**The Relation between Sustained Attention and Incidental and Intentional Object-Location Memory**

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Abstract

The role of attention allocation in object-location memory has been widely studied through incidental and intentional encoding conditions. However, the relation between sustained attention and memory encoding processes has scarcely been studied. The present study aimed at investigating performance differences across incidental and intentional encoding conditions using a divided attention paradigm. Furthermore, the present study aimed to examine the relation between sustained attention and incidental and intentional object-location memory performance. Forty-nine women participated in the study and completed the psychomotor vigilance test, as well as object-location memory tests, under both incidental and intentional encoding divided attention conditions. Performance was higher in the intentional encoding condition than in the incidental encoding condition. Furthermore, sustained attention correlated with incidental, but not with intentional, memory performance. These findings are discussed in light of the automaticity hypothesis, specifically as it regards the role of attention allocation in encoding object-location memory. Furthermore, the role of sustained attention in incidental memory performance is discussed in light of previous animal and human studies that have examined the brain regions involved in these cognitive processes.

Keywords: object-location memory, sustained attention, incidental encoding, intentional encoding

Introduction

Object-location memory is a complex neurocognitive ability that presents a challenge for our cognitive system. This type of memory involves three components: (1) object-processing, (2) spatial-location processing, and (3) object-location binding (Postma, Kessels, & van Assele, 2008). Object-location memory is a fundamental ability that is needed in our daily lives. Given its adaptive value for both humans and animals, it has been suggested that object-location memory is not only driven by conscious recollections of objects’ locations, but rather that it is an automatic process and possibly influenced by unconscious memory (Hasher & Zacks, 1979).

The automaticity hypothesis (Hasher & Zacks, 1979), in regard to the role of attention allocation in encoding object-location memory, has been widely studied by comparing memory performance across *incidental* and *intentional* encoding conditions. In intentional encoding conditions, participants are explicitly instructed of a required subsequent retrieval phase, whereas in incidental encoding conditions, participants are shown an array of stimuli without awareness of a subsequent retrieval phase. Memory performance findings are inconsistent -- some studies have shown that the locations of objects were learned without participants receiving explicit instruction to remember the locations (e.g., Shadoin & Ellis, 1992), thus supporting the automaticity hypothesis, whereas other studies have shown that intention to remember locations improved memory performance (e.g., Naveh-Benjamin, 1988). Given this controversy, Postma and colleagues (2008) speculated that each component of object-location memory differs in its processing automaticity, with the spatial-location component operating more automatically than the object identity and object-location binding processing components.

Other attention allocation tasks involve differentiating between *divided* versus *full* attention. In divided attention tasks, participants are required to respond to both target and distractor stimuli, whereas in full attention tasks, participants are required to direct their attention to the target stimulus only (Ballesteros & Mayas, 2015). Studies investigating memory have typically demonstrated that in various memory tasks, divided attention during incidental or intentional encoding reduces performance (e.g., Ballesteros & Mayas, 2015; Mulligan, 1998; Parkin & Russo, 1990; Szymanski & MacLeod, 1996). However, more recently, it has been suggested that under specific conditions, divided attention may facilitate memory performance. For example, Nussenbaum, Amso, and Markant (2017) have shown that increasing the number of distractors in a divided attention condition did not impair memory for the target content. Furthermore, when distractors contained information that conflicted with the target content, increasing the number of distractors actually enhanced participants’ memory.

The effects of attention during object-location memory encoding has been scarcely studied. To our knowledge, only two studies have examined the role of attention during object-location memory encoding under divided and full attention conditions. One study presented participants with an array of actual objects, and incorporated a verbal arithmetic task as a distraction in the divided attention condition (Barel, 2018). The second study used a paper-and-pencil task to present object locations and a tone discrimination task as an auditory distraction (Barel, 2019). Both studies demonstrated that, with intentional encoding instruction, participants performed better in the full attention condition than the divided attention condition. However, under the incidental encoding conditions, this finding was replicated only in the study that used the actual array of objects, and not in the paper-and-pencil paradigm study. In accordance with previous studies examining the role of attention in various memory tasks, these findings suggest that the influence of attention allocation on memory performance is not uniform, but rather it is affected by the nature of the distractors -- including the modality and the relatedness of the distractor to the target -- as well as the nature and the modality of the target.

The role of attention in memory performance has been also studied through a central component of executive function: *executive attention* or *attentional control*. Attentional control refers to attentional processes that support the ability to sustain information in the presence of internal or external distractions (Unsworth & Robison, 2019). There are several attentional control abilities, including: attention restraint, attention constraint (Kane et al., 2016), and sustained attention (Unsworth & Robison, 2019). Sustained attention refers to attentional control processes needed to preserve attention and task engagement over time (also referred to as vigilant attention; Langer & Eickhoff, 2013; Lim & Dinges, 2008; Robertson & O'connell, 2010). Studies that have addressed the relation between sustained attention, measured by the psychomotor vigilance task, and working memory capacity revealed that sustained attention was positively correlated with working memory capacity (e.g., Unsworth et al., 2009). Unsworth and Robison (2019) recently proposed a cognitive-energetic model to explain the relation between sustained attention and various cognitive constructs, including memory. The underlying notion of the model is that intensity of attention varies within and between individuals. The intensity of attention is influenced by both intrinsic and extrinsic motivation levels, overall arousal levels, and intrinsic alertness. When attention intensity levels are high, task engagement is high and control levels are optimal. In four experiments examining the relation between sustained attention and working memory capacity, Unsworth and Robison (2019) showed that this relationship is mediated by variation in intrinsic alertness – the ability to voluntarily control the intensity of attention on a continuous basis.

In the search for the underlying cause of the reduction in sustained attention, a phenomena called vigilance decrement, two theories have been suggested: the under-load theory and the over-load theory (Cheyne et al., 2009; Dockree et al., 2004; Helton & Warm, 2008). In the under-load theory, the decrement is deemed to be due to boredom, mindlessness, or goal habituation (Ariga & Lleras, 2011), whereas in the over-load theory, vigilance decrement is considered to be due to mental fatigue and resource depletion. In order to examine these two theories, a few studies sought to investigate the influence of various working memory demands on vigilance decrement. For example, in Helton and Russell's (2011) study, participants performed a vigilance task while simultaneously performing either a verbal or spatial working memory task. The researchers found that the concurrent verbal and spatial working memory load impacted the vigilance decrement among the participants. They concluded that vigilance decrement was caused by high cognitive resource demands, thus supporting the over-load theory.

The role of executive attention has also been examined in relation to incidental and intentional memory. Kontaxopoulou and colleagues (2017) assessed participants' episodic memory performance via virtual reality stimuli, both incidentally and intentionally, using both verbal and visuospatial tests. Additionally, participants completed a neuropsychological battery assessing attention and executive functioning. The researchers found that almost all attentional and executive functioning measures were associated with participants’ incidental, but not intentional, memory performance. They further reported that aging affected incidental (but not intentional) encoding processes. Given these two findings, Kontaxopoulou and colleagues (2017) proposed that the ability to effectively execute incidental memory processes is more strongly connected with the overall cognitive system than is the ability to carry out intentional memory processes, as indicated by the association found with attention and executive functions. Indeed, memory studies among aging populations have shown that low scores on memory tasks were correlated with reduced activation in the frontal lobes (e.g., Rosen et al., 2002). Furthermore, imaging studies have shown that there is a positive correlation between executive functioning and prefrontal cortex volume (for a meta-analysis, see Yuan & Raz, 2014). Therefore, it is suggested that incidental encoding processes, which hold a more prominent function in our daily lives, are perhaps more influenced by executive attention than intentional encoding processes.

The present study aimed at exploring individual differences in the role that executive attention, especially sustained attention, plays in incidental and intentional object-location memory performance. In line with the over-load theory, the present study was conducted under conditions of divided attention, in order to uncover the role of sustained attention on memory performance. Our main hypotheses were:

1. Memory performance would be higher under intentional encoding as compared to incidental encoding.
2. Sustained attention, as measured by the psychomotor vigilance test, would be associated with incidental, but not intentional, encoding measures.

***Method***

***Participants***

Forty-nine female students (age range: 20-30) from a college in the north of Israel participated in the study. Participants were recruited through advertisements at the college, and received course credit for their participation. We chose to recruit a female sample given the extensive body of research suggesting females’ superior performance in object-location memory tasks as compared to males (for a meta-analysis, see Voyer, Voyer, & Saint-Aubin, 2017).

***Materials and Procedure***

The study was approved by the institutional review boards (IRBs) of the college (no: EMEK  YVC 2018-20  ). All participants arrived to the lab between 8:00 a.m.- 12:00 p.m. to partake in the experiment. After providing informed consent, participants completed a brief demographic questionnaire and a number of tasks, as outlined below.

*Object location memory – Incidental encoding* - The study included a stimulus array of 25 black-and-white drawings of objects, based on those used in the Eals and Silverman (1994) study. The stimuli were presented on standard size A4 white paper. Participants were instructed to complete both a pricing task and a distraction task within one minute. In the pricing task, participants were asked to write in a price tag for each object directly on the paper. They were told that if they are unable to estimate a price for the object, they should provide a guess (Gallagher, Neave, Hamilton, & Gray, 2006). In the distraction task, a pre-recorded soundtrack of piano tones randomized for pitch (low or high) was presented in intervals of 2 or 3 seconds (Palmer et al., 2013). The participants were asked to indicate the low-pitched tone by raising their left hand and the high-pitched tone by raising their right hand. Immediately afterward, the participants were shown another stimulus array, in which 14 of the objects were in different locations. They were given 60 seconds to mark which objects’ locations were unchanged and circle the ones whose positions had changed. A manipulation check indicated that the participants were not suspicious about the purpose of the experiment.

*Object location memory – Intentional encoding* - The design of the intentional encoding condition, including all of the materials presented, was identical to the incidental encoding task phase. However, the one difference was that in in the intentional encoding task, participants were given one minute to "try to memorize as many objects in the array as possible and their approximate locations" (Eals & Silvermn, p. 100, 1994).

**Cognitive, *Psychomotor Vigilance Test* (PVT):**

Participants completed a visual psychomotor vigilance task (PVT). This task is sensitive to sleep loss and circadian phase (Johnson et al., 1992; Cajochenet al., 1999; Wright, Hull, Czeisler, 2002). The PVT is the most widely used measure of behavioral alertness. The standard duration of the PVT is 10 minutes; however, the optimal duration of the PVT is shorter than 10 minutes. Based on sensitivity to total sleep deprivation (TSD) and chronic partial sleep deprivation (PSD), a brief PVT (PVT-B) was evaluated (Basner & Dinges, 2011). Most studies use PVT outcomes to monitor sensitivity to total and partial sleep loss (Dinges et al., 1987; Dinges, Pack, Williams, 1997), and to differentiate sleep-deprived subjects from alert subjects (Van Dongen et al., 2003). Sleep deprivation induces reliable changes in PVT performance, causing an overall slowing of response times, and an increase in the number of errors (Doran, Van Dongen, Dinges, 2001; Van Dongen et al., 2003).

However, in the present study the use of the PVT was for a different purpose (besides evaluating sensitivity to sleep loss; Lim et al., 2008); the PVT was used to explore individual differences in the role that sustained attention plays in incidental and intentional object location memory performance. The PVT-B (Joggle Research Program) is a sustained attention reaction time task, and it was performed on an iPad in the current study. Participants were instructed to maintain *vigilant attention* on a target box and respond as quickly as possible to the appearance of a stimuli, while avoiding responding prematurely.

The outcome measures of the current study included the following four variables: (1) responses, (2) errors, (3) coincident false starts and (4) an aggregate score.

*Responses.* Number of stimuli that were presented. The sum of participants’ valid responses and non-responses was calculated. This measure did not include false starts and coincident false starts.

*Errors.* Thenumber of participants’ early response errors were summed, including both false starts and coincident false starts.

*Coincident False Starts.* This measure included the number of responses that were provided in under 100ms.

*Aggregate Score.* A score metric that penalized participants based on the percentage of responses that were lapses and the percentage of responses that were considered to be early response errors was calculated. The calculation was as follows: Aggregate Score = (1 – (Lapses/Responses) – (Errors/Responses)) \* 100.

With regard to executive attention, it is important to emphasize that there is extensive evidence that the neurobehavioral consequences of sleep loss can be measured through certain aspects of cognitive functioning (Banks, Dinges 2007; Goel, Rao, Durmer, Dinges 2009; Van Dongen, Vitellaro, Dinges 2005). Among the most reliable effects of sleep deprivation is degradation of attention (Goel, Rao, Durmer, Dinges 2009; Lim, Dinges 2010), including vigilant attention (Lim, Dinges 2008; Dorrian et al., 2005).

*Sleep patterns –* The purpose of the objective sleep test was to control the quality and quantity of sleep, and to ensure that subjects did not suffer from sleep deprivation during the four days prior to the study.

Objective sleep patterns were measured using an actigraph (AMI, NY). This small device measures sleep patterns in one’s natural environment and provides objective data of one’s sleep patterns. Participants wore the actigraph in the four nights preceding the experiment. Actigraph recodings provided an estimation of participants’ sleep onset, wake time, sleep latency, sleep duration, true sleep minutes, wake after sleep onset (WASO), and sleep efficiency.

***Results***

*Sleep measures*

Participants’ objective sleep patterns were characterized by sleep measures that fell within the typical ranges, a sleep duration that matched the recommended duration, and a high quality of sleep (i.e, sleep efficiency was high; see Table 1).

*Incidental vs. Intentional memory performance*

To test the difference in object-location memory performance across the incidental and intentional encoding conditions, we performed a paired sample t-test and found a significant effect, *t*(48) = 6.32, *p =* .000*, Cohen's d* = .90. Participants scored higher on location memory in the incidental encoding condition as compared with the intentional encoding condition (see Fig. 1).

*The role of sustained attention in incidental vs. intentional memory performance*

Correlations were performed between sustained attention, as measured by the psychomotor vigilance test, and incidental and intentional memory performance. Significant correlations were found only in the incidental encoding condition. A positive correlation was found between the number of responses on vigilant attention and memory performance, with higher scores on vigilant attention correlating with higher scores on object-location memory. Another positive correlation was found between the aggregate score on vigilant attention and memory performance, with higher scores on vigilant attention correlating with higher scores on object-location memory. A negative correlation was found between coincident false starts and memory performance, such that a greater number of false starts correlated with lower scores on object-location memory. Another negative correlation was found between the number of errors made and memory performance, with higher error rates correlating with lower scores on object-location memory. None of the correlations between vigilant attention and memory performance in the intentional encoding condition were significant (see Table 1).

***Discussion***

The present study aimed to examine performance differences in incidental and intentional memory under divided attention conditions. Furthermore, the present study sought to examine the relation between sustained attention and incidental and intentional memory performance. With regard to memory performance under conditions of incidental and intentional encoding, spatial memory studies are characterized by long-lasting controversies. Whereas automaticity hypothesis supporters suggest that the encoding of objects’ locations can occur even without attention allocation (Hasher & Zacks, 1979), other studies find that participants’ awareness of subsequent retrieval requests can improve performance (e.g., Naveh-Benjamin, 1988). The present study provides support for previous studies that have shown that intention to learn locations improves memory performance. However, although it occurred to a lesser extent, participants also exhibited the ability to encode locations even without explicit instruction to do so. Moreover, in both the incidental and intentional memory conditions, participants memorized objects' locations under the divided attention condition, during which they were additionally requested to direct their attention to an auditory task. Even though their attention resources were limited due to the need to allocate attention to another task, the distraction task did not deplete their attention resources, as evidenced by their ability to encode object locations to memory in both the intentional and incidental conditions. Therefore, the present findings stress the notion proposed by Postma and colleagues (2008) that object-location memory has several components that differ in processing automaticity, and specifically that the spatial-location component operates more automatically as opposed to the object identity and object-location binding processing components.

The present study additionally focused on the relation between sustained attention and incidental and intentional memory performance. We found that sustained attention measures correlated with incidental, but not intentional, memory performance. Our findings are in line with a recent study that examined the role of executive attention in relation to incidental and intentional memory (Kontaxopoulou et al., 2017). In that study, the researchers found that almost all attentional and executive functioning was associated with incidental memory performance, but not with intentional memory performance. It is important to note though that Kontaxopoulou and colleagues (2017) measured memory performance on both verbal and spatial tasks, whereas the present study examined object-location memory.

Furthermore, the present study examined memory performance under attention load conditions through a divided attention paradigm in order to uncover the role of sustained attention on wide conditions of memory encoding. Sustained attention is one of several attentional control, or executive attention, abilities (Unsworth & Robison, 2019). Brain imaging studies implicate that several regions are associated with sustained attention, especially the anterior cingulate cortex and the right prefrontal cortex (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Lim et al., 2010). Additionally, Smith and colleagues (1996) reported greater activity in the right hemisphere during tasks of spatial working memory, thus suggesting a coupling between memory demands and sustained attention (Parasuraman, 1979). However, the association between sustained attention and memory performance was found in the present study for the incidental encoding condition only. Based on Kontaxopoulou and colleagues’ (2017) finding that aging affects incidental, rather than intentional, encoding processes, they proposed that the ability to effectively execute incidental memory processes is more strongly connected with the overall cognitive system, as indicated by the association found between incidental memory and attention and executive functions. Indeed, memory studies conducted with elderly populations have shown that low scores on memory tasks were associated with reduced activation in the frontal lobes (e.g., Rosen et al., 2002). Furthermore, imaging studies support a positive correlation between executive functioning and prefrontal cortex volume (for a meta-analysis, see Yuan & Raz, 2014). Further support comes from animal studies. For example, Parnell, Grasby, and Talk (2012) demonstrated that lesions on the medial prefrontal cortex impacted incidental encoding for locations in rodents. The authors suggested that the prefrontal cortex is needed for sustained attention to incidental cues that would lead to incidental encoding of locations.

The present study has some limitations. First, the present study focused on female participants only. Given previous results indicating sex differences in object-location memory performance and specifically the female advantage in these tasks, we chose to focus on females. However, future studies should expand the sampling frame to include male participants as well; this will allow for uncovering sex differences in processing strategies utilized in memory encoding and sustained attention. Second, the present study focused on divided attention conditions. The object-location memory literature has typically explored encoding manipulations under full attention conditions. Only scarcely have divided attention conditions been used (Barel, 2018; 2019). In order to shed light on the role of sustained attention in memory encoding, the present study chose to utilize an attention load paradigm using divided attention conditions. However, to deepen our understanding on the role of attention control on memory encoding processes, a broader examination including various attention conditions (e.g., full, selective) is still needed. Third, the present study used a distraction task which did not appear to dilute the attentional resources allocated for the memory task, as illustrated by the relatively high performance of the participants. Future studies should examine various distraction modalities, including various component numbers in order to identify the precise conditions under which attentional resource allocation facilitates, as opposed to inhibits, memory performance.

In sum, the present findings suggest that memory encoding benefits from explicit instructions to memorize locations under divided attention conditions. Nevertheless, the present findings also demonstrated that in incidental encoding conditions, the distraction task did not completely diminish participants’ attentional resources, as they still exhibited relatively high memory performance; this suggests that object-location memory possesses several components that differ in processing automaticity. Furthermore, to the best of our knowledge, the present study is the first to examine the relation between sustained attention and object-location memory. We found that sustained attention plays an important role in incidental, but not in intentional, encoding, thus supporting previous findings which have examined other memory tasks. Moreover, our findings provide support for animal and human imagery studies which have shown that executive attention and incidental memory performance are connected with the same brain regions, including the prefrontal cortex in particular. Future studies should focus on other incidental memory tasks prominent in our daily lives and their relation to executive attention.

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Table 1: Actigraphic sleep pattern.

|  |  |
| --- | --- |
|  | Mean±SD |
| *Sleep Onset* | 00:22±1.09 |
| *Wake Time* | 8:47±0.89 |
| *Sleep Latency* | 13.92±12.13 |
| *Sleep Duration* | 445.93±65.74 |
| *True Sleep Minutes* | 410.35±61.97 |
| *Waso(min)* | 15.83±13.41 |
| *Sleep Efficiency (%)* | 96.17±3.0 |

Table 2

*Correlations between vigilant attention measures and location-exchanged objects during divided attention incidental and intentional encoding conditions*

|  |  |  |
| --- | --- | --- |
|  | Incidental Encoding | Intentional Encoding |
| 1. Responses | .37\*\* | .07 |
| 2. Errors | -.28\* | .08 |
| 3. Coincident false starts | -.40\*\* | -.09 |
| 4. Aggregate score | .30\* | .12 |

*\* P < .05 \*\* P < .01*

*Fig. 1. Mean number of correctly detected location-exchanged objects under divided attention incidental and intentional encoding conditions. Error bars represent standard errors of the mean (SEM).*