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

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Abstract

The role of attention allocation at encoding object-location memory, has been widely studies through incidental and intentional encoding conditions. However, the relation between sustained attention in memory encoding processes has been scarcely studied. The present study aimed at investigating performance differences in incidental vs. intentional encoding under divided attention conditions. Furthermore, the present study aimed to examine the relation between sustained attention and incidental and intentional object-location memory performance. Fourty-nine women participated completed the psychomotor vigilance test as well as object-location memory tests with incidental and intentional encoding under divided attention. Performance was higher in intentional encoding in comparison with incidental encoding. Furthermore, sustained attention correlated with incidental but not with intentional memory performance. These findings are discussed in light of the automaticity hypothesis regarding the role of attention allocation at encoding object-location memory. Furthermore, the role of sustained attention in incidental memory performance is discussed in light of previous animal and human studies regarding 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 forms a challenge for our cognitive system. It involves three components: a. object-processing, b. spatial-location processing, and c. object location binding (Postma, Kessels, & van Assele, 2008). Object-location memory is a fundamental ability needed in our daily life, and given its adaptive value for humans as well as animals, it has been suggested that object-location memory is automatic and may be influenced by unconscious memory, and not only by conscious recollections of the object's location (Hasher & Zacks, 1979).

The automaticity hypothesis (Hasher & Zacks, 1979) regarding the role of attention allocation at encoding object-location memory, has been widely studies through *incidental* and *intentional* encoding conditions. While in intentional encoding conditions, participants are aware of the requirement of subsequent retrieval via explicit instruction, in incidental encoding conditions, participants are shown a stimuli array without awareness of the subsequent retrieval phase. Findings are inconsistent, with some studies showing location of objects was learned without explicit instruction to remember their locations (e.g., Shadoin & Ellis, 1992), thus supporting the automaticity hypothesis, whereas others showing that intention to remember locations improved performance (e.g., Naveh-Benjamin, 1988). Given this controversy, Postma and colleagues (2008) speculated that each component of object-location memory differ in processing automaticity, with spatial-location component operates more automatically as opposed to object identity and object location binding processing.

Other attention allocation tasks involve *divided* versus *full* attention. In divided attention tasks, participants are required to respond to both target and distractor stimuli; in full attention tasks, participants are required to direct their attention to the target stimulus only (Ballesteros & Mayas, 2015). Studies investigating memory usually have 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, lately 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 target content. Furthermore, when distractors contained information conflicting with the target, increasing the numbers of distractors enhanced memory.

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

 The role of attention in memory performance has been also studied through a central concept in executive function: *executive attention* or *attention control*. Attention 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 attention control abilities, including: attention restraint, attention constraint (Kane et al., 2016), and sustained attention (Unsworth & Robison, 2019). Sustained attention refers to attention control processes needed to preserve attention and task engagement over time (referred also as vigilant attention; Langer & Eickhoff, 2013; Lim & Dinges, 2008; Robertson & O'connell, 2010). Studies addressing the relation between sustained attention, using 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 explaining 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 participants. 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 relation is mediated by variation in intrinsic alertness – the ability to voluntarily control the intensity of attention on continuously basis.

 In the search for the underlying cause of the reduction in sustained attention, a phenomena labeled as 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 due to boredom, mindlessness, or goal habituation (Ariga & Lleras, 2011), whereas in the over-load theory, vigilance decrement is due to mental fatigue and resource depletion. In order to examine these two theories few studies investigated the influence of various working memory demands on vigilance decrement. For example, in Helton and Russell' (2011) study, participants performed a vigilance task while simultaneously performing either verbal or spatial working memory task. They found that the concurrent verbal and spatial working memory load impacted the vigilance decrement. They concluded that vigilance decrement caused by high cognitive resource demands, thus supporting the over-load theory.

The role of executive attention was also 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. Furthermore, particiants completed a neuropsychological battery assessing attention and executive functioning. They found that almost all attentional and executive functioning were associated with incidental memory but not with intentional memory performance. They further reported aging affected incidental rather than intentional encoding processes, and therefore 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 with attention and executive functions. Indeed, memory studies in aging populations have shown reduced activation in the frontal lobes among elderly with low scores on memory tasks (e.g., Rosen et al., 2002). Furthermore, imaging studies showed a positive correlation between executive functioning and prefrontal cortex volume (for a meta-analysis see Yuan & Raz, 2014). Therefore, it is suggested that perhaps incidental encoding processes which are more prominent function in our daily life are more influenced by executive attention.

The present study aimed at exploring the role of executive attention, especially sustained attention in individual differences 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 are:

1. Memory performance will be higher under intentional encoding rather than under incidental encoding.
2. Sustained attention as measures by the psychomotor vigilance test will be associated with incidental rather than intentional encoding measures,

***Method***

***Participants***

Fourty nine female students from a college in the north of Israel (age 20-30yrs) participated in the study. Participants were recruited through advertisements at the college, and received course credit for their participation. We chose female sample given extended body of research suggesting female superiority to males on object location memory performance (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 arrive to the lab between 08-12am for the experiments. After giving their informed consent, participants completed a brief demographic questionnaire and the following tasks:

*Object location memory – Incidental encoding* - The study included 25 black-and-white drawing of objects in a stimulus array based on those used in the Eals and Silverman (1994) study. The stimuli were presented on size A4 white paper. Participants were instructed to complete both a pricing task and a distraction task in a time limit of one minute. In the pricing task, participants were asked to give a price tag for each object in writing on the paper. They were told that if they are unable to estimate the price, they should guess (Gallagher, Neave, Hamilton, & Gray, 2006). In the distraction task, a pre-recorded soundtrack of piano tones randomized for pitch (low or high) in intervals of 2 or 3 s was presented (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 array in which 14 of the objects were in different locations and were given 60 seconds to mark the unchanged objects and circle the ones whose position 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 and all the materials were identical to those used in the incidental encoding phase, except that in the intentional encoding the 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 PVT is 10min, however, optimal PVT duration is shorter than 10-min. Based on sensitivity to total sleep deprivation (TSD) and chronic partial sleep deprivation (PSD) brief PVT (PVT-B) was evaluated (Basner & Dinges, 2011). Most studies used PVT outcomes to monitor sensitivity to total and partial sleep loss (Dinges et al., 1987; Dinges, Pack, Williams, 1997) and to differentiate sleep deprived from alert subjects (Van Dongen et al., 2003). Sleep deprivation induces reliable changes in PVT performance, causing an overall slowing of response times, and increase 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 (than to sensitive to sleep loss; Lim et al., 2008), the aim was to explore the role of sustained attention in individual differences in incidental and intentional object location memory performance.

The PVT-B (Joggle Research Program) is a sustained attention reaction time task that was performed on the I-Pad. Participants must maintain *vigilant attention* on a target box, and respond as quickly as possible to the appearance of a stimuli, and must avoid responding prematurely.

The outcome measures in the current study that were include in our analyses were the following 4 variables:

*Responses:* Number of stimuli that were presented. This is a sum of the number of valid responses and the Non Responses and does not include False Starts and Coincident False Starts.

*Errors:* Number of early response errors (False Starts and Coincident False Starts).

*Coincident False Starts:* Number of responses shorter than 100ms.

*Aggregate Score:* A score metric that penalizes based on the % of responses that were lapses and the % of responses that were early response errors (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 in 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) include 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, to ensure that subjects did not suffer from sleep deprivation during the 4 days prior to the study.

Objective sleep patterns were measured using an actigraph (AMI, NY). This small device measures sleep patterns in the natural environment and provides objective data of sleep patterns. Participants wore the actigraph during 4 nights before the experiment. Actigraph recoding provided an estimation of the sleep onset, wake time, sleep latency, sleep duration, True sleep minutes, wake after sleep onset (WASO), and sleep efficiency.

***Results***

*Sleep measures*

Objective sleep patterns of the participants presents sleep measures in the norm, sleep duration as recommended and high quality of sleep (sleep efficiency found high; see Table 1).

*Incidental vs. Intentional memory performance*

To test the difference in object location memory performance under incidental versus intentional encoding we performed paired sample t test and found a significant effect [*t*(48) = 6.32, *p =* .000*, Cohen's d* = .90]. Participants under incidental encoding scored higher on location memory rather than under intentional 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 for the incidental encoding rather than intentional encoding: A positive correlation was found between 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. Negative correlation was found between coincident false starts and memory performance, with higher scores on false starts correlating with lower scores on object location memory. Another negative correlation was found between numbers of errors 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 under intentional encoding 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 in incidental and intentional encoding, spatial memory studies are characterized by long lasting controversies. Whereas the automaticity hypothesis supporters suggest that encoding of object's location occurs even without attention allocation (Hasher & Zacks, 1979), other studies found that awareness of participants to the subsequent retrieval request can improve performance (e.g., Naveh-Benjamin, 1988). The present study provided support for previous studies showing that intention to learn locations improves memory performance. However, although to a lesser extent, participants yet exhibited the ability to encode locations even without explicit instruction to do so. Moreover, objects' locations were memorized under divided attention condition – while participants were requested to apply to another, auditory task, on both, incidental and intentional memory. 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 resulting in memory encoding of object locations in intentional as well as incidental conditions. Therefore, the present findings stresses the notion proposed by Postma and colleagues (2008) that object-location memory has several components that differ in processing automaticity, with spatial-location component operates more automatically as opposed to object identity and object location binding processing.

The present study focused also on the relation between sustained attention and incidental and intentional memory performance. We found that sustained attention measures correlated with incidental but not with intentional memory performance. Our findings are in line with previous study examining the role of executive attention in relation to incidental and intentional memory (Kontaxopoulou et al., 2017). They found that almost all attentional and executive functioning were associated with incidental memory but not with intentional memory performance. Kontaxopoulou and colleagues (2017) 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 divided attention paradigm in order to uncover the role of sustained attention on wide conditions of memory encoding. Sustained attention is one of several attention control, or executive attention abilities (Unsworth & Robison, 2019). Brain imaging studies implicated several regions associated with sustained attention, especially the anterior cingulate cortex and the right prefrontal cortex (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Lim et al., 2010). Furthermore, Smith and colleagues (1996) reported greater activity in the right hemisphere for spatial working memory, thus suggesting coupling between memory demand and sustained attention (Parasuraman, 1979). However, the potential association was found in the present study for incidental encoding only. Based on their finding that aging affected incidental rather than intentional encoding processes, Kontaxopoulou and colleagues (2017) 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 with attention and executive functions. Indeed, memory studies in aging populations have shown reduced activation in the frontal lobes among elderly with low scores on memory tasks (e.g., Rosen et al., 2002). Furthermore, imaging studies showed 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 lesion 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 at incidental encoding of locations.

The present study has some limitations. First, the present study focused on female participants only. Given previous results showing the variance in object-location memory performance and the female advantage in these tasks, we chose to focus on females. However, future studies should elaborate the sampling frame to males as well, in order to uncover sex differences in processing strategies embedded in memory encoding and sustained attention. Second, the present study focused on divided attention conditions. The object-location memory literature usually explored encoding manipulations under full attention conditions. Only scarcely, divided attention conditions were used (Barel, 2018; 2019). In order to shed light on the role of sustained attention in memory encoding, the present study chose attention load paradigm using divided attention conditions. However, to deepen our understanding as for the role of attention control on memory encoding processes, a broaden examination including various attention conditions (e.g., full, selective) are still needed. Third, the present study used a distraction task which have not diluted the attentional resources allocated for the memory task, given the relatively high performance of the participants. Future studies should examine various distraction modalities including various component numbers in order to precise the conditions under which attention resources allocation facilitate as opposed to inhibit 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 the distraction task did not dilute completely the attention resources allowing a relatively high memory performance, suggesting that object-location memory possesses several components differing 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 important role in incidental but not in intentional encoding, thus supporting previous findings regarding other memory tasks. Moreover, our findings provide support to animal and human imagery studies connecting executive attention and incidental memory performance to the same brain regions, including especially, the prefrontal cortex. Future studies should focus on other incidental memory tasks prominent in our daily life and their relation to executive attention.

References

Ariga, A., & Lleras, A. (2011) Brief and rare mental ‘‘breaks’’ keep you focused: deactivation and reactivation of task goals preempt vigilance decrements. *Cognition, 118,* 439–443.

Ballesteros, S., & Mayas, J. (2015). Selective attention affects conceptual object priming and recognition: a study with young and older adults. *Frontiers in Psychology, 5,* article 1567.

Banks, S., Dinges, D.F. (2007) Behavioral and physiological consequences of sleep restriction. J Clin Sleep Med 3:519-28.

Barel, E. (2018). The role of attentional resources in explaining sex differences in object location memory. *International Journal of Psychology*, *53*, 365-372.‏

Barel, E. (2019). Effects of attention during encoding on sex differences in object location memory. *International Journal of Psychology*, *54*, 539-547.‏

Basner, M., Dinges, D.F. (2011) Maximizing sensitivity of the Psychomotor Vigilance Test (PVT) to sleep loss. *Sleep, 34:581–591.*

Cheyne, J. A., Solman, G. J. F., Carriere, J. S. A., & Smilek, D. (2009) Anatomy of an error: a bidirectional state model of task engagement/ disengagement and attention-related errors. *Cognition, 111*, 98– 113.

Dinges, D.F., Orne, M.T., Whitehouse, W.G., Orne, EC. (1987) Temporal placement of a nap for alertness: contributions of circadian phase and prior wakefulness. *Sleep 10:313-29.*

Dinges, D.F., Pack, F., Williams, K, et al. (1997) Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep 20:267-77.*

Doran, S.M., Van Dongen, H.P., Dinges, D.F. (2001) Sustained attention performance during sleep deprivation: Evidence of state instability. Archives Italiennes de Biologie: *A Journal of Neuroscience 139:1-15.*

Dorrian, J., Rogers, N.L., Dinges, D.F., Kushida, C.A. (2005) Psychomotor vigilance performance: Neurocognitive assay sensitive to sleep loss. Sleep deprivation: clinical issues, pharmacology and sleep loss effects. *New York, NY: Marcel Dekker, Inc.39-70.*

Dockree, P. M., Kelly, S. P., Roche, R. A., Hogan, M. J., Reilly, R. B., & Robertson, I. H. (2004) Behavioural and physiological impairments of sustained attention after traumatic brain injury. *Cognition & Brain Research, 20*, 403–414.

Eals, M., & Silverman, I. (1994). The Hunter-Gatherer theory of spatial sex differences: Proximate factors mediating the female advantage in recall of object arrays. *Ethology & Sociobiology, 15,* 95-105.

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. L., & Posner, M. I. (2005). The activation of attention networks. *NeuroImage, 26,* 471–479.

Gallagher, P., Neave, N., Hamilton, C., & Gray, J. M. (2006). Sex differences in object location memory: Some further methodological considerations. *Learning and Individual Differences, 16,* 27-290.

Goel, N., Rao, H., Durmer, J.S., Dinges, D.F. (2009) Neurocognitive consequences of sleep deprivation. *Semin Neurol 29:320-39.*

Hasher, L. & Zacks, T. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General*, *108*, 356-388.

Helton, W. S., & Russell, P. N. (2011). Working memory load and the vigilance decrement. *Experimental brain research*, *212*(3), 429-437.‏

Helton, W. S., & Warm, J. S. (2008) Signal salience and the mindlessness theory of vigilance. *Acta Psychologica, 129*, 18–25

Kane, M. J., Meier, M. E., Smeekens, B. A., Gross, G. M., Chun, C. A., Silvia, P. J., & Kwapil, T. R. (2016). Individual differences in the executive control of attention, memory, and thought, and their associations with schizotypy. *Journal of Experimental Psychology: General*, *145*, 1017.‏

Kontaxopoulou, D., Beratis, I. N., Fragkiadaki, S., Pavlou, D., Yannis, G., Economou, A., ... & Papageorgiou, S. G. (2017). Incidental and intentional memory: their relation with attention and executive functions. *Archives of Clinical Neuropsychology*, *32*, 519-532.‏

Langner, R., & Eickhoff, S. B. (2013). Sustaining attention to simple tasks: A meta-analytic review of the neural mechanisms of vigilant attention. *Psychological Bulletin, 139,* 870–900. <http://dx.doi.org/10.1037/a0030694>

Lim, J., & Dinges, D. F. (2008). Sleep deprivation and vigilant attention. *Annals of the New York Academy of Sciences, 1129,* 305–322.

http://dx.doi.org/10.1196/annals.1417.002

Lim, J., Dinges, D.F. (2010) A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. Psychol Bull, 36:375-89.

Lim, J., Wu, W., Wang, J., Detre, J. A., Dinges, D. F., & Rao, H. (2010) Imaging brain fatigue from sustained mental workload: an ASL perfusion study of the time-on-task effect. *NeuroImage, 49*, 3426–3435

Mulligan, N. W. (1998). The role of attention during coding on implicit and explicit memory. *Journal of Experimental Psychology – Learning, Memory, & Cognition, 24*, 27–47.

Naveh-Benjamin, M. (1988). Recognition memory of spatial location information: Another failure to support automaticity. *Memory & Cognition*, *16*, 437-445.‏

Nussenbaum, K., Amso, D., & Markant, J. (2017). When increasing distraction help leaning: Distractors number and content interact in their effects on memory. *Attention, Perception, & Psychophysics, 79,* 2606-2619.

Palmer, M. A., Brewer, A., & Horry, R. (2013). Understanding gender bias in face recognition: Effects of divided attention at encoding. *Acta Psychologica, 142*, 362–369.

Parasuraman R (1979) Memory load and event rate control sensitivity decrements in sustained attention. *Science, 205*, 924–927.

Parkin, A. J., & Russo, R. (1990). Implicit and explicit memory and the automatic/effortful distinction. *European Journal of Cognitive Psychology, 2*, 71–80.

Parnell, R., Grasby, K., & Talk, A. (2012). The prefrontal cortex is required for incidental encoding but not recollection of source information in rodents. *Behavioural brain research*, *232*, 77-83.‏

Postma, A., Kessels, R. P., & van Asselen, M. (2008). How the brain remembers and forgets where things are: The neurocognition of object–location memory. *Neuroscience & Biobehavioral Reviews*, *32*, 1339-1345.‏

Robertson, I. H., & O’Connell, R. G. (2010). Vigilant attention. In A. C. Nobre & J. T. Coull (Eds.), *Attention and time* (pp. 79–88). Oxford, UK: Oxford University Press. [http://dx.doi.org/10.1093/acprof:oso/9780199563456.003.0006](http://dx.doi.org/10.1093/acprof%3Aoso/9780199563456.003.0006)

Rosen, A. C., Prull, M. W., O'Hara, R., Race, E. A., Desmond, J. E., Glover, G. H., ... & Gabrieli, J. D. (2002). Variable effects of aging on frontal lobe contributions to memory. *Neuroreport*, *13*, 2425-2428.‏

Shadoin, A. L., & Ellis, N. R. (1992). Automatic processing of memory for spatial location. *Bulletin of the Psychonomic Society*, *30*, 55-57.‏

Smith, E. E., Jonides J., & Koeppe, R. A. (1996) Dissociating verbal and spatial working memory using PET. *Cerebral Cortex, 6*, 11–20.

Szymanski, K. F., & MacLeod, C. M. (1996). Manipulation of attention at study affects an explicit but not an implicit test of memory. *Consciousness and Cognition, 5*, 165– 175.

Unsworth, N., Miller, J. D., Lakey, C. E., Young, D. L., Meeks, J. T., Campbell, W. K., & Goodie, A. S. (2009). Exploring the relations among executive functions, fluid intelligence, and personality. *Journal of Individual Differences, 30,* 194–200. http://dx.doi.org/10.1027/1614-0001.30.4.194

Unsworth, N., & Robison, M. K. (2019). Working memory capacity and sustained attention: A cognitive-energetic perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition*.‏

Van Dongen, H.P., Maislin, G., Mullington, J.M., Dinges, D.F. (2003) The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep 26:117-26.*

Voyer, D., Voyer, S. D., & Saint-Aubin, J. (2017). Sex differences in visual-spatial working memory: A meta-analysis. *Psychonomic bulletin & review*, *24*, 307-334.‏

Yuan, P., & Raz, N. (2014). Prefrontal cortex and executive functions in healthy adults: a meta-analysis of structural neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *42*, 180-192.‏

Table 1: Actigraphic sleep pattern.

|  |  |
| --- | --- |
|  | Mean±SD |
| *Sleep Onset* | 00:22±1.09 |
| *Wake-up 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 with incidental vs. intentional encoding under divided attention*

|  |  |  |
| --- | --- | --- |
|  | 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 with incidental vs. intentional encoding under divided attention. Error bars are standard errors of the mean (SEM).*