THE EFFECTS OF DISTRACTION DURING MEMORY RETRIEVAL ON THE PROBABILITY OF RECALL AND PRECISION OF MEMORANDA

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ABSTRACT

THE EFFECTS OF DISTRACTION DURING MEMORY RETRIEVAL ON THE PROBABILITY OF RECALL AND PRECISION OF MEMORANDA

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Keywords: long-term memory, remembering, distraction, multitasking, mixture modeling

Long-term memory (LTM) enables the encoding, storage, and retrieval of memories for extended durations. While divided attention has resulted in decrements in encoding to LTM, it has minimal or no effect on retrieval performance. The present study examined the possibility that the precision of representations may be more susceptible to detrimental effects of divided attention during retrieval by using the continuous report paradigm. Participants (N = 20) learned 180 object-orientation associations and retrieved those orientations under full or divided attention conditions. Mixture modeling fit on error distribution has shown that accessibility of representations was lower in the divided attention compared to full attention condition, with no difference in their precision. These results suggest that dividing attention during retrieval reduces the accessibility of memoranda while not affecting the precision of representations.

ÖZET

HATIRLAMADA BÖLÜNMÜŞ DİKKATİN ANILARIN HATIRLANABİLİRLİK VE ÇÖZÜNÜRLÜKLERİ ÜZERİNDEKİ ETKİSİ

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PSİKOLOJİ BÖLÜMÜ YÜKSEK LİSANS TEZİ, JULY 2022

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Anahtar Kelimeler: Uzun süreli bellek, hatırlama, dikkat çeldirici, çoklu görev, karışım modeli

Uzun süreli bellek (USB), anıların kaydedilmesini, saklanmasını ve geri çağrılmasını sağlar. Her ne kadar dikkatin bölünmesi, anıların uzun süreli belleğe kaydedilmesine zarar verse de, uzun süreli belleğe dayalı hatırlamaya etkisine dair bulgular net sonuçlar ortaya koymamaktadır. Bu çalışma, sürekli raporlama paradigmasını kullanarak temsillerin çözünürlüğünün bölünmüş dikkatin zararlı etkilerine daha duyarlı olma olasılığını incelemiştir. Katılımcılar (N = 20) 180 obje-oryantasyon eşleşmesi öğrendiler ve obje oryantasyonlarını tam ya da bölünmüş dikkat koşullarında hatırladılar. Hata oranına uydurulmuş karışım modeli, ulaşılabilirlikte bölünmüş dikkat koşulunda azalma olduğunu, ancak çözünürlüğün aynı kaldığını göstermiştir. Bu bulgular, bölünmüş dikkatin temsillerin ulaşılabilirliğini azalttığını gösterirken çözünürlükleri üzerine bir etkisi olmadığını göstermiştir.

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1. INTRODUCTION

Remembering is a crucial part of humans' daily lives that rely on long-term memory (LTM), and it is important to understand how and when a successful remembering occurs. For instance, correctly remembering our password for a website can be difficult if our attention is divided by the pop-up ads or the sound of the dog outside. However, contrary to consistent effects of attention observed in encoding, previous studies observed that LTM retrieval is generally resilient to the negative influence of divided attention. Several studies tried to identify the reasons behind observing divergent effects of attention on encoding to vs. retrieval from LTM. One line of research has found that the effect of divided attention on remembering depends on the nature of the retrieval task (Baddeley et al. (1984); Craik et al. (1996); Troyer and Craik (2000)). Accordingly, while divided attention does not affect recognition, it decreases performance in cued recall and free recall tasks observed as recalling fewer items (Craik, 1996). Another line of research argues that the representational similarity between the tasks used for retrieval and divided attention can explain the differential effects of divided attention on LTM retrieval. For instance, Craik et al. (1996) and Baddeley et al. (1984) did not observe the costs of dividing attention with a visual task while testing verbal memory. On the other hand, Fernandes and Moscovitch (2000, 2002, 2003) compared the effects of divided attention tasks being word vs. digit monitoring on verbal memory. They have found greater impairments in verbal memory when the divided attention task was word monitoring. These findings suggest that divided attention costs are present when the divided attention task taps onto the same representational format as retrieved memories (e.g., verbal-verbal). Overall, previous studies have proposed that the effect of attention on retrieval success depends on the type of the retrieval task and the representational similarity between the retrieval task and the secondary task. In this thesis, we argue for another possibility to reconcile the conflicting findings in the literature: divided attention disrupts the precision and not the accessibility of memoranda. This perspective would imply that the reason behind the inconsistent results in the literature is the difference in precision requirements across tasks.

1.1 Relationship Between Long-term Memory and Attention

Long-term memory is the massive storehouse of knowledge and experience that is also responsible for their encoding and retrieval. However, directing attention to information is critical for successful encoding and retrieval. Studies investigating the relationship between LTM and attention have focused on the concept of divided attention through the dual-task paradigm. In the dual-task paradigm, divided attention is observed when doing more than one cognitive task simultaneously, while attention is shared between two tasks. This paradigm enables researchers to monitor the effects of attention during the use of LTM in encoding and retrieval. Previous research has repeatedly shown that divided attention during encoding impairs LTM by reducing later recall or recognition performance (e.g., Anderson and Craik (1974); Baddeley et al. (1984); Craik et al. (1996); Naveh-Benjamin et al. (2000)). For instance, Craik, Eftekhari, and Binns (2018) investigated that when attention was divided with a task that required participants to detect a run of three consecutive odd digits among a list of digits presented sequentially, the probability of recall of words dropped significantly compared to full attention condition. On the other hand, divided attention during LTM retrieval has mixed effects. While some studies have shown that LTM retrieval is resilient to divided attention Baddeley et al. (1984); Craik et al. (1996); Weeks and Hasher (2017), others have found that divided attention reduces memory performance during retrieval (Fernandes and Moscovitch (2000, 2003)). Therefore, I will first discuss the reasons for observing the divergent effects of divided attention on LTM retrieval; then I will introduce a new possibility to reconcile the conflicting findings.

1.1.1 Retrieval Tasks

Long-term memory studies generally use four different recall tasks: recognition test, cued recall, free recall, and source recall. In the recognition test, participants are expected to learn several stimuli. After a retention period following the learning phase, participants' recognition memory is measured with the presentation of a test stimulus. Participants would be asked whether the subsequent test stimulus is novel or one of the studied stimuli. In cued recall, participants are asked to learn a stimulus along with a cue that will remind them of that stimulus (e.g., a car picture and the word "drive"). When the cue (e.g., drive) is shown during the test, the stimulus (e.g., car) is expected to be remembered. In the free recall task, participants are given a list of words to learn, and after a certain time, they are expected to recall the words without any cues and in any order. Accordingly, while divided attention does not affect retrieval in the recognition test since it becomes a priority, it decreases the recall performance in the cued recall and free recall tasks (Baddeley et al. (1984); Craik et al. (1996); Troyer and Craik (2000)). The effect of attention is most visible in the source recall task, where people are expected to remember the context of the information along with the information they are holding in mind. For instance, Troyer and colleagues (1999) read lists of words to the participants for them to memorize. While one of these lists was read by a male, the other was read by a female, and then the participants were asked whether a female or male read the words. Simultaneously with the source recall task, participants also performed one of two secondary tasks (finger tapping or visual reaction time task). The results of the study showed that the source recall was affected by divided attention. Taken together, it can be suggested that the retrieval task being recall as opposed to recognition is a determining factor in observing divided attention costs on retrieval.

1.1.2 Similarity Between the Tasks Used for Retrieval and Divided Attention

Representational similarity between the tasks used for retrieval and divided attention is another factor that can account for the differential effects of divided attention. For example, visual divided attention tasks such as card-sorting or visual continuous reaction time (CRT) did not impair verbal free recall accuracy (Baddeley et al. (1984); Craik et al. (1996)). On the other hand, Fernandes and Moscovitch (2000) observed greater costs on a verbal memory retrieval task when attention was divided with a word monitoring compared to a digit monitoring task. Therefore, divided attention may disrupt retrieval when the distractor task and retrieved information tap onto the same representational system (e.g., verbal-verbal). Given the overlap of neural networks that represent newly acquired and retrieved information, this effect could be due to increased interference in the neural mechanisms that represent information encoded for the divided attention task and information reinstated via LTM retrieval (Favila, Lee, and Kuhl (2020); Fukuda and Woodman (2017); Gisquet-Verrier and Riccio (2012); Long, Kuhl, and Chun (2018)).

1.2 Accessibility and Precision of Memoranda

Until recently, retrieval performance was thought to operate on the all-or-non principle. In other words, remembering has been identified as, for a given moment, having the information in mind or not. However, recent studies using the mixture modeling approach have shown that, in addition to the accessibility of representations in both working memory and LTM, their precision can be a measure of retrieval performance (Bays, Catalao, and Husain (2009); Brady et al. (2013); Zhang and Luck (2008)). The continuous report paradigm is usually used in order to measure the accessibility and precision of representations. In this paradigm, participants reproduce a memory feature on a continuous scale. For instance, they may be required to choose the color of an object on a color wheel with 360 different colors, including different shades of the target memory. Thus, the difference between the encoded and remembered color can be measured sensitively on a 360-degree scale. This enables the calculation of accessibility (i.e., whether participants report the target memory) and precision (i.e., how precise the target memory is reported in terms of its exact feature value) of the color's representation in mind by using mixture modeling.

Studies using continuous report paradigms found that the precision of items in working memory decreases with increasing memory load (Biderman et al. (2019); Zhang and Luck (2008)), duration of storage (Rademaker et al. (2018)), and perceptual interference (van Moorselaar et al. (2015)). Moreover, Klyszejko, Rahmati, and Curtis (2014) found that when the representations in working memory are prioritized by using a reward or a cue, the precision of the recalled representations is higher than those that are not cued, suggesting that the precision of representations in working memory is affected by attention. Similarly, several studies have investigated the precision and accessibility aspects of LTM retrieval (Fan and Turk-Browne (2013); Richter et al. (2016)). For instance, Fan and Turk-Browne (2013) evaluated how retrieving a feature (e.g., color) of an object affects the precision of other features (e.g., location). They found that when people retrieved one feature, while the precision remained the same, the probability of guessing was increased for the second feature. However, to our knowledge, how divided attention during the retrieval affects the precision and accessibility of representation in LTM has not been investigated before.

1.3 Current Study

In this study, we aimed to investigate a different possibility for the divergent findings of the effects of divided attention on LTM retrieval by relying on the differences between accessibility and precision. We hypothesized that divided attention disrupts the precision and not the accessibility of memoranda. Considering that recall tasks are more prone to disruption by divided attention than recognition, we reasoned that this could be due to the precision requirements of the recall tasks. In a simple recognition task, participants compare a target representation with a perceptually available probe item distinct from the target. Therefore, they don't need to hold the detailed representation in mind to give a correct response. However, in a recall task, participants need to reproduce the representation in mind to be able to retrieve it correctly. Here, we used a continuous report paradigm that requires high precision since participants were required to learn and then reproduce the locations (Experiment 1A, 1B) and orientations (Experiment 2) of objects in a continuous manner. This paradigm enabled us to investigate the precision and accessibility of representations by using mixture modeling.

To compare the effects of divided attention on precision and accessibility, we first needed to confirm that divided attention indeed impairs LTM retrieval. Therefore, we first compared the mean error rate of participants for divided attention and full attention conditions. Then, after applying mixture modeling to the data, we looked at the effects of divided attention on precision and accessibility. Since the effects of divided attention are usually observed in tasks requiring high precision, we expected to find a significant difference between divided attention and full attention conditions in terms of precision. As opposed to our predictions, accessibility was lower under divided attention while precision remained unaffected. Although our results do not explain why some studies failed to observe divided attention costs on retrieval, we show that divided attention, when detrimental to retrieval, primarily affects the accessibility of memories with no effect on their precision.

2. PILOT STUDIES

2.1 Experiment 1A

2.1.1 Method

2.1.1.1 Participants

Thirty-three undergraduate students from Sabanci University participated in the experiment for course credit. Participants who reported having a normal or corrected-to-normal vision and having no neuropsychological disorders were accepted for the experiment. Eleven participants with less than 75% accuracy were excluded from the analysis.

2.1.1.2 Materials

The experiment was programmed in PsychoPy (Peirce et al. (2019)) and remotely run through Pavlovia.org. The stimulus set consists of 1598 real-world objects (Brady et al. (2008, 2013); Konkle et al. (2010); Google Images) and audio recordings of numbers from 1 to 50.

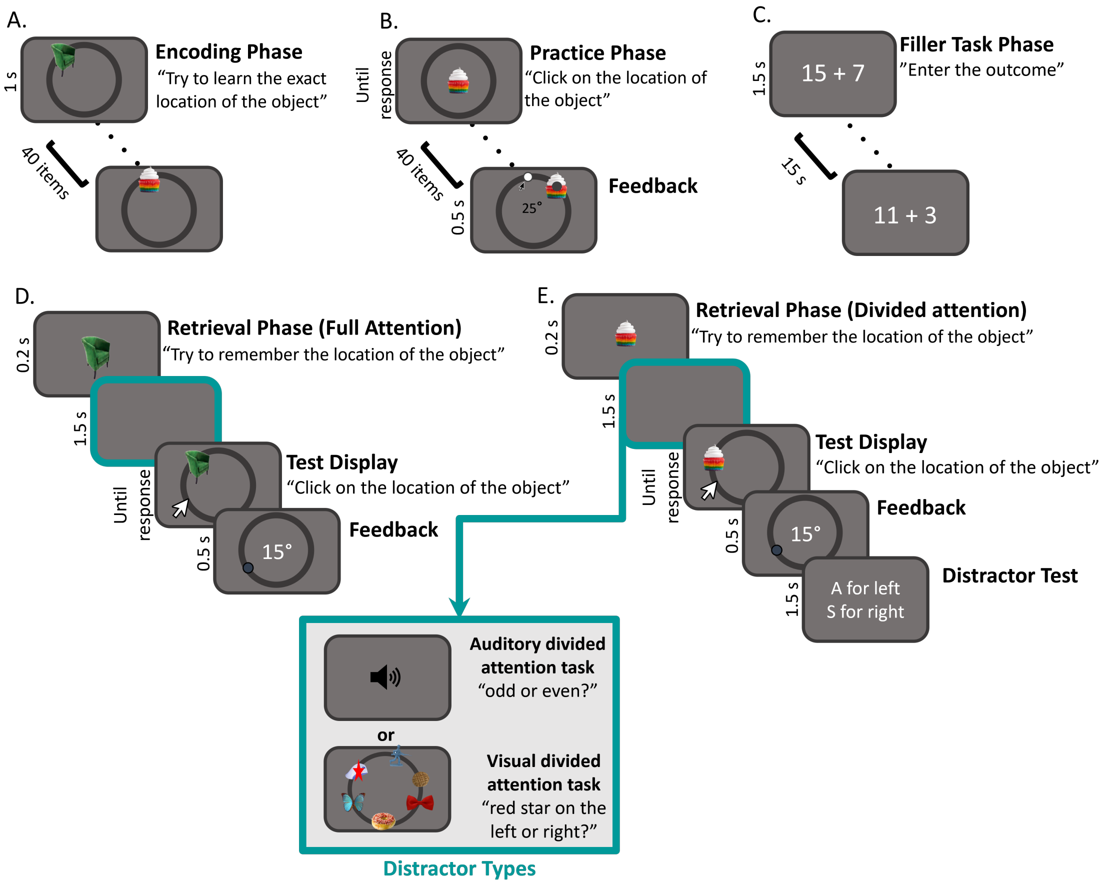
2.1.1.3 Design

The experiment has three within-subject conditions (full attention, auditory divided attention, visual divided attention). Conditions were randomized across full attention and divided attention blocks. There were 6 blocks of the full attention condition and 6 blocks of divided attention conditions, each consisting of 40 trials, summing up to 480 trials in total.

2.1.1.4 Procedure

Before the experiment, participants filled out computer-based consent and demographic forms. Then, they were given detailed instructions about the study. The experiment consisted of 4 phases: encoding phase, practice phase, filler task phase, and retrieval phase. In the encoding phase, participants first saw forty objects sequentially, placed on a circle on the screen for one second, and were asked to keep in mind the location of the objects on the circle (Figure 2.1a). In the practice phase, each object the participants saw in the learning phase appeared at the center of the screen sequentially, and the participants were asked to remember the learned location of the objects (Figure 2.1b). Then, participants clicked on the point they remembered and received feedback on the degree of difference between the original object location and the position they had remembered. The practice phase was repeated until the degree error was less than 20 degrees for each object. In the filler task phase, participants were asked to do simple mathematical operations for 15 s (Figure 2.1c). The purpose of the filler task was to make sure that the object-location pairs do not remain in working memory but pass into the long-term memory. In the retrieval task, participants engaged in retrieval in one of three different distractor conditions. In the full attention condition, participants were shown a blank screen for the duration of the distractors under other conditions, and then they were asked click on the location of the object on the circle. In the auditory divided attention condition, participants saw the object on the screen and heard one number from one to fifty. Here, their goal was to try to remember the location of the object and, at the same time, decide whether the number they heard was odd or even. After indicating that by pressing the keys "A" and "S" on the keyboard, the response screen appears with the circle and participants were asked to click on the location of the object as in the full attention condition. Similarly, the visual divided attention condition started with the display of an object on the screen. Then, 12 distracting objects, one with a red star on top of it, appeared on the screen as the participants tried to remember the object's location. Here, they were required to indicate whether the object with the red star was on the right or left side of the screen by pressing the keys "A" and "S" on the keyboard. Immediately after this screen, the response screen appeared with the circle, and the participants were asked to click on the location of the object as they remembered (Figure 2.1d).

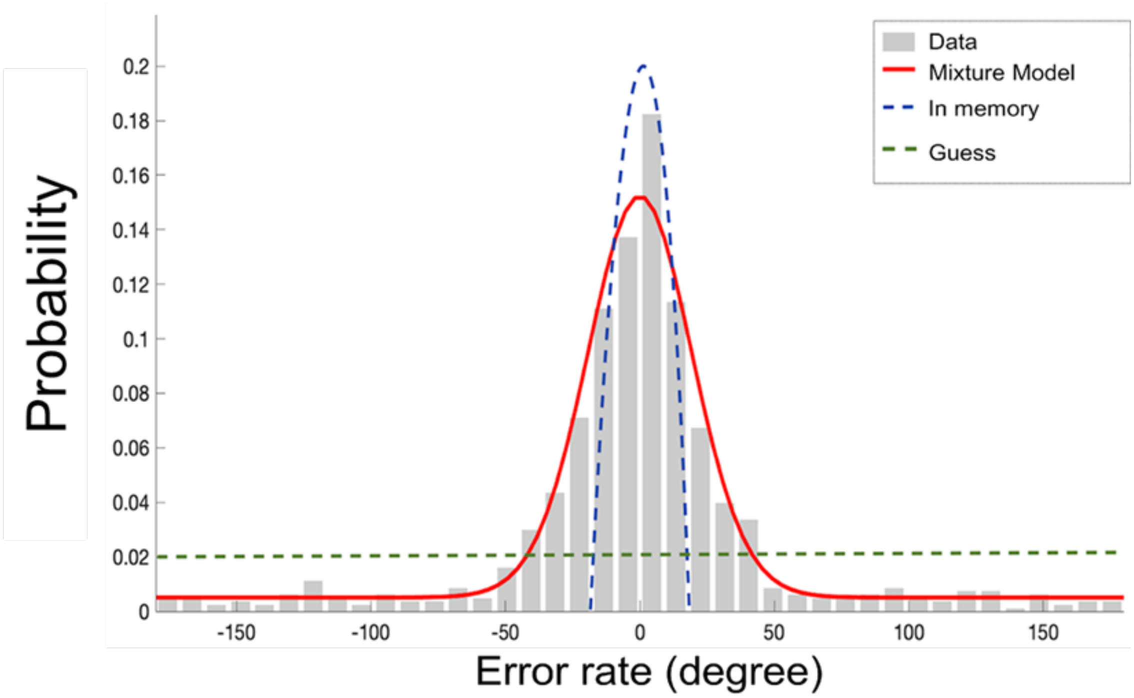
Figure 2.1 Illustration of the trial design for the experiment.



2.1.1.5 Data analysis

Studies using the continuous report paradigm in the literature have shown that mixture modeling is suitable for analyzing continuous data (e.g., Brady et al. (2013); Zhang and Luck (2008), but see., Schurgin, Wixted, and Brady (2020)). Accordingly, the error distribution of the participants consists of the combination of two distributions. One is a circular normal distribution (i.e., von Mises distribution) around the target memory value for trials where the memory was accessible. The standard deviation of the distribution around the target memory value provides the precision parameter. The other distribution is a uniform distribution of errors when the target memory is not accessible; therefore, participants guessed. The vertical offset of the uniform distribution gives the guess rate (g), and we obtain accessibility by subtracting the guess rate from one (i.e.,1-g). We estimated each parameter separately for each participant and condition using the maximum likelihood estimation method provided by MemToolbox (Suchow et al. (2013)). MATLAB (Mat (2020)) and Jamovi (Project (2020)) are used for the significance testing. Sphericity violations were corrected using Greenhouse–Geisser epsilon (Wood and Jennings (1976)).

Figure 2.2 Mixture Modeling

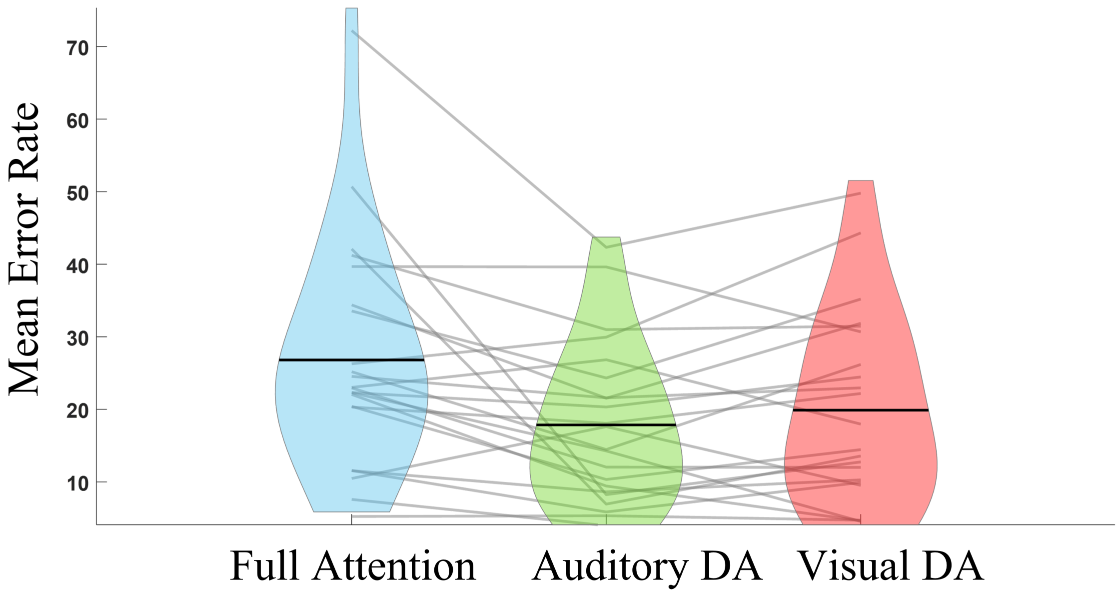


2.1.2 Results

2.1.2.1 Mean error rate

To test whether divided attention has an impact on LTM retrieval, first, we calculated the absolute value of the degree difference between the memory location and response for each condition and participant separately. Then, we used a repeated measures ANOVA to compare the effect of divided attention on the mean error rate of participants for each condition. There was a statistically significant difference in the mean error rate between at least two groups ($F(21, 2) = 7.559$, $p = 0.004$, $\eta^2 = 0.265$). The mean error rate was significantly higher in the full attention ($M = 26.80$, $SD = 15.57$) condition compared to the visual divided attention condition ($M = 20.48$, $SD = 12.96$), $t(21) = 2.719$, $p_{bonf} = .028$, $d = 0.476$ and auditory divided attention condition. ($M = 18.04$, $SD = 10.96$), $t(21) = 3.767$, $p_{bonf} = .002$, $d = 0.659$ (Figure 2.3). These results show that dividing attention with a visual or auditory secondary task does not impair LTM retrieval of location information.

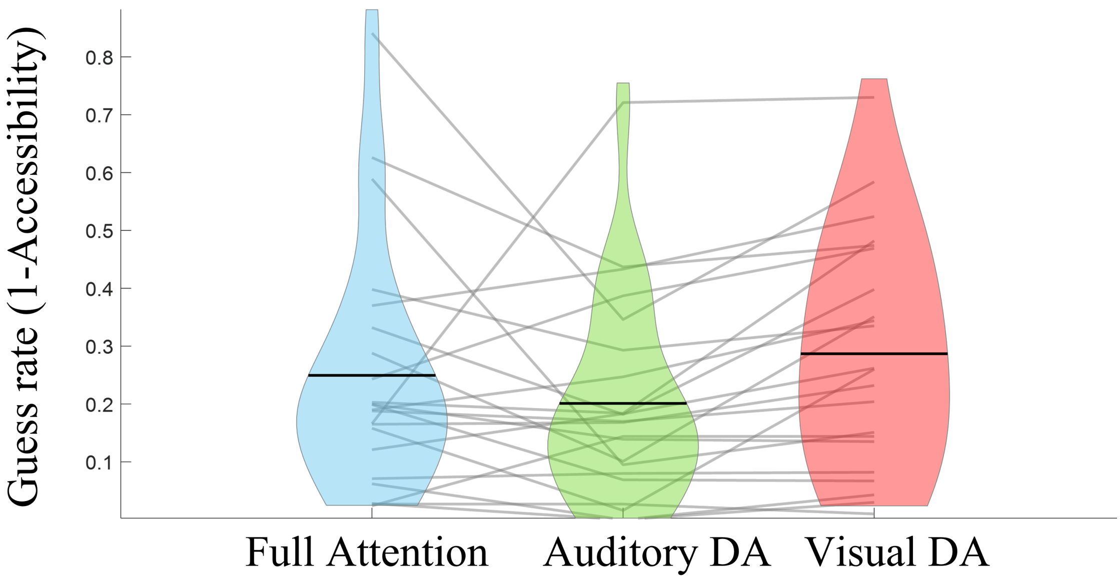
Figure 2.3 Mean Error Rate for each condition and each participant separately.



2.1.2.2 Accessibility

Guess rate (i.e., 1- Accessibility) for each participant was obtained using mixture modeling to measure accessibility. A repeated measures ANOVA was conducted to test whether divided attention affects the accessibility of the representations. There was no significant difference between any of the conditions in their guess rate ($F(21,2) = 2.611$, $p = 0.108$, $\eta^2 = 0.111$) (Figure 2.4). These results imply that divided attention impairs the accessibility of representations.

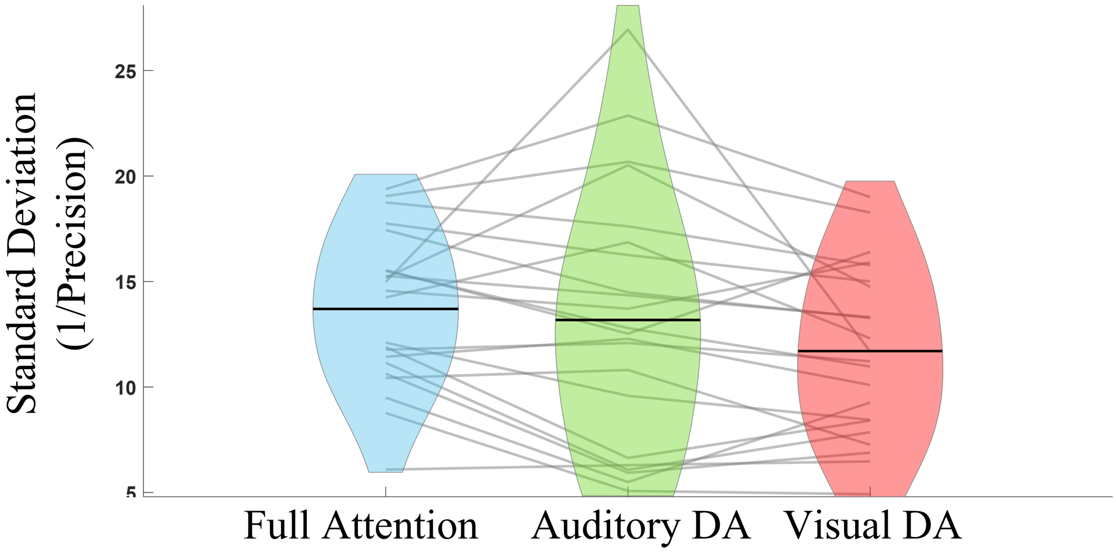
Figure 2.4 Accessibility for each condition and each participant separately.



2.1.2.3 Precision

Each participant's precision ($1/SD$) was obtained using mixture modeling. A repeated measures ANOVA revealed a statistically significant difference in precision between at least two groups ($F(21,2) = 4.082$, $p = 0.043$, $\eta^2 = 0.163$). The precision was significantly higher in the visual divided attention ($M = 11.702$, $SD = 4.025$) condition compared to the full attention condition ($M = 13.699$, $SD = 3.599$), $t(21) = 2.755$, $p_{bonf} = .026$, $d = 0.435$ (Figure 2.5), suggesting an improvement in the precision in LTM representations when there is a visual divided attention task.

Figure 2.5 Precision for each condition and each participant separately.



2.1.3 Discussion

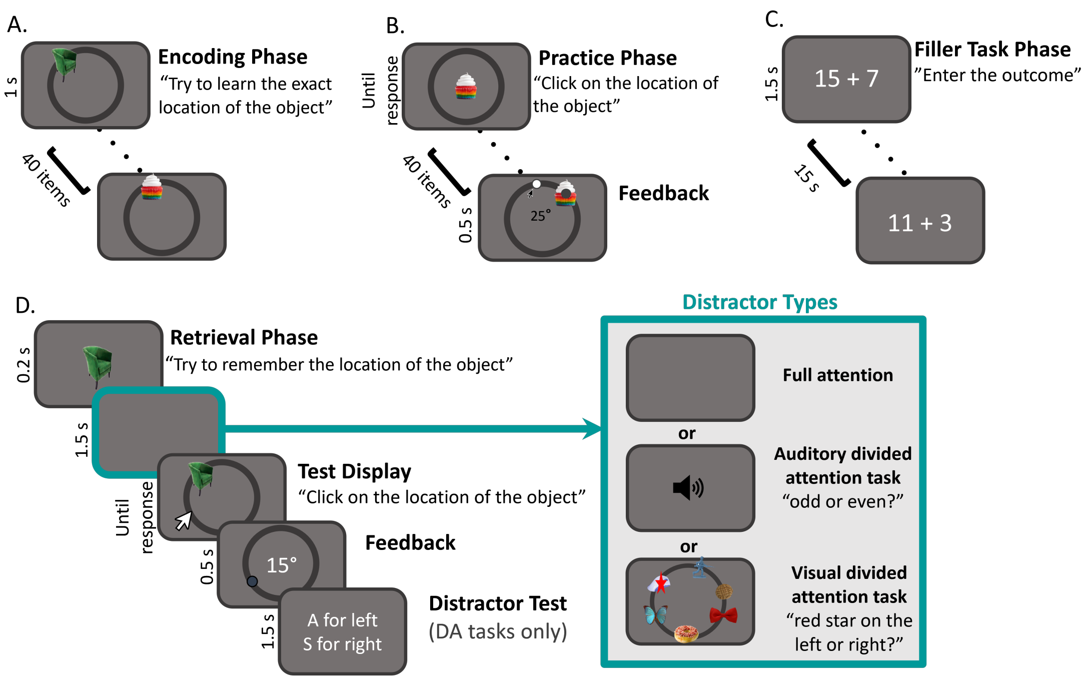
In Experiment 1, we wanted to test the effects of divided attention on accessibility and precision of representations in long-term memory. To test this, we first need to confirm that there is a negative effect of divided attention on long-term memory retrieval. However, our mean error rate suggested that contrary to our expectations, participants performed better in both auditory and visual divided attention conditions compared to the full attention condition. Since there were no studies reporting better performance with divided attention and there are some studies finding detrimental effects of divided attention on LTM retrieval, we reasoned that not being able to observe a negative effect of divided attention can be explained by our experimental design. First, the experiment has a blocked design where participants engaged in the same condition (full attention vs. divided attention) for 40 trials. Participants might have become bored and less engaged in the task in the full attention condition compared to the divided attention conditions, resulting in worse performance. Second, throughout the experiment, participants retrieved the same 40 objects repeatedly, which may have caused enhanced retrieval performance due to the retrieval practice effect. Therefore, one reason for not observing the effects of divided attention on LTM retrieval is that retrieval becomes automatic after repetitions.

While comparing the precision and accessibility of representation under full attention and divided attention conditions, we found no significant difference between any of the conditions in the accessibility of representations. Again unexpectedly, we have found that the visual divided attention condition has significantly higher precision than the full attention condition. We reasoned that maybe since we have used a blocked design, participants might have an expectation of distractor, resulting in holding more precise representations in mind for the visual divided attention condition. To overcome possible limitations of the experimental design and to better understand the relationship between divided attention and long-term memory, we designed Experiment 2 by changing the design to an intermixed trial design and limiting the number of repetitions for each object.

2.2 Experiment 1B

In Experiment 1A, we could not observe the effects of divided attention on LTM retrieval, as shown in the literature. Possible reasons for not observing the negative effect of divided attention on LTM retrieval can be that participants put less effort due to boredom in full attention blocks, and retrieval became automatic after the same information was recalled repeatedly throughout the experiment. Moreover, unexpectedly, the precision of representations was highest in the visual divided attention condition. To eliminate the effects of blocked design on the results of Experiment 1A, we designed Experiment 1B. Experiment 1B was identical to Experiment 1A except that conditions were intermixed across 60 mini blocks of 6 trials (2 trials of each condition), and each object was repeated only two times throughout the experiment.

Figure 2.6 Illustration of the trial design for the Experiment 1B.

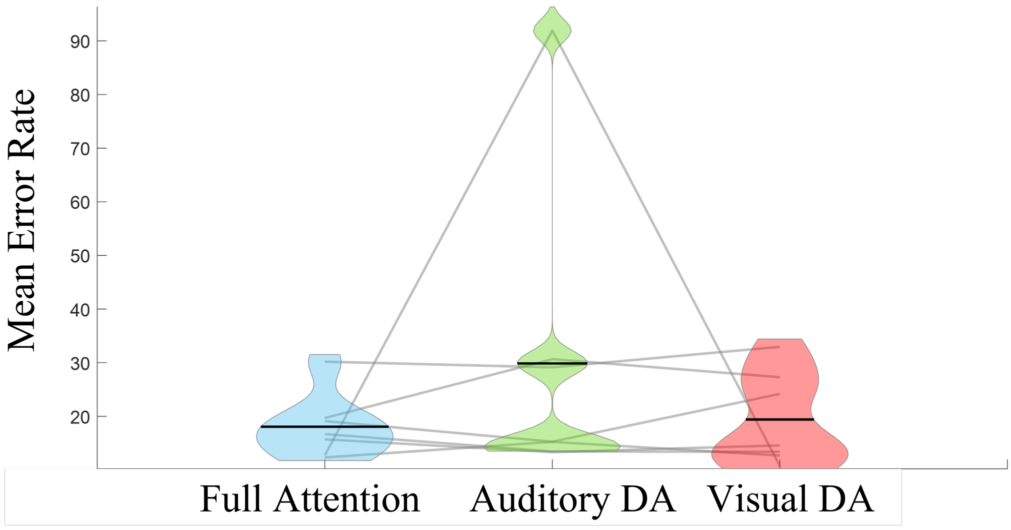


2.2.1 Results

2.2.1.1 Mean error rate

A repeated measures ANOVA was used to compare the effect of divided attention on the mean error rate of participants for each condition. There was no significant difference between any of the conditions, ($F(6,2) = 0.913$, $p = 0.378$, $\eta^2 = 0.132$). (Figure 2.7). These results show that dividing attention with a visual secondary task is not detrimental to LTM retrieval of location information.

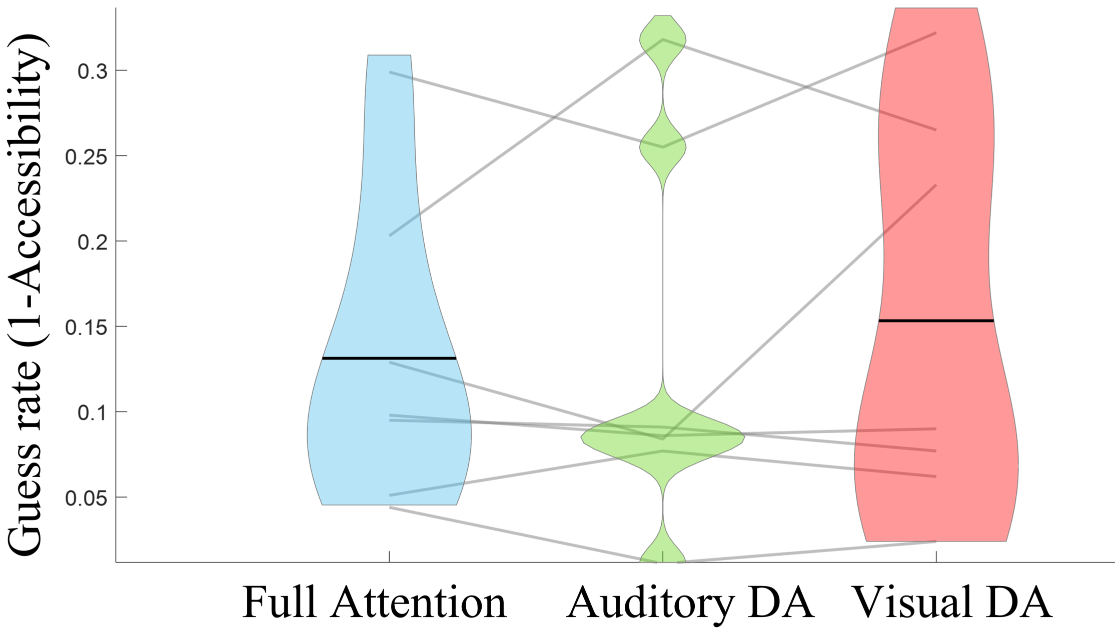
Figure 2.7 Mean Error Rate for each condition and each participant separately.



2.2.1.2 Accessibility

Guess rate (i.e., 1- Accessibility) for each participant was obtained using mixture modeling to measure accessibility. There was no significant difference between any of the conditions, ($F(6,2) = 0.680$, $p = 0.525$, $\eta^2 = 0.165$) (Figure 2.8). These results show that dividing attention with a visual secondary task is not detrimental to the accessibility of location information.

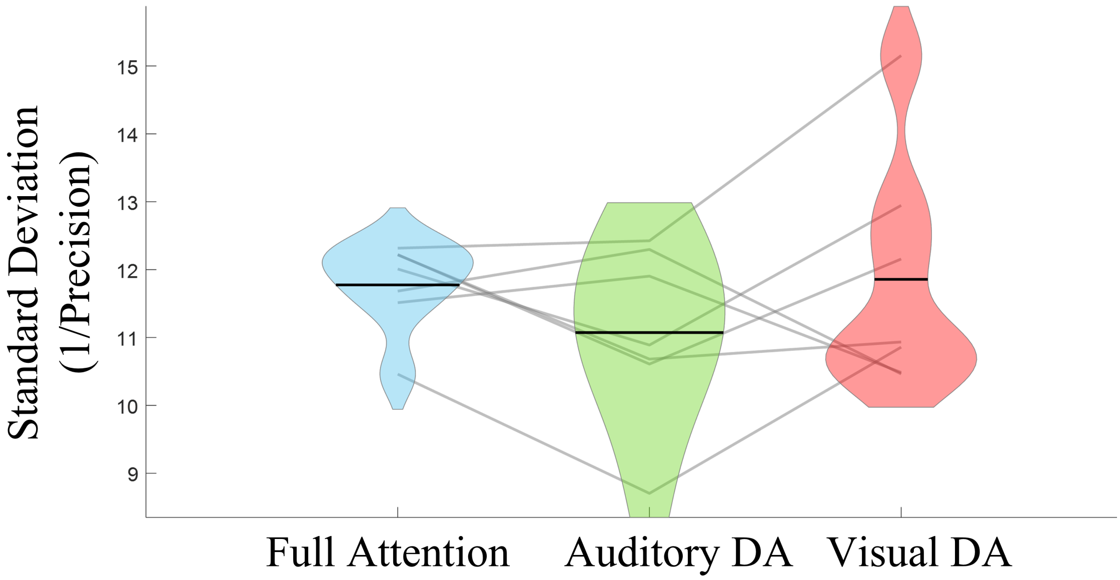
Figure 2.8 Accessibility for each condition and each participant separately.



2.2.1.3 Precision

Each participant's precision (1/ SD) was obtained using mixture modeling. A repeated measures ANOVA was conducted to test whether divided attention affects the precision of the representations. There was no significant difference between any of the conditions, ($F(6,2) = 1.184$, $p = 0.332$, $\eta^2 = 0.165$) (Figure 2.9). These results show that dividing attention with a visual secondary task is not detrimental to the precision of location information.

Figure 2.9 Precision for each condition and each participant separately.



2.2.2 Discussion

Experiment 1B aimed to eliminate the effects of blocked design and multiple repetitions observed in Experiment 1A. According to the results, there was no difference between the conditions in mean error rate, accessibility, and precision, suggesting that there is no effect of divided attention on LTM retrieval of location information. Although these results are inconsistent with our hypothesis, we could eliminate the confounding effects of blocked design and repetition that were observed as a higher error in the full attention condition and higher precision in the visual divided attention condition. One possible reason for not observing the detrimental effects of divided attention on LTM retrieval in this study is that retrieval of location information can be automatic, thus requiring less attention.

Previous studies have suggested that spatial representations have a special status in both working memory (Rajsic Wilson, 2014; Schneegans Bays, 2017; Foster et al., 2017) and long-term memory (Ekstrom Ranganath, 2017; Maguire et al., 2015; Kim et al., 2015). For example, it has been demonstrated that the location of an item is automatically encoded into WM even when the spatial information is task-irrelevant (Foster et al., 2017). Moreover, since the hippocampus has a special function in representing spatial information and rapid retrieval in LTM, we argue that location information can be less vulnerable to distraction than non-spatial information. In order to test this assumption, we designed Experiment 2, where we used orientation information rather than the location to test the effects of divided attention on LTM retrieval.

3. MAIN STUDY

3.1 Experiment 2

3.1.1 Method

3.1.1.1 Participants

Twenty undergraduate students from Sabanci University participated in the experiment for course credit. Participants who reported having a normal or corrected-to-normal vision and having no neuropsychological disorders were accepted for the experiment. One participant with less than 75% accuracy is excluded from the analysis. The study was approved by the Sabanci University Research Ethics Committee (SUREC).

3.1.1.2 Materials

The experiment was programmed and run through PsychoPy (Peirce et al. (2019)). Stimuli were presented on a computer screen at a viewing distance of approximately 70 cm. The stimulus set consists of 1598 real-world objects (Brady et al. (2008, 2013); Konkle et al. (2010); Google Images) and 180 categories. Participants learned 180 object-orientation associations from different categories.

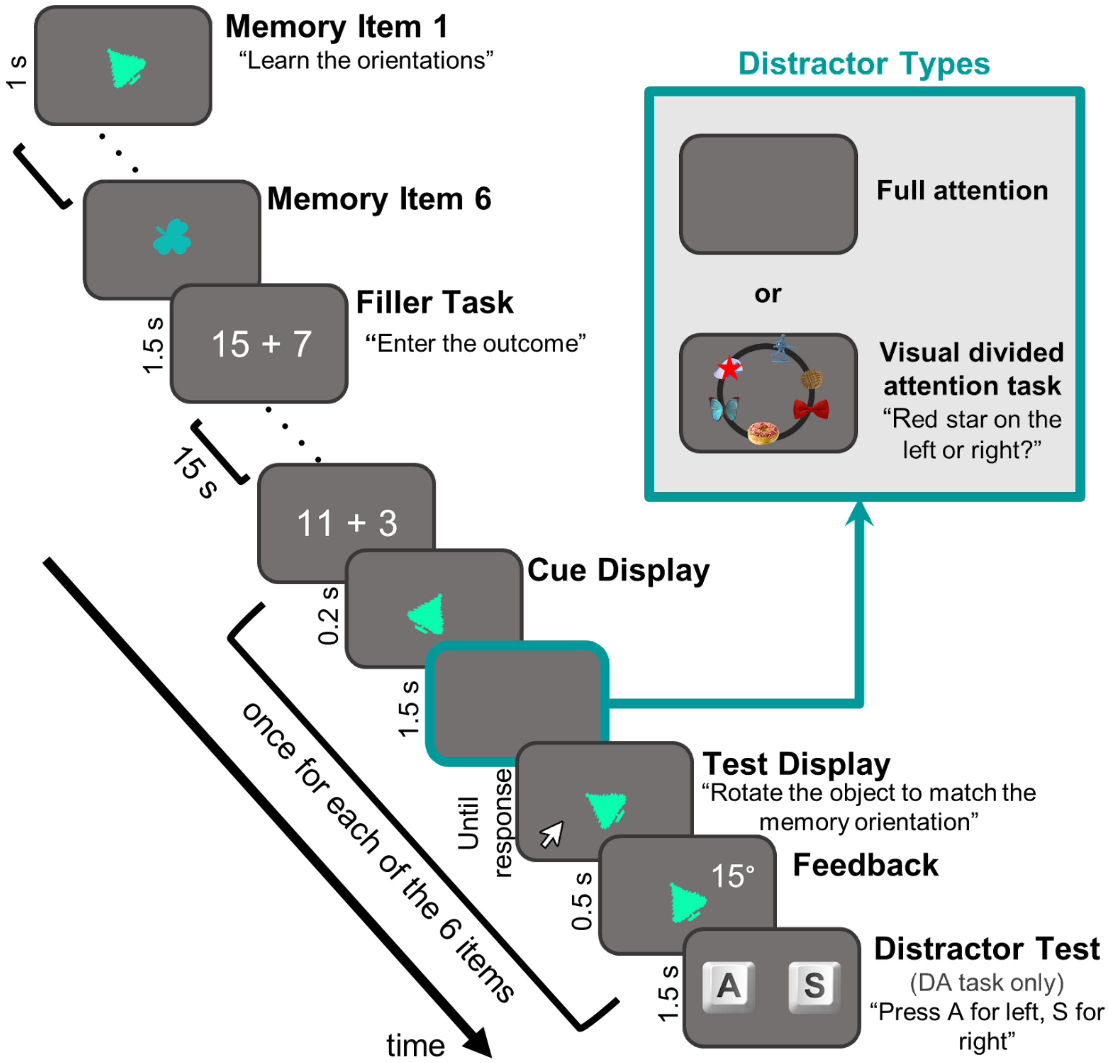
3.1.1.3 Design

The experiment has two within-subject conditions (full attention and divided attention) randomly intermixed across blocks. Each block consisted of an encoding phase, a filler task phase, a distraction phase (except for the full attention condition), and a test phase. There were 60 blocks of 6 trials summing up to 360 trials in total. After the first half of the study, participants restudied the 180 object-orientation associations they had learned before and were tested again with the same associations.

3.1.1.4 Procedure

Before the experiment, participants filled out computer-based consent and demographic forms. Then, they were given detailed instructions about the study and completed three practice blocks of 18 memory tests with the experimenter. Each block began with an encoding phase of the presentation of six objects with different angular orientations at the center of the screen, sequentially for 1 s each. Participants were instructed to learn these object-orientation associations. Next, they completed a 15 s filler task where they answered basic mathematical questions. After that, a retrieval phase of six trials started. First, they saw one of the objects at the center of the screen as a retrieval cue for 0.2 ms. In the full attention condition, participants directly started the test phase, where they needed to respond to the task by rotating the object with the mouse to match the memory orientation. Their response was saved with a mouse click. Lastly, they received the degree difference between the correct orientation and their response as feedback. In the divided attention condition, right after the cue was presented and before the test phase, participants saw 12 objects on a wheel for 1.5 s, and one of the objects had a red star on it. Participants' task was to remember whether the red star was on the left or right side of the wheel. While holding that information in mind, they needed to respond to the retrieval task by rotating the object to match the memorized orientation as in the full attention condition. After receiving the degree difference feedback, they were required to respond to the divided attention task by pressing 'A' if the red star was on the left and 'S' if it was on the right in 1.5 s. Lastly, they received visual feedback ('correct', 'incorrect', or after 1.5 s 'miss'). Upon completing one block of six trials, participants were informed about their accuracy and were able to take a self-paced break.

Figure 3.1 Illustration of the trial design for the Experiment 2.

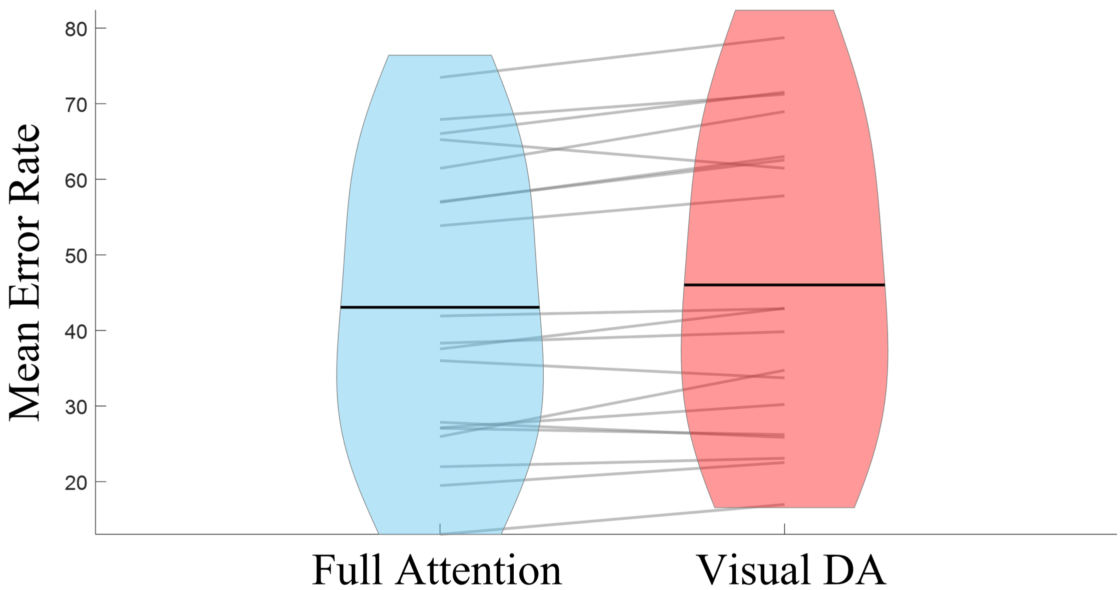


3.1.2 Results

3.1.2.1 Mean error rate

To test whether divided attention has an impact on LTM retrieval, first, we calculated the absolute value of the degree difference between the memory orientation and response for each condition and participant separately. Then, we used a paired sample t-test to compare the mean error rate of participants for each condition. The mean error rate was significantly higher in the divided attention ($M = 46.018$, $SD = 19.90$) condition compared to the full attention condition ($M = 43.065$, $SD = 18.92$), $t(18) = -3.75$, $p = .001$, $d = -0.86$ (Figure 3.2). These results show that dividing attention with a visual secondary task impairs LTM retrieval of orientation information.

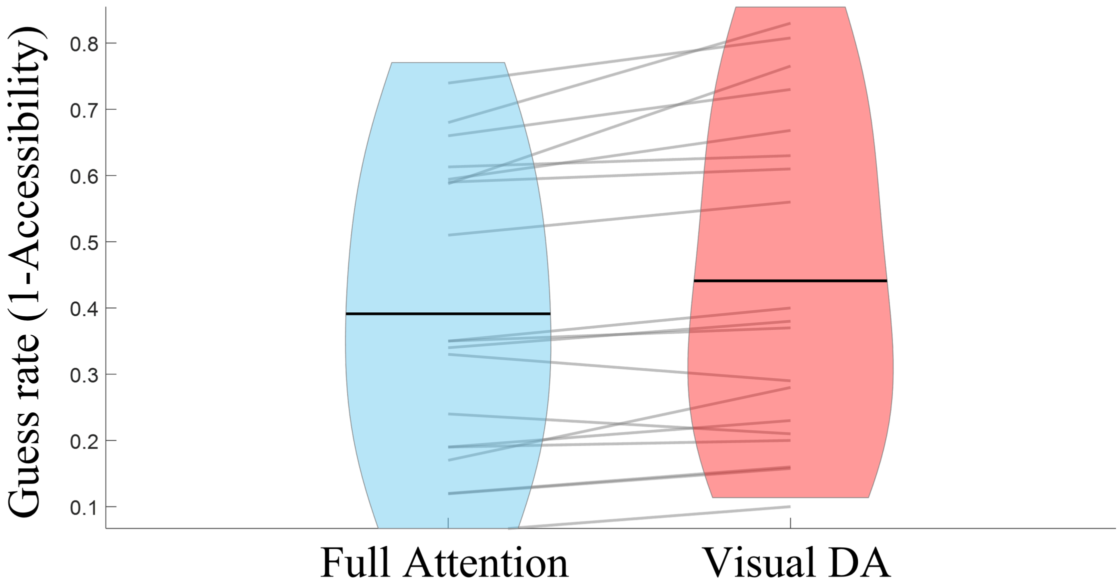
Figure 3.2 Mean Error Rate for each condition and each participant separately..



3.1.2.2 Accessibility

Guess rate (i.e., 1- accessibility) for each participant was obtained using mixture modeling to measure accessibility. A paired sample t-test was conducted to test whether divided attention affects the accessibility of the representations. Guess rate was significantly higher in the divided attention ($M = 0.441$, $SD = 0.247$) condition compared to the full attention condition ($M = 0.391$, $SD = 0.221$), $t(18) = 4.084$, $p < .001$, $d = -0.937$ (Figure 3.3). These results imply that divided attention impairs the accessibility of representations.

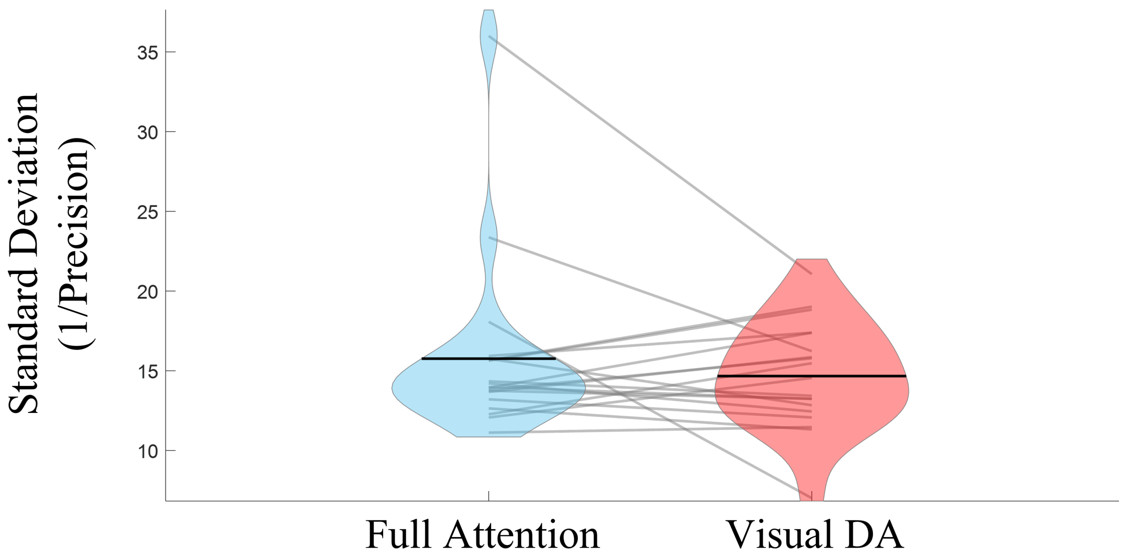
Figure 3.3 Accessibility for each condition and each participant separately.



3.1.2.3 Precision

Each participant's precision (1/ SD) was obtained using mixture modeling. A paired sample t-test was conducted to test whether divided attention affects the precision of the representations. There was no significant difference in precision between the divided attention and full attention conditions, $t(18) = -0.952$, $p = .354$, $d = -.218$ (Figure 3.4), suggesting the precision of representations is not affected by divided attention.

Figure 3.4 Precision for each condition and each participant separately.



3.1.2.4 Correlations

To assess the relationship between the accessibility and precision parameter, we first aggregated all guess rate (1-Accessibility) and standard deviation (1/Precision) scores for each participant and each condition. Second, we conducted a correlation analysis between this aggregated accessibility and precision parameters resulting in a significant correlation between the two parameters, $r(19) = .362$, $p = .025$ (Table 1).

Table 3.1 Pearson's Correlations among precision and accessibility variables

Variable		Accessibility	Precision
1.Accessibility	Pearson's r	—	
2. Precision	Pearson's r	0.362*	—

*Correlation is significant at the 0.05 level

To test the relationship between the divided attention task performance and the retrieval performance, we looked at the correlation between the divided attention task accuracy and the mean error rate in the visual divided attention condition. We found a strong negative correlation between divided attention task accuracy and the mean error rate in the visual divided attention condition, suggesting that the divided attention task impairs the performance in the retrieval task $r(19) = .611$, $p = .005$ (Table 2).

Table 3.2 Pearson's Correlations among DA Task Accuracy and Mean Error Rate

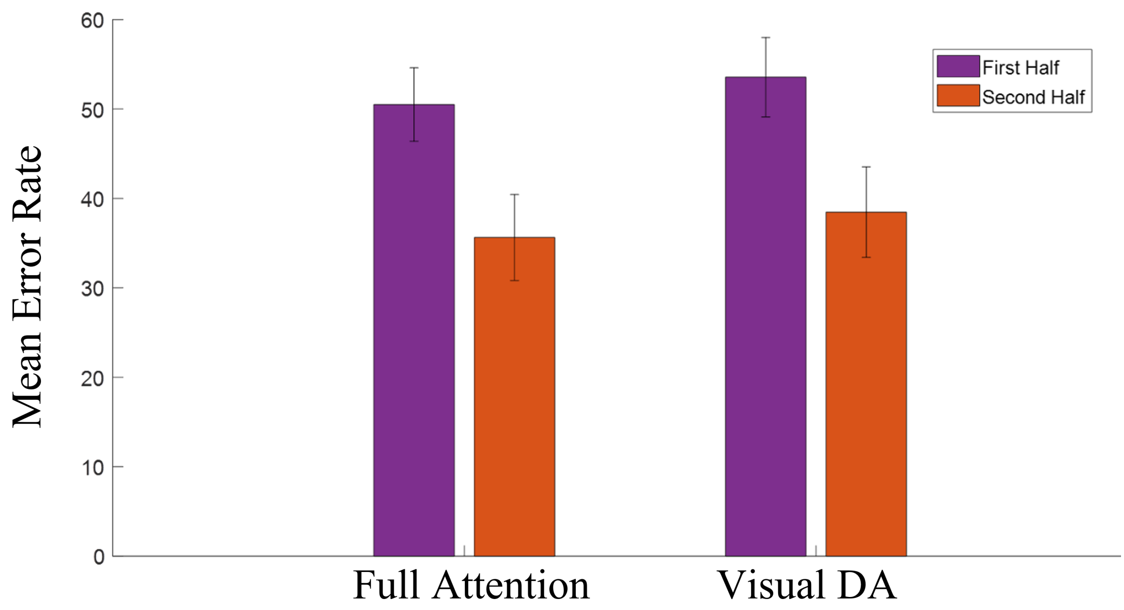
Variable		DA Task Accuracy	Mean Error Rate
1. DA Task Accuracy	Pearson's r	—	
2. Mean Error Rate	Pearson's r	-0.611*	—

*Correlation is significant at the 0.05 level

3.1.2.5 Comparison of the first and second half of the experiment

Since every object-orientation pair was repeated for a second time in the second half of the experiment, we wanted to test whether repetition affects the observed results. A paired samples t-test was conducted to see if participants' performance had changed throughout the experiment. First, there was a significant difference between first and second half of the experiment in both full attention , $t(18) = 6.95$, $p =< .001$, $d = 1.59$ and divided attention condition, $t(18) = 5.60$, $p =< .001$, $d = 1.29$. Second, there was a significant difference between full attention and divided attention conditions in both first ($t(18) = -2.20$, $p = .041$, $d = -.504$) and second ($t(18) = -2.34$, $p =< .001$, $d = -.537$) half of the experiment. Finally, we tested whether the effect of divided attention has changed between the first and second half of the experiment by calculating the cost of divided attention for the first and second half of the experiment. A paired samples t-test comparing the cost of divided attention in the first and second half of the experiment did not reveal any significant difference, ($t(18) = -0.108$, $p = .915$, $d = -.002$). These results suggest that, although participants have improved their performance in both conditions, the effect of divided attention on LTM retrieval did not change throughout the experiment.

Figure 3.5 Comparison of the first and second half of the experiment.



3.1.3 Discussion

Experiment 2 tested whether the effects of divided attention can be observed in the LTM retrieval task using orientation information. We used a continuous report paradigm where participants learned object-orientation associations and continuously reproduced the orientations. First, we hypothesized that divided attention would impair the LTM retrieval of orientation information. Second, we expected to find a detrimental effect of divided attention on precision but not the accessibility of LTM representations. Our mean error rate results indicated that divided attention impairs the LTM retrieval. Furthermore, investigation of the correlation between the divided attention task and the retrieval performance confirmed that the increased error rate in the retrieval task is related to the divided attention task. However, contrary to our hypothesis, the impairment in LTM retrieval stemmed from the loss of accessibility of representations rather than decreased precision. This is consistent with the previous studies suggesting that precision and accessibility are dissociable in LTM (Berens, Richards, and Horner (2020); Fan and Turk-Browne (2013)).

We have also found that accessibility and precision correlated across participants. Previously, Harlow and Yonelinas (2016); Harlow and Donaldson (2013); Richter et al. (2016) also found correlations between accessibility and precision, and they have concluded that each parameter accounts for unique variance in the memory performance. Here we assume that, this correlation can be stemming from the general arousal or sustained attention levels of the participants that might be affected both parameters at the same time.

The comparison of the two halves of the study in terms of the effect of divided attention on LTM retrieval revealed that although participants' performance improved throughout the experiment, the negative influence of divided attention remained consistent across trials. LTM retrieval itself is suggested to be one factor that can improve memory (Carpenter, Pashler, and Cepeda (2009); Carrier and Pashler (1992); Roediger and Karpicke (2006); Rohrer, Taylor, and Sholar (2010)). In this study, we also replicated the findings in the literature by showing that participants' performance improved in LTM retrieval in the second half of the experiment. On the other hand, based on the recent findings about the role of statistical regularities in distractor suppression (Gao and Theeuwes (2020); Wang and Theeuwes (2018*a*,*b*)), we might expect participants to get better at avoiding distractors over time by developing coping strategies or with repetition. However, we found that the negative influence of divided attention remained consistent across trials. This can be explained by the fact that although the divided attention task continued throughout the experiment, the identity and location of the distractors changed randomly every time they were presented. Together, this study showed that dividing attention during LTM retrieval decreases LTM accessibility while the precision of representations remains intact.

4. GENERAL DISCUSSION

Studies have shown that attention is essential in encoding information into LTM, but the effect of attention on LTM retrieval is unclear. This study investigated the effects of divided attention on LTM retrieval. Specifically, we were interested in how the divided attention affected the precision and accessibility of representations. Based on the finding in the literature suggesting that recall tasks are more prone to disruption by divided attention, we hypothesized that precision, but not the accessibility of representations, would be affected by divided attention. Contrary to our hypothesis, our results indicated that divided attention impairs the accessibility of representations retrieved from LTM, while no effect was present on the precision of the representations.

Previously, the component process model was introduced by Moscovitch and colleagues (2000; 1992; 1990) to disentangle the divergent effects of divided attention on LTM retrieval. This model suggests that memory retrieval consists of two components: the reactivation of the stored memory trace and the initiation and maintenance of the retrieval mode (Moscovitch (1992); Moscovitch and Umiltà (1990). Notably, Moscovitch (1992) proposed that the reactivation of memory trace occurs automatically in the hippocampus without requiring attention. This can explain why recognition tasks are resilient to divided attention unless these two tasks employ the same representational system. On the other hand, he proposed that recall tasks additionally require the initiation and maintenance of retrieval mode until the reactivation of memory trace.

Contrary to the reactivation of the memory trace component, the initiation and maintenance of the retrieval mode requires attention and is regulated by the prefrontal cortex (PFC). However, this model is only indirectly supported by the finding that free recall tasks are affected by damage to or dysfunction of the PFC (Moscovitch (1994)). Along with the studies showing that being in a retrieval mode or having a retrieval orientation increases memory accessibility (Alban and Annibal (2022); Hornberger, Rugg, and Henson (2006); Rugg and Wilding (2000)), our results partially converge with the component process model since we also found that divided attention during recall impairs accessibility of representations. This may imply that the divided attention task during retrieval disrupts the maintenance of retrieval mode by demanding attentional resources, which in turn results in a decrease in accessibility. However, this assumption should be tested empirically to identify at what stages of retrieval (e.g., encoding the retrieval cue, initiation, and maintenance of retrieval mode, holding retrieved information in WM) the effects of divided attention are observed.

The detrimental effects of divided attention on LTM retrieval are present when the retrieval task and distractor task tap onto the same representational system (Fernandes and Moscovitch (2000, 2002, 2003)). In the current study, we have also used two tasks that rely on representations in the same modality (i.e., visual-visual), and we observed an increase in the mean error rate of the retrieval task. We have found that this increased error stems from the loss of accessibility rather than precision. The reason behind this asymmetry can be that when the retrieval task and distractor task use overlapping representational systems, they compete to allocate the same buffer, resulting in decrements in accessibility. This interpretation can be supported by the findings in working memory literature suggesting that when two tasks or representations are in the same domain, domain-specific resources become vulnerable to interference (cf. Cocchini et al. (2002); Kane et al. (2004); Kovacs, Molenaar, and Conway (2019); Shah and Miyake (1996)). Therefore, while these representations are trying to be stored in the same buffer, the retrieved memory item may be totally inaccessible as opposed to becoming less precise. On the other hand, the number of studies that have found the effect of divided attention when the retrieved memories and distractors are in different modalities is limited (Wais and Gazzaley (2011)). This can be due to divided attention being detrimental to the precision of retrieved memories when it uses a different representational system than retrieved contents (e.g., verbal vs. visual). Since accessibility of representations would be unimpaired, participants could be correctly retrieving the memories with less precision. However, to test this assumption, future studies should investigate the precision of retrieved memories under divided attention when the distractors and retrieved memories tap onto different representational systems.

This study converges with previous studies that have also used the dissociation between accessibility and precision of representations to understand how memory performance is enhanced as well as how forgetting occurs. For example, the retrieval practice effect is a well-established phenomenon that shows that LTM retrieval improves performance in a subsequent memory test (e.g., Carpenter, Pashler, and Cepeda (2009); Carrier and Pashler (1992); Roediger and Karpicke (2006); Rohrer, Taylor, and Sholar (2010)). To better understand how retrieval practice improves memory performance, Sutterer and Awh (2016) dissociated the accessibility and precision of representations retrieved from LTM using a continuous report paradigm. They have found that while retrieval practice enhances the accessibility of representations, it does not improve precision. In the context of forgetting, Berens, Richards, and Horner (2020) investigated how the precision and accessibility of representations in LTM change over time. They have found that as the time between encoding and retrieval increased, accessibility of representations decreased while precision remained the same. Together with the results from the current study, one can argue that accessibility and not the precision of representations is the underlying factor in observing the effects of divided attention, delay, and retrieval practice on LTM performance.

Although investigating the accessibility and precision of representations using mixture modeling has become increasingly popular among working memory, and long-term memory researchers, Schurgin, Wixted, and Brady (2020) recently brought a new perspective to understanding mixture models of memory. They have argued that the dissociations found using mixture models were flawed due to not taking into account the psychophysical similarity of representations. To explain variations in visual memory, they have proposed the Target Confusability Competition (TCC) model, which predicts memory performance in various memory tasks and stimuli types via a single parameter: memory strength (d'). Though seeming plausible, the TCC model currently does not account for the behavioral and neural dissociations in accessibility and precision; thus, it requires further investigations.

The limitation of this study can be regarding the nature and timing of the divided attention task. In this task, we used a paradigm similar to visual search tasks used in the working memory literature, which required finding a target object among distractors (e.g., Vickery, King, and Jiang (2005); Yang and Zelinsky (2009)). First, it could have been better to use a visual distractor task using the same feature of an object (orientation rather than location) which is tested in the retrieval. This would have better supported the representational similarity account in explaining the effects of divided attention on LTM retrieval. Second, previous studies testing the effects of divided attention on LTM retrieval have used more continuous divided attention tasks where the divided attention task is done concurrently with the retrieval for the whole duration of the retrieval phase. However, in our design, the divided attention task was limited to the period right after the cue presentation. This can imply that the effect we found in the accessibility of representations can be limited to that particular time range of the retrieval. Overall, it is important to test the use of different features of objects, and the timing of the distractors should be tested in future studies.

To conclude, we have shown that dividing attention during LTM retrieval reduces the accessibility of representations while their precisions remain intact. Therefore, the findings of the present study inform the literature on the relationship between LTM and attention by dissociating precision and accessibility of representations.

BIBLIOGRAPHY

Alban, Michael W, and Sarah C Annibal. 2022. "Varying retrieval conditions to study survival processing." *Memory* pp. 1–16.

Anderson, CMB, and FIM Craik. 1974. "The effect of a concurrent task on recall from primary memory." *Journal of Verbal Learning and Verbal Behavior* 13(1): 107–113.

Baddeley, Alan, Vivien Lewis, Margery Eldridge, and Neil Thomson. 1984. "Attention and retrieval from long-term memory." *Journal of Experimental Psychology: General* 113(4): 518–540.

Bays, P. M., R. F. G. Catalao, and M. Husain. 2009. "The precision of visual working memory is set by allocation of a shared resource." *Journal of Vision* 9(September): 7–7.

Berens, Sam C., Blake A. Richards, and Aidan J. Horner. 2020. "Dissociating memory accessibility and precision in forgetting." *Nature Human Behaviour* 4(August): 866–877.

Biderman, Natalie, Roy Luria, Andrei R Teodorescu, Ron Hajaj, and Yonatan Goshen-Gottstein. 2019. "Working memory has better fidelity than long-term memory: The fidelity constraint is not a general property of memory after all." *Psychological Science* 30(2): 223–237.

Brady, Timothy F, Talia Konkle, George A Alvarez, and Aude Oliva. 2008. "Visual long-term memory has a massive storage capacity for object details." *Proceedings of the National Academy of Sciences* 105(38): 14325–14329.

Brady, Timothy F., Talia Konkle, Jonathan Gill, Aude Oliva, and George A. Alvarez. 2013. "Visual Long-Term Memory Has the Same Limit on Fidelity as Visual Working Memory." *Psychological Science* 24(June): 981–990.

Carpenter, Shana K., Harold Pashler, and Nicholas J. Cepeda. 2009. "Using tests to enhance 8th grade students' retention of U.S. history facts." 23(6): 760–771.

Carrier, Mark, and Harold Pashler. 1992. "The influence of retrieval on retention." 20(6): 633–642.

Cocchini, Gianna, Robert H. Logie, Sergio Della Sala, Sarah E. MacPherson, and Alan D. Baddeley. 2002. "Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems." *Memory & Cognition* 30(October): 1086–1095.

Craik, Fergus I. M., Eldar Eftekhari, and Malcolm A. Binns. 2018. "Effects of divided attention at encoding and retrieval: Further data." *Memory & Cognition* 46(November): 1263–1277.

Craik, Fergus I. M., Richard Govoni, Moshe Naveh-Benjamin, and Nicole D. Anderson. 1996. "The effects of divided attention on encoding and retrieval processes in human memory." *Journal of Experimental Psychology: General* 125(2): 159–180.

Fan, Judith E., and Nicholas B. Turk-Browne. 2013. "Internal attention to features in visual short-term memory guides object learning." *Cognition* 129(November): 292–308.

Favila, Serra E., Hongmi Lee, and Brice A. Kuhl. 2020. "Transforming the Concept of Memory Reactivation." *Trends in Neurosciences* 43(December): 939–950.

Fernandes, Myra A., and Morris Moscovitch. 2000. "Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding." *Journal of Experimental Psychology: General* 129(2): 155–176.

Fernandes, Myra A., and Morris Moscovitch. 2002. "Factors modulating the effect of divided attention during retrieval of words." *Memory & Cognition* 30(July): 731–744.

Fernandes, Myra A., and Morris Moscovitch. 2003. "Interference effects from divided attention during retrieval in younger and older adults." *Psychology and Aging* 18(2): 219–230.

Fukuda, Keisuke, and Geoffrey F. Woodman. 2017. "Visual working memory buffers information retrieved from visual long-term memory." *Proceedings of the National Academy of Sciences* 114(May): 5306–5311.

Gao, Ya, and Jan Theeuwes. 2020. "Learning to suppress a distractor is not affected by working memory load." *Psychonomic Bulletin & Review* 27(1): 96–104.

Gisquet-Verrier, Pascale, and David C Riccio. 2012. "Memory reactivation effects independent of reconsolidation." *Learning & Memory* 19(9): 401–409.

Harlow, Iain M, and Andrew P Yonelinas. 2016. "Distinguishing between the success and precision of recollection." *Memory* 24(1): 114–127.

Harlow, Iain M, and David I Donaldson. 2013. "Source accuracy data reveal the thresholded nature of human episodic memory." *Psychonomic Bulletin & Review* 20(2): 318–325.

Hornberger, Michael, Michael D Rugg, and Richard NA Henson. 2006. "fMRI correlates of retrieval orientation." *Neuropsychologia* 44(8): 1425–1436.

Kane, Michael J., David Z. Hambrick, Stephen W. Tuholski, Oliver Wilhelm, Tabitha W. Payne, and Randall W. Engle. 2004. "The Generality of Working Memory Capacity: A Latent-Variable Approach to Verbal and Visuospatial Memory Span and Reasoning." *Journal of Experimental Psychology: General* 133(June): 189–217.

Klyszejko, Zuzanna, Masih Rahmati, and Clayton E Curtis. 2014. "Attentional priority determines working memory precision." *Vision research* 105: 70–76.

Konkle, Talia, Timothy F Brady, George A Alvarez, and Aude Oliva. 2010. "Conceptual distinctiveness supports detailed visual long-term memory for real-world objects." *Journal of experimental Psychology: general* 139(3): 558.

Kovacs, Kristof, Dylan Molenaar, and Andrew R.A. Conway. 2019. "The domain specificity of working memory is a matter of ability." *Journal of Memory and Language* 109(December): 104048.

Long, Nicole M, Brice A Kuhl, and Marvin M Chun. 2018. "Memory and attention." *Stevens' handbook of experimental psychology and cognitive neuroscience* 1: 285.

Mat. 2020. *MATLAB version 9.10.0.1613233 (R2020b).*

Moscovitch, Morris. 1992. "Memory and Working-with-Memory: A Component Process Model Based on Modules and Central Systems." *Journal of Cognitive Neuroscience* 4(July): 257–267.

Moscovitch, Morris. 1994. "Cognitive resources and dual-task interference effects at retrieval in normal people: The role of the frontal lobes and medial temporal cortex." *Neuropsychology* 8(4): 524–534.

Moscovitch, Morris, and Carlo Umiltà. 1990. "Modularity and neuropsychology: Modules and central processes in attention and memory." *Behavioral and Brain Sciences* 19(January).

Naveh-Benjamin, Moshe, Fergus I M Craik, James G Perretta, and Simon T Tonev. 2000. "The Effects of Divided Attention on Encoding and Retrieval Processes: The Resiliency of Retrieval Processes." p. 17.

Peirce, Jonathan, Jeremy R. Gray, Sol Simpson, Michael MacAskill, Richard Höchenberger, Hiroyuki Sogo, Erik Kastman, and Jonas Kristoffer Lindeløv. 2019. "PsychoPy2: Experiments in behavior made easy." *Behavior Research Methods* 51(February): 195–203.

Project, Jamovi. 2020. "jamovi (Version 1.2)[Computer Software].".

Rademaker, Rosanne L, Young Eun Park, Alexander T Sack, and Frank Tong. 2018. "Evidence of gradual loss of precision for simple features and complex objects in visual working memory." *Journal of Experimental Psychology: Human Perception and Performance* 44(6): 925.

Richter, Franziska R, Rose A Cooper, Paul M Bays, and Jon S Simons. 2016. "Distinct neural mechanisms underlie the success, precision, and vividness of episodic memory." *eLife* 5(October): e18260.

Roediger, Henry L., and Jeffrey D. Karpicke. 2006. "Test-Enhanced Learning: Taking Memory Tests Improves Long-Term Retention." 17(3): 249–255.

Rohrer, D., Kelli M. Taylor, and Brandon Sholar. 2010. "Tests enhance the transfer of learning.".

Rugg, Michael D, and Edward L Wilding. 2000. "Retrieval processing and episodic memory." *Trends in cognitive sciences* 4(3): 108–115.

Schurgin, Mark W, John T Wixted, and Timothy F Brady. 2020. "Psychophysical scaling reveals a unified theory of visual memory strength." *Nature human behaviour* 4(11): 1156–1172.

Shah, Priti, and Akira Miyake. 1996. "The separability of working memory resources for spatial thinking and language processing: An individual differences approach." *Journal of Experimental Psychology: General* 125(1): 4–27.

Suchow, J. W., T. F. Brady, D. Fougnie, and G. A. Alvarez. 2013. "Modeling visual working memory with the MemToolbox." *Journal of Vision* 13(August): 9–9.

Sutterer, David W., and Edward Awh. 2016. "Retrieval practice enhances the accessibility but not the quality of memory." *Psychonomic Bulletin & Review* 23(June): 831–841.

Troyer, Angela K, and Fergus IM Craik. 2000. "The effect of divided attention on memory for items and their context." *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale* 54(3): 161.

van Moorselaar, Dirk, Eren Gunseli, Jan Theeuwes, and Christian NL Olivers. 2015. "The time course of protecting a visual memory representation from perceptual interference." *Frontiers in human neuroscience* 8: 1053.

Vickery, Timothy J., Li-Wei King, and Yuhong Jiang. 2005. "Setting up the target template in visual search." 5(1): 8.

Wais, Peter E, and Adam Gazzaley. 2011. "The impact of auditory distraction on retrieval of visual memories." *Psychonomic Bulletin & Review* 18(6): 1090–1097.

Wang, Benchi, and Jan Theeuwes. 2018*a*. "How to inhibit a distractor location? Statistical learning versus active, top-down suppression." *Attention, Perception, & Psychophysics* 80(4): 860–870.

Wang, Benchi, and Jan Theeuwes. 2018*b*. "Statistical regularities modulate attentional capture." *Journal of Experimental Psychology: Human Perception and Performance* 44(1): 13.

Weeks, Jennifer C, and Lynn Hasher. 2017. "Divided attention reduces resistance to distraction at encoding but not retrieval." *Psychonomic bulletin & review* 24(4): 1268–1273.

Wood, Charles C, and J Richard Jennings. 1976. "Speed-accuracy tradeoff functions in choice reaction time: Experimental designs and computational procedures." *Perception & Psychophysics* 19(1): 92–102.

Yang, Hyejin, and Gregory J. Zelinsky. 2009. "Visual search is guided to categorically-defined targets." 49(16): 2095–2103.

Zhang, Weiwei, and Steven J. Luck. 2008. "Discrete fixed-resolution representations in visual working memory." *Nature* 453(May): 233–235.

APPENDIX A

Sabancı Üniversitesi

Sabancı University Research Ethics Council (SUREC)

Date: Ağustos 2021

To: Eren Günseli
From: Prof. Mehmet Yıldız, Chair of the Research Ethics Committee

Protocol Number: FASS-2021-70
Protocol Name: Hatırlamada dikkat çeldiricilerinin hatırlanabilirlik ve çözünürlük üzerindeki etkisi (The effects of distraction during memory retrieval on the probability of recall and precision of memoranda)

Subject: SUREC Approval
Official Approval Date: September 2nd, 2021

Sabancı University Research Ethics Council has approved the above named and numbered protocol through expedited review. You are responsible for promptly reporting to the SUREC:

- any severe adverse effects
- any unanticipated problems involving risks to subjects or others;
- any proposed changes in the research activity

Enclosed you can find the below noted approved documents.

☒ Protocol Application

☒ Informed Consent Form

If you have any questions please feel free to contact me via phone at 216-483 9010 or via e-mail at meyildiz@sabanciuniv.edu

Best Regards,

Prof. Mehmet Yıldız
Chair of the Ethics Committee

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APPENDIX B

Stimuli Examples