory load cost of interference cost for the studied item condition (i.e., Studied (load 3 $_{(interference-no\ interference)}$ - load 1 $_{(interference-no\ interference)}$)) vs the novel item condition (i.e., Novel (load 3 $_{(interference-no\ interference)}$ - load 1 $_{(interference-no\ interference)}$)) with a Bayesian paired-samples t-test, which suggested that with anecdotal evidence ($BF_{10} = 1.509$) load difference of the interference cost in studied item condition was higher (M = -0.82, SD = 0.112, CI = [-0.125 -0.038]) compared to the novel item condition (M = -0.025, SD = 0.100, CI = [-0.064 0.014]). The descriptives suggested that in the studied item condition in which the participants memorized one item, RTs were longer when the participants were interfered (M = 0.652, SD = 0.114) vs not interfered (M = 0.621, SD = 0.113). Interestingly, this trend was reversed when participants memorized three items instead of one; RTs were longer when participants were not interfered (M = 0.882, SD = 0.201) vs interfered (M = 0.831, SD = 0.196). We further analyzed the strength of this trend by conducting two Bayesian paired-samples t-tests to compare the memory load cost (load 3 - load 1) across interference and no interference conditions separately for the studied item vs novel item conditions. The results suggested that the cost of memory load was larger across the interference conditions in the studied item condition with strong evidence ($BF_{10} = 50.560$), meaning that there was a stronger memory load cost on RT in the studied item no interference condition (M = 0.260, SD = 0.120, CI = [0.214 0.307]) compared to the interference

condition (M = 0.179, SD = 0.118, CI = [0.133 0.225]. Lastly, the cost of memory load was absent across the interference conditions in the novel item condition with moderate evidence (BF $_{10}$ = 0.522, interference M = 0.206, SD = 0.135, CI = [0.154 0.259], no interference M = 0.231, SD = 0.115 CI = [0.186 0.276]).

3.3.2 EEG

3.3.2.1 CDA

The time course of CDA throughout the trial is shown in Figure 3.3A. To examine WM reactivation for each condition, we averaged the CDA observed from 1350 to 2150 ms after the memory display. The average CDA for each condition is shown in Figure 3.3B. 6 Bayesian one-sample t-tests were conducted to compare the CDA in the interference, no interference, novel item, studied item, memory load 1, and memory load 3 conditions against zero. The results suggested that there was a significant CDA in all conditions with strong evidence (BFs$_{10}$ = $1.103 \times 10^{+7}$, $1.612 \times 10^{+7}$, $1.837 \times 10^{+7}$, $6.983 \times 10^{+6}$, $1.440 \times 10^{+6}$, $4.077 \times 10^{+6}$, respectively). Next, we computed a 2 (interference) x 2 (study) x 2 (memory load) Bayesian Repeated Measures ANOVA to look at the effects of the conditions and their interactions. We found an effect of load conditions (BF$_{\text{inclusion}}$=17.030) with strong evidence, meaning that the memory load 3 condition had a larger CDA (M=-1.064, SD=0.645) compared to the memory load 1 condition (M=-0.675, SD=0.433). Furthermore, there was no effect of the interference conditions (BF$_{10}$ = 0.208, moderate evidence) and study conditions (BF$_{10}$ = 0.476, anecdotal evidence) on CDA (see Figure 3.3B for descriptives). There was no interference x study condition and interference x load condition interaction effect with anecdotal evidence (BF$_{10}$ = 0.335 and BF$_{10}$ = 0.336, respectively), and no study x load condition interaction with moderate interference (BF$_{10}$ = 0.279). Finally, there was no interaction effect of interference x study x load conditions with moderate evidence (BF$_{10}$ = 0.268).

We investigated the RT benefit of the interference that is present for memorizing 3 studied items by running a Bayesian correlation between the interference cost on RT (RT$_{\text{interference}}$ - RT$_{\text{no interference}}$) and the interference cost on CDA (CDA$_{\text{interference}}$ − CDA$_{\text{no interference}}$). The results suggested strong evidence for a negative correlation (Pearson's r = -0.566, BF$_{10}$ = 25.571). The direction of the correlation and the descriptives suggested that lower CDA amplitudes (interference cost on CDA M = -0.038, SD = 0.749) are correlated with slower responses in the no interference condition (interference cost on RT M = -0.051, SD = 0.146).

Figure 3.3 CDA results
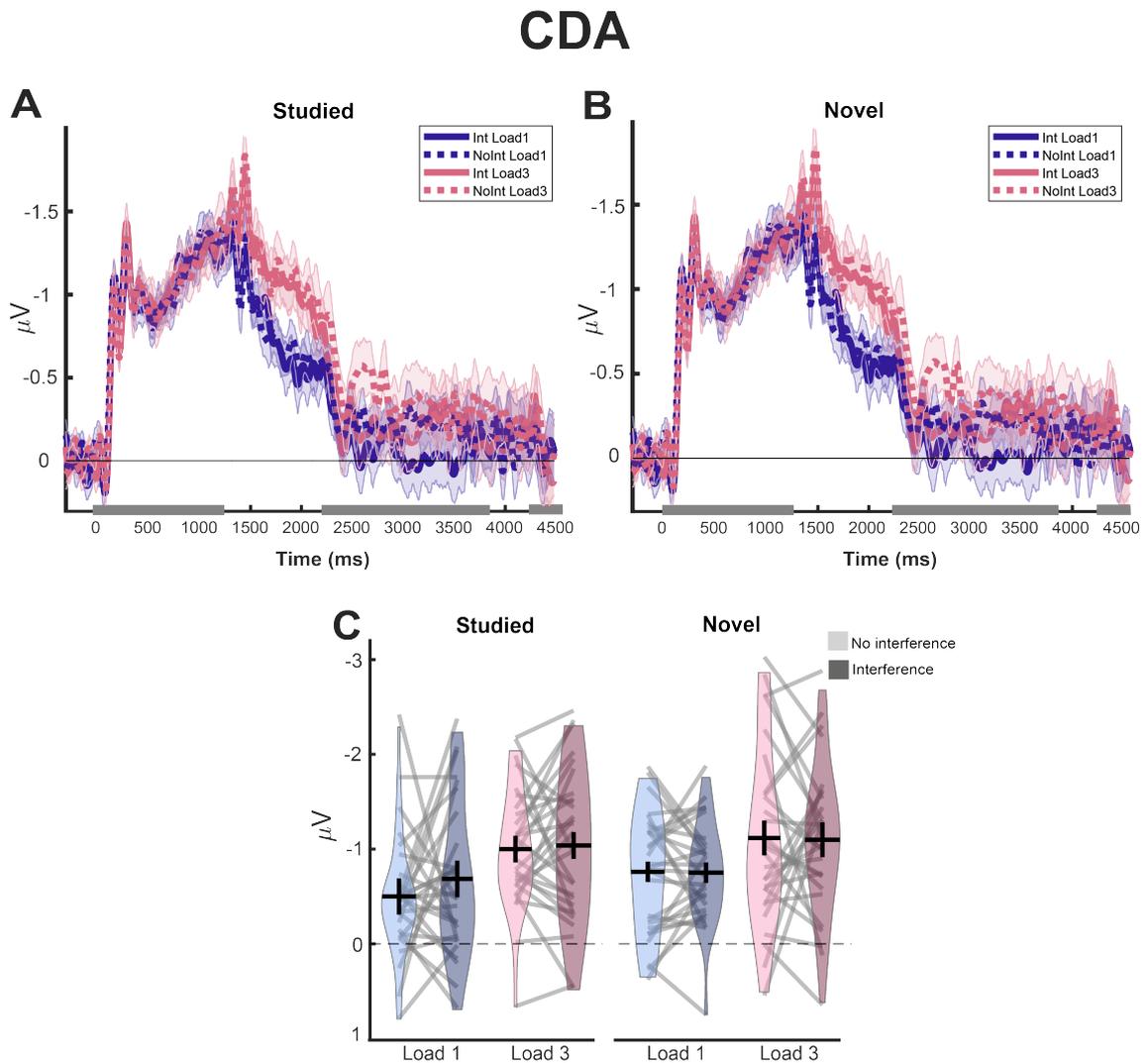
The waveforms for the CDA of studied (A) and novel (B) items are shown. Solid lines indicate the interference condition and the dashed lines indicate the no interference condition. Blue lines indicate the memory load 1 condition and pink lines indicate the memory load 3 condition. The dark gray areas on the x-axis show the timing of the memory, interference, and probe displays, respectively. The shaded light gray area shows the time interval used for computing the average CDA. (C) Violin plots that show the CDA averaged conditions. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference).

### 3.3.2.2 Lateralized alpha-band (8-14 Hz) power suppression

We examined the spatial attention allocated in each condition, by averaging the contralateral alpha power observed from 1350 to 2150 ms after the memory display. The average contralateral alpha power for each condition is shown in Figure 3.4B. 6 Bayesian one-sample t-tests were conducted to compare the contralateral alpha power in the interference, no interference, novel item, studied item, memory load 1, and memory load 3 conditions against zero. The results show weak evidence regarding a contralateral alpha power suppression in all of the conditions (BFs_{10}=0.976, 0.784, 0.734, 1.049, 1.343, 0.595, respectively, see Figure 3.4C for descriptives).

The time course of contralateral alpha power shown in Figure 3.4A&B suggests that at the beginning of the retention interval, there was no observable suppression, however, after almost 500 ms in the retention interval, the suppression became more visible. To account for this change, we divided the retention interval into early pre-interference (1350 to 1800 ms) and late pre-interference (1800 to 2150 ms) based on visual inspection and ran the same analyses again for both intervals. There was no significant contralateral alpha power suppression in the early pre-interference period in none of the conditions (interference, no interference, novel item, studied item, memory load 1, and memory load 3) as revealed by 6 Bayesian one-sample t-tests against zero (BFs_{10} = 0.392, 0.423, 0.353, 0.469, 0.622, 0.297, respectively). This effect had moderate evidence in the memory load 3 condition and anecdotal evidence in the other conditions. However, in the late pre-interference period, there was a significant contralateral alpha power suppression with moderate evidence in the interference condition (BF_{10} = 3.313) and with anecdotal evidence for the rest of the conditions (no interference, novel item, studied item, memory load 1 and memory load 3; BFs_{10} = 1.483, 1.871, 2.588, 2.788, 1.684). We then checked whether the change in the contralateral alpha power suppression between the early and late pre-interference interval was significant by computing the early-late difference for all conditions and comparing it against zero with 6 Bayesian one-sample t-tests (see Figure 3.4D for descriptives). Results suggested that the contralateral alpha power suppression increased from the early to late period with strong evidence in the interference condition (BF_{10} = 11.579, M = 0.253, SD = 0.420, CI = [0.090 0.416]) and in the memory load 3 condition (BF_{10} = 16.959, M = 0.259, SD = 0.407, CI = [0.102 0.417]). The increase from the early to late period was significant in the novel item condition with moderate evidence (BF_{10} = 4.445, M = 0.232, SD = 0.453, CI = [0.057 0.408]), and in the no interference (BF_{10}= 1.373, M = 0.191, SD = 0.495, CI = [-9.821×10-4 0.383]), studied item (BF_{10} = 1.987, M = 0.212, SD = 0.495, CI = [0.020 0.404]), and memory load 1 (BF_{10} = 1.115, M = 0.259, SD = 0.077,

CI = [0.102 0.417]) conditions with anecdotal evidence. However, the repeated measures ANOVA comparing the late-early period contralateral alpha power suppression across conditions did not find any effect of the conditions and their interactions ($\text{BF}_\text{inclusion}$(interference) = 0.247, $\text{BF}_\text{inclusion}$(study) = 0.213, $\text{BF}_\text{inclusion}$(load) = 0.281, $\text{BF}_\text{inclusion}$(interference x study) = 0.632, $\text{BF}_\text{inclusion}$(interference x load) = 0.324, $\text{BF}_\text{inclusion}$(study x load) = 0.273, and $\text{BF}_\text{inclusion}$(interference x study x load) = 0.828).

Figure 3.4 Contralateral alpha power suppression results

Contralateral Alpha Power (8-12 Hz)
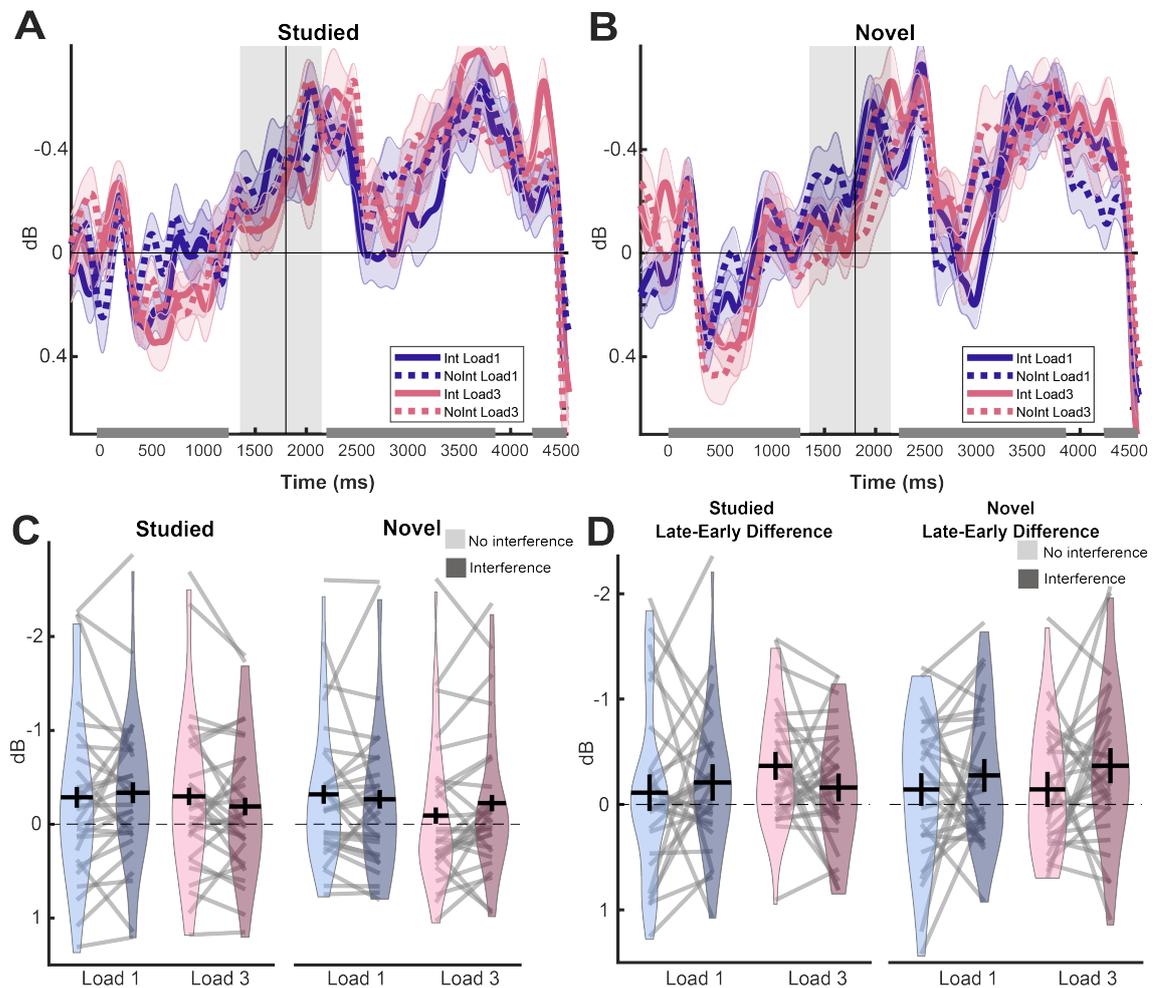
The waveforms for the contralateral alpha power suppression of studied (A) and novel (B) items are shown. Solid lines indicate the interference condition and the dashed lines indicate the no interference condition. Blue lines indicate the memory load 1 condition and pink lines indicate the memory load 3 condition. The dark gray areas on the x-axis show the timing of the memory, interference, and probe displays, respectively. The shaded light gray area shows the time interval used for computing the average contralateral alpha power. (C) Violin plots on the left side show the contralateral alpha power averaged conditions. (D) Violin plots on the right side show the contralateral alpha power difference from the early to late pre-interference period. Solid lines show average values across individuals. Each gray line shows data from one participant. The error bars indicate the standard error of the mean for the within-participant interference condition differences (i.e., interference – no interference).

Next, we computed a 2 (interference) x 2 (study) x 2 (memory load) Bayesian Repeated Measures ANOVA in the late pre-interference period of contralateral alpha power suppression. There was no effect of interference ($BF_{inclusion} = 0.241$), study ($BF_{inclusion} = 0.230$), and load ($BF_{inclusion} = 0.272$) conditions, and the interference x load ($BF_{inclusion} = 0.252$) and study x load ($BF_{inclusion} = 0.290$) conditions' interactions on contralateral alpha power suppression with moderate evidence. Also, there was no effect of interference x study condition's interaction with anecdotal evidence ($BF_{inclusion} = 0.778$). However, there was a significant effect of the three-way interaction between interference x study x load conditions with strong evidence ($BF_{inclusion} = 8.557$). We further explored this interaction effect in the late pre-interference period by comparing the conditions with Bayesian paired-samples t-tests. Results showed that the interaction mainly stems from the comparison between novel vs studied item conditions in the no interference memory load 3 condition ($BF_{10} = 8.915$), meaning that, there was higher contralateral alpha power suppression in the no interference memory load 3 studied item condition (M = -0.502, SD = 0.917, CI = [-0.858 -0.146]) compared to no interference memory load 3 novel item condition (M = -0.172, SD = 1.164, CI = [-0.800 0.103]). Moreover, the comparison between memory load 1 vs 3 in the no interference novel item condition was different with anecdotal evidence ($BF_{10} = 1.030$), suggesting slightly higher contralateral alpha power suppression in the memory load 1 condition (M = -0.396, SD = 0.889, CI = [-0.741 -0.052]) compared to load 3 condition (M = -0.172, SD = 0.939, CI = [-0.536 0.192]). Lastly, the comparison between interference vs no interference in the memory load 3 studied item condition was different with anecdotal evidence ($BF10 = 1.653$) meaning that there was higher contralateral alpha power suppression in the no interference condition (M = -0.502, SD = 0.917, CI = [-0.858 -0.146]) compared to interference condition (M = -0.279, SD = 0.865, CI = [-0.614 0.056]). Finally, we explored whether the contralateral alpha power in the late pre-interference period could explain the accuracies by running a series of Bayesian correlations. In all conditions, contralateral alpha power negatively correlated with accuracy scores, meaning that more contralateral alpha power suppression, therefore more attentional allocation was correlated with increased accuracy (for interference $BF_{10} = 1.238$, Pearson's r = -0.358, no interference $BF_{10} = 13.184$, Pearson's r = -0.532, studied item $BF_{10} = 3.561$, Pearson's r = -0.448, novel item $BF_{10} = 3.403$, Pearson's r = -0.445, memory load 1 $BF_{10} = 10.595$, Pearson's r = -0.519, memory load 3 $BF_{10} = 1.125$, Pearson's r = -0.348).

3.4 Discussion

In this study, we explored the effect of anticipating an interfering task on WM activation while memorizing one vs three items. We used a commonly studied EEG index of WM load, the CDA (Gunseli et al. 2018; Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014; Hakim et al. 2019, 2020; Vogel and Machizawa 2004). The CDA was larger for memory load 3 vs memory load 1, replicating the well-established load effect on the CDA (Ikkai, McCollough, and Vogel 2010; Luria et al. 2010; McCollough, Machizawa, and Vogel 2007; Vogel and Machizawa 2004). However, CDA did not differ across interference conditions, meaning that anticipating an interfering task did not have an effect on WM activation levels (Ataseven et al. 2022; Hakim et al. 2020). On the other hand, behavioral measures were impacted by all the experimental conditions, and the time course of contralateral alpha power suppression, an index of spatial attention (Foster et al. 2016; Gould, Rushworth, and Nobre 2011; Gunseli et al. 2017; Kelly et al. 2006; Thut, Nietzel, Brandt, and Pascual-Leone 2006), showed a significant difference across conditions, which are discussed below.

Accuracy results suggested a significant cost of doing an interfering task. This was in line with the literature suggesting that doing a secondary task has a significant cost on memory (Hakim et al. 2021; McLeod 1977; Moscovitch 1994; Pashler 1990). Moreover, participants had lower accuracy when memorizing 3 items compared to 1 item, meaning that there was a cost of memory load on accuracy, which also replicates the literature (Fukuda and Woodman 2017). Also, participants had higher accuracy when memorizing previously studied items compared to novel items, suggesting a benefit of memorizing studied items. Importantly, the cost of interference on accuracy was more prominent when participants memorized novel items compared to studied items. A possible reason for this could be that after the memory items are impaired by the interfering task before the main task probe is presented, the memory items can be recovered if LTM representations are available. However, since it is not possible for the novel items, any detriments from the interference are irreversible, leading to more interference costs. Overall, these findings suggest that performing a secondary task is costly for storing information briefly in memory, and having this information previously studied reduces these costs.

Participants were slower to give a response when they memorized 3 items vs 1 item in line with the literature (for a review see Vergauwe and Cowan 2014) and when they memorized novel items vs studied items. Although there was no main effect of the interference task on reaction time, the interaction effects revealed that the

cost of the interference task was significantly prominent when memorizing novel items. This finding is in line with the accuracy results suggesting that information is better protected from interference when it is previously studied. However, it is unclear whether this protection is due to having more robust WM representations when previously studied or being able to retrieve the intact LTM traces when WM is disrupted.

We found that the cost of memorizing 3 objects compared to 1 on RT was more prominent in the no interference condition. The follow-up tests suggested that this effect comes from the studied item condition, suggesting that the memory load cost is present in the studied item no interference condition only. This might indicate that when upcoming interference is not anticipated, memory items might have been stored via passive states, therefore, the selection of the target memory item among the other items might be more effortful. This finding is in line with previous studies suggesting that episodic memory retrieval takes time (Spaniol, Madden, and Voss 2006). Moreover, when participants memorized 3 previously studied items, less WM reactivation, hence relying more on passive traces, was correlated with slower response times in the no interference condition. This finding also supports the idea that when remembering multiple previously learned items and not anticipating interference, information might be stored passively.

To account for the WM reactivation, we averaged the CDA amplitude from 1350 to 2150 ms after the memory display onset prior to the anticipated interference and found significant memory reactivation in all conditions. There was a significant effect of memory load on CDA; the CDA in memory load 3 was larger than memory load 1. This is in line with previous studies suggesting that CDA is a measure that tracks the number of items reactivated (Ikkai, McCollough, and Vogel 2010; Luria et al. 2010; McCollough, Machizawa, and Vogel 2007; Vogel and Machizawa 2004). However, there was no effect of having LTM representations or not on memory reactivation. This means that on average when the studied memory items are re-experienced, they are retained in WM similar to when experiencing novel items. Visual WM (VWM) represents the current state of our environment (Logie 1995). Hence, when previously studied items are re-experienced, for instance, when you look at your coffee cup, it is internally represented in VWM. Therefore, encoding the internally represented items back to LTM when anticipating interference might not be strategic. One reason for this is that divided attention during memory encoding is found to be very detrimental to memories compared to divided attention during memory retrieval (Craik et al. 1996; Naveh-Benjamin and Guez 2000; Naveh-Benjamin et al. 2000). In a difficult and long experiment like the current one, it might be more strategic to retain the already present VWM representation

of the studied items instead of engaging in LTM encoding. Future studies should investigate this possibility with cued LTM retrieval since when the cue is perceived, engaging in retrieval or not can be strategically decided. Previous studies suggested that LTM retrieval can bypass WM reactivation (Liu et al. 2022). Therefore, a possible scenario in which WM reactivation can be bypassed can be when anticipating interference.

There was no effect of anticipating an interfering task on memory reactivation. Given the large costs of interference on behavioral indices in the current study, the interfering task was difficult enough to allow participants to possibly prepare for it. However, the lack of an effect of interference on memory reactivation might suggest that increased or decreased memory reactivation does not account for preparing to protect memory items. Furthermore, these findings are in contrast with the slower reaction times when memorizing 3 studied items in the no interference condition. There can be two possible explanations for this conflict. Since the interference task involves a memorized item category, the memorized items can be scanned while responding to the interference task in the interference condition. This scanning prior to the main task probe can benefit the selection of the target memory items among other memory items. So the first possibility is that since prior scanning of the memory items is not necessary for the no interference condition, this scanning and selecting the target memory item can take place when the main task probe is presented which results in longer reaction times. Another possibility is that although the memorized items are reactivated in WM, they are not brought to the region of direct access, a region of WM that stores information to be used in an ongoing cognitive operation that is functionally distinct from the reactivated portion of LTM and the FoA (see more in Oberauer 2002, 2013). Since the FoA cannot store 3 items, the studied items might have been kept in the activated portion of LTM. Bringing the items back to the region of direct access and comparing them to the probe item can be the reason for the longer reaction times.

Memory reactivation and attention are shown to be closely linked to each other (for a review see Chun and Turk-Browne 2007). Increased attention to items in WM is shown to be protected from interference (Matsukura, Luck, and Vecera 2007; Oberauer and Lin 2017; van Moorselaar et al. 2015; but also see Allen and Ueno 2018; Hitch et al. 2018). Therefore, we analyzed the allocation of spatial attention to memory items when anticipating an interference task by measuring the contralateral alpha power suppression in the same time period as the CDA was calculated. Although there was no significant attentional allocation in the early pre-interference period, attention increased prior to the interference period specifically in the interference condition. This finding could indicate attentional preparation for the

upcoming interference task since previous studies showed that anticipated task demands modulate attentional allocation (Rummel and Meiser 2013).

The following analyses suggested that the interaction between the interference, memory load, and study conditions had an effect on attention with strong evidence. Participants attended more when they memorized 3 studied items and did not anticipate interference compared to when they memorized 3 novel items and did not anticipate interference. These findings suggest that memorizing more than one item requires different attentional resources when the items have LTM representation compared to novel items. This is interesting because previous studies suggested that memory performance increases as the memory items are learned (Fukuda and Woodman 2017) as also suggested by the behavioral results of the current study, therefore it could require less effort to be maintained. An explanation for this finding could be that the participants simply cannot attend to three novel items successfully. Since the novel item memory load 3 conditions had the lowest accuracy scores, maybe the participants cannot retain all items successfully, and this results in lower attentional allocation for that condition. Therefore, this finding does not necessarily mean that memorizing 3 novel items requires less attention compared to studied items, rather they might fail to attend to all 3 novel items compared to studied items. Another question is why this study condition difference in attentional allocation is present in the no interference condition but not present in the interference condition. Rummel and Meiser (2013) found that anticipating different task demands modulated preparatory attention. Maybe preparing for the interference consumed the attentional resources and the participants could not attend to the memory items regardless of the LTM availability when they prepared for the upcoming interference. Finally, increased attentional allocation in the late pre-interference period was associated with increased accuracy rates. This correlation was prominent for the no interference condition, however, it had anecdotal evidence in the interference condition. This might suggest that decreased attention to the locations of the memory items may inhibit involuntary encoding of the interference items appearing on the attended locations (Hillyard, Vogel, and Luck 1998; Kelly et al. 2006; Rees, Frith, and Lavie 1997; Worden et al. 2000).

In summary, there was no difference in WM reactivation of one or three novel or studied items when anticipating an interfering task vs not. The interfering task had a significant cost on memory performance, however, having LTM representations of the memorized items helped protect the information against interference. Moreover, increased spatial attention in the late pre-interference period was correlated with increased accuracies specifically when participants did not anticipate interference.

3.4.1 Acknowledgments

4.   SUMMARY AND GENERAL DISCUSSION

Interaction between WM and LTM is crucial to navigating everyday life. For instance, you need to remember that your next best friend's birthday is next week to get her a gift on time. Behavior is found to be guided by both WM and LTM (Gunseli, Olivers, and Meeter 2014; Gunseli, Meeter, and Olivers 2014). However, memory systems are shown to be impaired by divided attention (Craik 1983; Craik and Byrd 1982; Jennings and Jacoby 1993; Kilb and Naveh-Benjamin 2007; Rabinowitz, Craik, and Ackerman 1982). Therefore, if upcoming attentional demands are anticipated, a predictive brain could develop adaptive strategies to protect memories against interference while not wasting excessive energy resources.

WM reactivation is shown to be a factor that protects information because attentional resources can be directed to items in WM to act as a shield (Matsukura, Luck, and Vecera 2007; Oberauer and Lin 2017; van Moorselaar et al. 2015). However, the literature regarding this topic is inconsistent. Some other studies suggest that memories that are prioritized in WM are more vulnerable to interference (Allen and Ueno 2018; Hitch et al. 2018). In this thesis, my aim was to address how memory reactivation levels could possibly change to protect LTMs when upcoming interference is anticipated.

To conclude, Chapter 2 investigated this by using perceptual interference. The results suggested that anticipating interference did not lead to any preparatory WM reactivation differences. However, internal attention directed to spatial locations of the memory items was reduced when anticipating perceptual interference. This finding might mean a strategic attentional inhibition to prospective locations of the distractors, probably to suppress distractor encoding. Lastly, we divided the participants into two groups in terms of the WM reactivation levels when anticipating interference and found that participants who have more WM reactivation when anticipating interference (WM preparers) did not experience a behavioral cost of the interference. Additionally, WM preparers significantly reduced attention to memory locations before interference. Overall, Chapter 2 suggested that there could be

individual differences in WM reactivation when preparing for interference and high-lighted the importance of internal attention in preparing for anticipated interference.

Chapter 3 investigated the effect of anticipating interference on WM reactivation when the interference is more costly. Moreover, it investigated whether memorizing varying memory loads that could exceed the capacity of the FoA would encourage different preparatory strategies. Results suggested that there was no difference between anticipating interference vs not when memorizing one or three novel or studied items, however, studied items were better protected from the cost of dual-task interference. In the no interference condition, increased spatial attention preceding the sham interference presentation was correlated with increased accuracies. A possible reason why Chapter 3 did not replicate the attentional inhibition findings could be because in Chapter 2 participants could ignore the distractors and allocate spatial attention accordingly, whereas in Chapter 3 they have to attend to the display to give a response to the interfering task.

4.1 Limitations

The cost of interference was significant in all conditions, however, the cost was larger in the novel item condition compared to the studied item condition. A possibility is that LTM availability of the information is a factor that supports memory performance. After the representation of the studied item is disrupted by interference, information could be recovered from LTM before the main task probe. However, since the participants could move their eyes while answering the interfering task, it is not possible to reliably measure the memory recovery in the after-interference interval.

The current thesis investigates the preparatory strategies when LTMs are re-experienced. The information shown in the visual world is represented in VWM (Logie 1995). Encoding the already represented back to LTM when anticipating interference might be effortful. Also, since the literature suggests that interference while encoding information is detrimental to memory the most (Moscovitch, 1994), it might be inadaptive to encode information back to LTM in the interference condition. Therefore, it might be favored to retain the information in WM. Future research should investigate the WM reactivation levels when LTMs are cued to be retrieved. Doing this can allow for the strategic representation of LTMs in WM more clearly.

4.2 Summary

In sum, this thesis suggests that on average there is no WM reactivation difference when preparing for interference, however, individual differences might suggest possible WM reactivation differences. Moreover, attention is another cognitive factor that potentially modulates preparation strategies that should be further explored.

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