SHORT-TERM CONSOLIDATION OF INFORMATION FOR EPISODIC MEMORY

A THESIS SUBMITTED TO
THE INFORMATICS INSTITUTE
OF
THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
THE DEPARTMENT OF COGNITIVE SCIENCE

MARCH 2008

Approval of the Graduate School of Informatics

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ABSTRACT

SHORT-TERM CONSOLIDATION OF INFORMATION
FOR EPISODIC MEMORY

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March 2008, 112 pages

Abstract. Several lines of evidence from rapid serial visual presentation, attentional blink, and dual-task interference phenomena propose that human beings have a significant limitation on the short-term consolidation process. Short-term consolidation is transferring early representations to more durable forms of memory. Although previous research has shown that masks presented after targets interrupt the consolidation process of information, there is not enough evidence for the role of attention in consolidation for episodic memory. One electrophysiological and five behavioral experiments were conducted to investigate the effects of attention and stimulus onset asynchrony (SOA) between targets and masks on episodic memory. Masks were presented after targets with varying SOAs. The participants in the divided attention condition but not the ones in the full attention condition performed the attention-demanding secondary task after the presentation of the masks. The results showed that reducing SOA between targets and masks caused an impairment in memory performance for divided attention but not for full attention, providing evidence for the necessity of attention for the short-term consolidation process. Electrophysiological results demonstrated that this impairment did not result from perceptual processes.

Keywords: Short-term consolidation, episodic memory, interference, divided attention, event-related potentials.

ÖZ

OLAYSAL BELLEK İÇİN BİLGİLERİN KISA-SÜRELİ KONSALİDASYONU

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Mart 2008, 112 sayfa

Hızlı seri görsel sunum, dikkat kırpması, ve ikili görev olgularından elde edilen kanıtlar insanoğlunun kısa-süreli konsalidasyon sürecinde anlamlı bir sınırlılığı olduğunu öne sürmektedir. Kısa-süreli konsalidasyon, erken temsillerin daha kalıcı bellek biçimlerine nakledilmesidir. Yapılmış çalışmalar hedef uyaranlardan sonra gösterilen maskelerin bilgilerin konsalidasyonunu yarıda kestiğini göstermesine rağmen, bilgilerin olaysal bellek için konsalidasyonunda dikkatin rolü hakkında yeterli kanıt yoktur. Dikkatin ve hedef uyaran ile maske arasındaki uyaran başlangıcı senkronizasyonsuzluğunun (UBS) oluntusal belleğe etkisini incelemek için bir elektrofizyolojik ve beş davranışsal deney yapılmıştır. Maskeler hedef uyaranlardan sonra değişen UBS'lerde sunulmuştur. Bölünmüş dikkat koşulundaki katılımcılar maskelerin sunumundan sonra dikkat gerektiren ikincil bir iş yaparken tam dikkat koşulundaki katılımcılara böyle bir görev verilmemiştir. Sonuçlar göstermiştir ki; hedef uyaranlar ile maskeler arasındaki UBS'yi düşürmek bölünmüş dikkatte bellek performansını düşürürken tam dikkatte performansı etkilememiştir. Bu bulgular kısa-süreli konsalidasyon sürecinde dikkatin gerekliliğini desteklemektedir. Elektofizyolojik sonuçlar bu zayıflığın algısal süreçlerden kaynaklanmadığını göstermiştir.

Anahtar kelimeler: Kısa-süreli konsalidasyon, olaysal bellek, yarıda kesmek, bölünmüş dikkat, olaya-bağlı potansiyeller.

To my love, Neşe Şahin Özçelik

ACKNOWLEDGEMENTS

I would like to thank my advisor, Hasan Gürkan Tekman and my informal supervisors at Rotman Research Institute, Fergus I. M. Craik and Terence W. Picton for their support and guidance throughout the study. I should also express my appreciation to my examining committee members, Nurhan Er, Didem Gökçay, Annette Hohenberger, and Bilge Say for their valuable suggestions and comments. I would like to extend my thanks to the members of the Craik Memory Lab at University of Toronto and the ERP Lab at Rotman Research Institute, especially Sharyn Kreuger, Matt Burke, and Patricia Van Roon for their help and assistance. I should also thank to Kürşat Çağıltay for letting me work in his project while I was writing this dissertation.

I would like to express my love to my wife, Neşe Şahin Özçelik and my daughter, Sude Yağmur Özçelik, and all the members of my family for their patience and support during the study.

This work was partially supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK) fellowship awarded to Erol Özçelik, NSERC grant awarded to Fergus I. M. Craik, and TÜBİTAK SOBAG 104K098 grant awarded to Kürşat Çağıltay.

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LIST OF ABBREVIATIONS

AB:	Attentional blink
CRT:	Choice-reaction time
DA:	Divided attention
EEG:	Electroencephalography
ERP:	Event-related potential
FA:	Full attention
fMRI:	Functional magnetic resonance imaging
ITI:	Intertrial interval
M:	Mean
PET:	Positron emission tomography
RSVP:	Rapid serial visual presentation
SD:	Standard deviation
T1:	First target
T2:	Second target
SOA:	Stimulus onset asynchrony
WM:	Working memory

CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Assume that you are searching for the heading "Attention" in a book. You try to select the target text among nontargets. You can easily perceive and identify nontarget words. Identification of meaningful stimuli such as words rapidly activates conceptual representations (Potter, 1999). However, when you are asked to recollect the words you have seen after the visual search task, you will recall very few words (Horowitz & Wolfe, 1998). This example shows that having an intact perception and identification of information does not guarantee to create a long-lasting new episode in memory.

A visual input received from the eyes is first temporarily stored in the visual sensory register (Dick, 1969). The capacity of the visual sensory register is large (Gegenfurtner & Sperling, 1993). Information stored in the visual sensory register has no meaning (Sperling, 1960). After sensory encoding, patterns are recognized (Jolicoeur & Dell'Acqua, 1998). Relevant information from the long-term memory is retrieved and conceptual representations are activated in this stage (Potter, 1999). The rapid activation of these representations enables human beings to understand their environments and to survive. However, these early conceptual representations are short-lived. They can be easily lost due to decay or interference if they are not further processed (Potter, 1993). Transferring of these early representations into more permanent form is called short-term consolidation (Jolicoeur & Dell'Acqua, 1998; Vogel, Woodman, & Luck, 2006).

1.2 Short-term Consolidation

It is proposed that a new memory trace is at first in a fragile state (McGaugh, 2000). This memory trace can be easily disrupted. Unless the information is successfully consolidated, it is vulnerable to decay or interference (Thompson & Madigan, 2005). The consolidation theory also suggests that a memory trace is not formed instantly during or immediately after the event (McGaugh, 1966), but strengthened by time (Muller & Pilzecker, 1900; cited in Berlau, 2006). In other words, "memory is not fixed at the moment of learning, but continues to stabilize (or consolidate) with the passage of time" (Squire, 1986, p. 1615).

Three unique properties enable short term consolidation to be a distinct process. First, the short-term consolidation process is suggested to be limited in capacity such that only one item can be consolidated at a time (Chun & Potter, 1995). If two targets are presented successively, the second target needs to wait the end of the consolidation of the first target. The second target can be consolidated whenever the bottleneck is no longer occupied by the first target.

Second, the short-term consolidation bottleneck is proposed to be a central and an amodal processing limitation (Arnell, 2006; Jolicoeur, 1999a, Jolicoeur & Dell'Acqua, 1998; Jolicoeur & Dell'Acqua, 1999; Stevanovski & Jolicoeur, 2007). A central processing limitation occurs when the same processing mechanisms are shared among separate and unrelated tasks (Ferreira & Pashler, 2002). An amodal processing limitation occurs if the targets are in different modalities (Arnell, 2006). Short-term consolidation of a stimulus causes a slowing in the performance of a concurrent task that is presented in a different modality, because the concurrent task can not be processed until the central processing mechanisms are free from the consolidation of the stimulus.

Third, short-term consolidation takes time and the required time for this process is longer if more information needs to be encoded (Jolicoeur & Dell'Acqua, 1999). Performance reaches asymptote when enough time is given for the short-term consolidation process (Vogel, Woodman, & Luck, 2006). Increasing the processing time more than the necessary time for short-term consolidation does not further facilitate memory performance.

Long-term consolidation is different from the short-term consolidation process. Unlike the very short duration (e.g. 500 ms) of the short-term consolidation process, it may take hours, days or even years for the long-term consolidation process. The classic long-term consolidation theory suggests that retrieval of memory traces initially depend on hippocampal system, but after consolidation memories are retrieved directly from neocortex independent of hippocampal system (Squire & Alvarez, 1995). For this reason, damage of hippocampal system impairs memory for new memories but not remote memories. A gradient of memory loss is observed in retrograde amnesia such that patients suffering from retrograde amnesia are impaired at recollecting more of recent than of old memories (Meeter & Murre, 2004).

1.3 Significance of the Study

Previous studies (Gegenfurtner & Sperling, 1993; Vogel, Woodman, & Luck, 2005) have shown that pattern masks (masks having contours overlapping the target with no conceptual meaning) presented after targets interfere with the consolidation of information. On the other hand, some studies (Intraub, 1984; Loftus & Ginn, 1984; Loftus, Hanna, & Lester, 1988) have demonstrated that only meaningful masks can interfere with the ongoing consolidation process. Meaningful masks are suggested to be attention demanding stimuli (Intraub, 1984). This inconsistency in research findings (i.e. whether pattern masks or meaningful masks interfere with the consolidation process) creates the need to address the role of attention in the short-term consolidation process. The findings of this study can show whether attention is necessary for short-term consolidation of information.

Most of the paradigms that have been employed to support the existence of a distinct short-term consolidation process are very complex and includes several processing stages other than consolidation (Jolicoeur, 1999a). For instance, the task of participants in the attentional blink paradigm is to identify predefined set of targets and to detect whether a probe is displayed among a rapid stream of distractors. Besides, these paradigms have unnecessary and potentially confounding features (McLaughlin, Shore, & Klein, 2001). For instance, inclusion of a stream of distractors may contaminate the results of these complicated paradigms (Shore, McLauglin, & Klein, 2001). Kawahara (2003) argued that the mandatory identification of the distractors caused cognitive overload and processing delay. Participants' errors included reports of the distractor presented immediately after the target, suggesting that attentional engagement for the target may be delayed in these studies (Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005). Considering these problems, a simpler paradigm can minimize these confounding factors. The paradigm employed in this study is simple, because it includes presentation of a single target followed by a mask. With the onset of the mask, participants either perform a secondary task or pay full attention to study the targets.

The neural correlates of the short-term consolidation process are not clear. Marois, Chun, and Gore (2000) found in a functional magnetic resonance imaging (fMRI) study that activations in right intraparietal sulcus and frontal cortex were associated with consolidation. Marcantoni, Lepage, Beaudoin, Bourgouin, and Richer (2003) argued that inferotemporal cortex activations were related with this process. Patients with lesions at inferior parietal lobe have more problems in consolidation of information compared to healthy controls (Shapiro, Hillstrom, & Husain, 2002).

Electrophysiological evidence suggests that activities in the parietal areas are delayed when the consolidation process is impaired (Vogel, Woodman, & Luck, 2006). The current study may add to our understanding of the neural correlates of the short-term consolidation process. Electrophysiological data may reveal when and where this short-term consolidation happens.

1.4 Purpose of the Study

The main goal of this study was to investigate the role of attention in short-term consolidation on episodic memory. Episodic memory is a memory system that provides re-experience of personal events by mentally traveling back in time (Wheeler, Stuss, & Tulving, 1997). Episodic memories include not only item information but also temporal, contextual, and perceptual information about events (Tulving, 1983). Another goal of the study is to find out whether electrophysiological data can show the time course and the anatomic correlates related to the short-term consolidation process. Electrophysiological data may demonstrate whether the impairment in memory performance is due to perceptual or post-perceptual processes.

Specifically, the effects of attention and SOA between the onset of targets and masks on episodic memory and on secondary task response time (RT) are examined in the current study. If consolidation of information requires uninterrupted processing for some amount of time, then division of attention during this process will disrupt episodic memory performance. On the other hand, memory performance will be intact provided that participants are given enough time for consolidation of information.

If a secondary task is presented after the target, there will be a slowing in RT to the secondary task when SOA is shorter than the necessary amount of time for short-term consolidation, because processing of secondary task has to wait the consolidation of the target. No dual task slowing effect will be observed in the secondary task performance when SOA is long enough for the short-term consolidation process, because in such a situation there will be no overlap between processing of the target and the secondary task.

The divided attention paradigm is used in this study. The aim of utilizing this paradigm is to examine the role of attention in the short-term consolidation. Performing a secondary task in a divided attention condition is expected to consume attentional resources. If the consolidation process needs attentional resources, then withdrawal of attentional resources should impair the short-term consolidation process and consequently memory performance should suffer.

The divided attention paradigm employed in this study is different from the classical divided attention paradigm. Participants have to perform both the primary and the secondary tasks together for the whole duration of the study trial in the classical divided attention paradigm. However, subjects in the divided attention condition in this study have to perform the attention-demanding secondary task starting with the onset of the masks after the presentation of targets. Thus, participants can process the targets uninterruptedly until the presentation of masks in the divided attention condition. With the presentation of the secondary task, it is expected that this task will interrupt the ongoing short-term consolidation when there is not enough attentional resources for the short-term consolidation process. In other words, the secondary task is expected to consume the processing resources that are needed for the consolidation and consequently impair this process.. The divided attention paradigm used in this study is not novel. It is similar to the dual-task paradigm in which an attentional demanding task (e.g. responding to tones) is presented after targets (e.g. letters) and masks.

1.5 Hypotheses of the Study

Several investigators (e.g. Chun & Potter, 1995; Jiang, 2004; Jolicoeur & Dell'Acqua, 1999) have suggested that that the short-term consolidation process needs full attentional resources for about 500 ms. It is expected that reducing the SOA between targets and masks will cause a deficit in episodic memory for divided attention but not for full attention, because consolidation process will not be disrupted in full attention conditions by merely presentation of masks. It is also anticipated that increasing the SOA more than sufficient amount of time for short-term consolidation (say 800 ms) will not improve episodic memory.

Another dependent variable is response time for the secondary tasks in divided attention conditions. Short-term consolidation of targets is expected to cause lengthening the response time for the secondary task presented after the memory task, because the secondary task can not be processed when the attentional resources are busy with the consolidation of information. Thus, response time in the secondary task should be longer in short SOA conditions compared to long SOA conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 Visual Sensory Register

Sperling (1960) found that participants could recall about 4 letters when participants were asked to report as many letters as they could from an array of display consisting of 9 to 12 letters presented for a very short duration (i.e. 50 ms). When the exposure duration was decreased to 15 ms or increased to 500 ms, performance did not differ. This shows that the poor performance was not a result of the difficulty in seeing the letters. The number of reported symbols was constant even if more items were presented in the display, indicating the existence of a limited memory capacity for visual sensory store. However, this finding was inconsistent with the proposal that the capacity of sensory registers was large.

Sperling thought that people might see all the items but they might forget them quickly. In order to examine this possibility, he asked his participants to report one row of letters in the array that was signaled by a random tone (e.g. high tone for the top row, medium tone for the middle row, low tone for the bottom row). The tone was presented after the offset of the display and the subjects did not know in advance which row to report. Sperling argued that if participants could recall 4 letters from a randomly cued row, the actual capacity of the sensory register was 12 letters (4 letters X 3 rows). The results showed that the capacity of sensory register was much more than 4 letters (i.e. about 9 letters). In order to determine how long participants could store these letters, Sperling varied the interstimulus interval (ISI) between the memory array and the tone. Interstimulus internal is the time between two stimuli. He found that performance was at chance levels when the ISI was increased to 300 ms, showing that the contents of visual sensory register decayed very rapidly. In sum, these results showed that nearly all the letters in the display were perceived initially but afterwards these perceptual representations faded away rapidly before subjects could register them.

Similar results were obtained in the partial-report procedure when a visual arrow was placed close to the to-be-reported character (Averbach & Sperling, 1961). On the other hand, when a circle marker surrounding the location of the character was used, performance decreased substantially. Averbach and Sperling claimed that visual sensory memory was interfered by the circle that was shown on the place of the target letter. Presenting a visual stimulus after the offset of the target on the same spatial location was called backward masking (Breitmeyer, 1984). Averbach and Sperling argued that in addition to passive decay, another source of memory loss in visual sensory store was the interference by the visual mask.

Sperling (1960) also examined whether the information in the visual sensory register was precategorical. A precategorical representation has not been categorized and has no meaning. If the contents of the sensory register are in precategorical form, then using a categorical cue (e.g. asking subject to report only letters of numbers in the array) should yield poor performance, because the extra time needed for the categorization process will cause decay of the contents of the sensory memory. The results showed that participants in the categorical cue condition were not better than the ones in the whole report condition, suggesting that information was stored in precategorical form .

2.2 Episodic Memory

Early perceptual representations need to be transferred from sensory register to permanent memory in order to be remembered. One type of permanent memory is episodic memory. Episodic memory is defined as a memory system providing re-experience of personal events by mentally traveling back in time (Wheeler, Stuss, & Tulving, 1997). It involves storage and retrieval of contextual information related with events. Episodic memory includes self-knowing and consciously recollecting events. Another type of permanent memory is semantic memory. Semantic memory is defined as general world knowledge of the world including memory for facts, concepts, and rules (Sternberg, 1999). It does not include information about when and where you acquired this memory (Tulving, 1983). For instance, remembering the fact that the capital city of Turkey is Ankara is a semantic memory whereas remembering where you learned this information is an episodic memory. When you first experience the fact that the capital city of Turkey is Ankara, you will form an episodic memory. Nevertheless, with time and repetitions you may assimilate this information into semantic memory (Parkin, 1983). No episodic details such as when and where you acquired this information will be associated with the semantic memory.

Episodic memory is accepted to be distinct from semantic memory (Tulving, 1983; see also McKoon & Ratcliff, 1986). Several pieces of evidence suggest that older adults have memory problems in episodic memory whereas their semantic memory is preserved (Mitchell, Brown, & Murphy, 1989). For instance, older adults have worse performance on recognition of pictures compared to younger adults, but aging does not have an effect on picture-naming latency (Mitchell et al., 1989). In another study, it was found that whereas participants were less accurate in recognizing pictures as the interval between study and test was increased from 1 week to 6 weeks, picture naming latency did not decrease by changing this interval (Mitchell & Brown, 1988). Neuropsychological findings also support this distinction.

Amnesic patients such as K.C. had impaired episodic memory but had intact semantic memory (Tulving, Schacter, McLachlan, & Moscovitch, 1988).

2.3 Impaired Consolidation as a Cause of Forgetting

People sometimes fail to retrieve from episodic memory. One reason of forgetting is retrieval failure, which is the inability to find the existing memory trace. Another cause is storage failure, which is the inability to create a permanent memory trace (Parkin, 1993). Several sources of evidence from rapid serial visual presentation (RSVP), attentional blink (AB), masking and dual-task paradigms have suggested that the human cognitive system has a limitation in transferring early perceptual representations into a more stable form of memory (Potter, 1976; Jolicoeur & Dell'Acqua, 1999; Vogel & Luck, 2002). This critical process, called short-term consolidation (Jolicoeur, 1999a) has an important role for successful storage of information in episodic memory. The next sections will present evidence from several paradigms to demonstrate that the short-term consolidation is critical for memory.

2.3.1 Evidence from the Rapid Serial Visual Presentation Paradigm

It has been known that human beings have a huge capacity for storing pictorial information (Nickerson, 1968; Shepard, 1967; Standing, 1973; Standing, Conezio, & Haber, 1970). These findings were supported by recent studies when different memory tests were used (i.e. Hamilton & Geraci, 2006; Kinjo & Snodgrass). Memory performance in a recognition test for 10,000 colored photographs presented for 5 seconds was very high (Standing, 1973). Subjects could remember photographs even if the memory test was administered one year later (Nickerson, 1968). However, sequentially presented photographs of ordinary scenes (see Figure 2.1) that were shown for a brief period of time (say, 333 ms) were recognized very poorly (Potter, 1976; Potter et al., 2002; Potter, Straub, & O'Connor, 2004). Recognition memory decreased from 93% to 16% as presentation duration of pictures was decreased from 2000 ms to 125 ms (Potter & Levy, 1969).

Figure 2.1. Rapid serial visual presentation paradigm

The impairment in memory performance may be due to inability to perceive the pictures that were presented at high rates (Potter, 1976). This hypothesis was tested by asking viewers to detect previewed pictures. Previews of the pictures were presented prior to the RSVP stream. Performance was very high even in fast rates, suggesting that subjects had intact perception of these pictures. Nonetheless, high detection performance may stem from identifying low level physical features of pictures. In order to eliminate this possibility, participants were required to search for a target that was described by a verbal name such as "picnic". These target names were too general to match pictures based on simple visual attributes such as color or shape (Potter, 1990). The results showed that performance in detecting the pictures specified by verbal names was substantially higher than remembering the scenes. Providing verbal cues for the detection task may increase expectations of low level visual attributes of the target (Intraub, 1981). This possibility was tested by specifying the target by a negative category (e.g. "the picture that is not of food"). Detection was intact in these negatively cued trials, suggesting that expectancy was not responsible for the high performance. A study by Bacon-Mace´, Mace´, Fabre-Thorpe, and Thorpe (2005) supported these findings by demonstrating that accuracy in detecting whether a natural scene contained an animal or not was about 90% even if the pictures were presented for 40 ms followed by masks. It should be noted that the detection was not a memory task.

Presenting a visual noise mask (see Figure 2.2) that did not require conceptual processing after the picture within the ISI of 4.5 s did not impair recognition memory (Potter, 1976). Similarly, Intraub (1980) found that increasing the duration of the blank delay after presentation of pictures from 0 ms to 1390 ms increased recognition scores from 20% to 84%. These findings demonstrated the attention-demanding events that required conceptual processing immediately after the targets were responsible for memory impairments. When attentional resources were not withdrawn, memory performance did not suffer. These results together supported the proposal that scenes were identified rapidly (about 100 ms), but they were forgotten quickly if the additional processing (about 300 ms) after perception was interfered by an attended picture that followed (Potter, 1976).

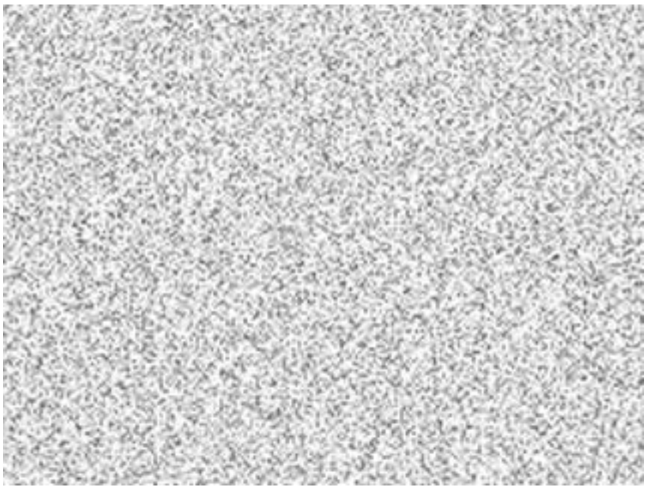

Figure 2.2. An example of a visual noise mask

Viewers might have better memory performance for the pictures that were shown longer because they might have more time for verbal coding (Intraub, 1979). In order to assess the role of implicit naming on memory, mean naming latency of picture lists and presentation duration of pictures were manipulated in a RSVP paradigm. Memory performance in recognition and free recall tests was influenced by presentation duration but not naming latency of pictures. Additionally, the correlation between naming latency and memory performance of pictures was not found as significant. Therefore, verbal coding was not the underlying reason for this phenomenon.

The last picture in the RSVP sequence was remembered better than other pictures (recency effect), showing the importance of masking for disrupting the consolidation process (Potter & Levy, 1969). Hines (1975) proposed that the last visual stimulus was transferred directly to long-term memory but not supported by verbal rehearsal or visual short-term memory mechanisms, because the recency effect was not affected by an intervening unfilled 30-s delay, an intervening 30-s visual copying task, or an intervening 30-s copying or a counting task. Hanna and Loftus (1992) found that the last item was not remembered better than the other items in the sequence, if participants were given sufficient time (e.g. 1200 ms) to process all of the pictures. However, recency effect was observed when subjects had inadequate amount of time (e.g. 400 ms) to process the pictures.

In a different task, Inui and Miyamoto (1981) presented line drawings, each portraying a stage in an episode. Four related pictures were shown consequently in a rapid fashion to explain a coherent meaningful event. The ordering of drawings in temporal sequence was either correct or incorrect. Participants' task was to decide the accuracy of the order of pictures in different SOAs. SOA is the time between onset of one stimulus and onset of the following stimulus. Correct identification of the sequence of the pictures was 19% in the 200 ms SOA condition, whereas performance was 75% in the 450 ms SOA condition, suggesting that subjects could not create the meaning of related pictures when the stimuli were presented in a rapid stream. Taken together, several evidence from RSVP paradigm showed that if representations activated by perception were not engaged in further processing, they could be easily lost due to interference (Potter et al., 2002).

2.3.2 Evidence from the Masking Paradigm

Evidence from the masking paradigm further supports the existence of the short-term consolidation process. In their study, Loftus and Ginn (1984) presented masks after picture targets displayed for 50 ms. They manipulated mask luminance (bright, dim), delay between pictures and masks (0 ms, 300 ms), and attention demand of masks (low attention demand, high attention demand) to examine how memory performance was influenced by these variables. Increasing attentional requirements of masks by using changing naturalistic photographs rather than using noise patterns reduced memory performance when the SOA between the offset of the pictures and masks was 300 ms. No effect of attention demand was obtained when masks were shown with no delay. On the contrary, luminance but not attention demand of the masks influenced picture memory when masks were presented immediately after the targets. These results showed that mask luminance influenced perceptual processing when masks were presented 50 ms after the onset of the visual stimuli, whereas attentional demand influenced conceptual processing when masks were presented 300 ms after the onset of pictures (Loftus & Ginn, 1984; Loftus, Hanna, & Lester, 1988).

In order to explore the effect of attention required by the mask on memory performance, Intraub (1984) presented pictures for 112 ms with a 1.5 s ISI. Either a repeating picture, a new picture, or a black screen was shown during this ISI. A deficit in memory performance was observed for novel pictures but not for repeating pictures. To examine whether novelty or meaningfulness of masks was responsible for the drop in memory performance, a new picture, a repeating picture, a nonsense picture, or a new picture that was inverted was used as mask. A new picture but not the other types of masks disrupted recognition memory, suggesting that a meaningful but not a novel picture acted as a conceptual mask interrupting consolidation of visual stimuli.

Hines and Smith (1977) presented random shapes rapidly followed by three kinds of masks: shapes, digits, or line grids. Subjects were required to either report the masks or ignore them. The interval between onset of the stimuli and masks was also manipulated. They found that attended shape masks and attended digit masks impaired recognition of random shapes to almost chance levels if total processing time for random shapes was about 100 ms. However, when the total processing time was increased, the masks were less disruptive of recognition performance. Neither ignored masks nor grid masks had an impact on memory, indicating that meaningfulness of mask was influential for the effectiveness of distractors. These findings are quite consistent with those of Intraub (1984).

Vogel, Woodman, and Luck (2006) used masks to interrupt the consolidation of visual information. "The masks were intended to disrupt processing after perceptual analysis was largely completed but before the representations had been consolidated" (p. 1439). Each trial included a memory array of colored squares, followed by a pattern mask at varying SOAs, and finally a test array (see Figure 2.3). Participants were asked to detect whether there was a change in the memory and test arrays or not. As the SOA between the memory array and the mask increased, performance in the change detection task improved and finally reached asymptote. The larger the memory array, the more processing time was required for consolidation of items. More time was needed to arrive at asymptotic performance when a further item was added to the memory array. This is a sign of the limited capacity of consolidation process. If the representations in working memory (WM) are consolidated, they can survive long periods of time. If they are not consolidated, on the other hand they will decay in a few hundred milliseconds.

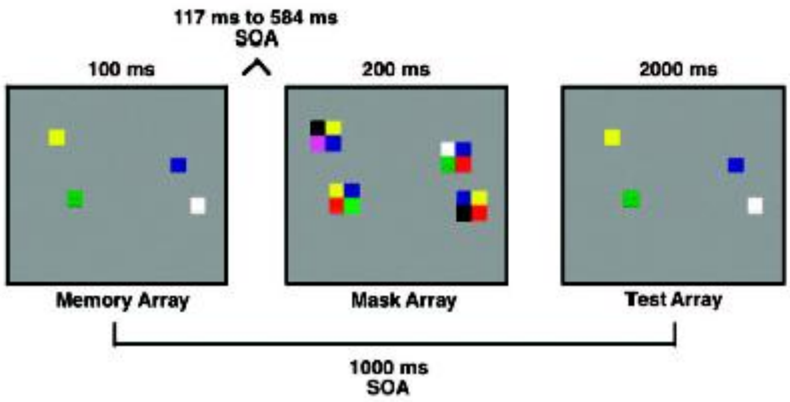

Figure 2.3. The masking paradigm (Vogel et al., 2006)

In order to rule out the possibility that masks impaired perception, Vogel et al. (2006) administered a visual search task to participants. Participants were very successful in the search task, indicating that consolidation but not perception was damaged by masks. Longer SOA was needed to reach asymptotic performance with larger array sizes. This may be as a result of higher possibility of making a decision error when more items had to be evaluated. This issue was examined by contrasting performance of subjects who were instructed to detect the change in the item that was cued at the end of the trial and who were given no cue. The participants in the no-cue condition needed to perform the task for the all the items in the array, whereas the participants in the cue condition needed to make a decision just for a single cued item. No significant difference between the no-cue and the cue conditions was found, indicating that decision processes were not influential for disparity of time courses for reaching asymptotic performance levels.

Ward, Duncan, and Shapiro (1996) examined how long identification of one object interfered with identification of a second object. In order to measure "attentional dwell time" (Duncan, Ward, & Shapiro, 1994), they presented only two objects sequentially followed by pattern masks with varying the SOAs between the objects. They found that interference of the first object on the second one lasted about 500 ms. When participants were instructed to identify only one item, no interference was observed. These findings showed that interference was not a result of perceptual masking but rather attention paid to the first object. Costs increased as the number of attended objects was increased but not as the number of to-be-reported attributes of an object increased, indicating that interference was a result of processing resources consumed for identifying objects.

Several studies have found that performance reached asymptotic level when masks are presented after the completion of the short-term consolidation process. For instance, Avons and Philips (1980) found no more enhancement in remembering novel visual patterns that were masked when poststimulus processing time was increased from 400 ms to 2700 ms. Similarly, Kikuchi (1987) showed that a mask was no longer effective if presented 500 ms after the target random dot patterns. Performance in the change detection task did not improve anymore when the consolidation of the array of colored squares was completed (Vogel et al, 2005). In sum, these results suggest that presenting masks after targets impairs memory performance. However, there is no consensus whether meaningful masks or neutral masks cause this impairment.

2.3.3 Evidence from Attentional Blink Phenomena

In addition to RSVP and masking paradigms, attentional blink (AB) phenomena provided evidence for the important role of attention and time interval between attention-demanding events for the consolidation process. In AB paradigm, stimuli were presented rapidly at rates of approximately 10 stimuli per second (see Figure 2.4). Participants were given two tasks. For instance, the first task was identifying a letter whether it was "a", "b", or "c" and the second task was detecting whether an "x" was presented in the stream. When two targets were presented among distractors in RSVP, identification of the first target (T1) caused an impairment of reporting the second target (T2) if it appeared within 200–500 ms (Broadbent & Broadbent, 1987; Weichselgartner & Sperling, 1987; Raymond, Shapiro, & Arnell, 1992). However, there was no impairment in detecting T2 when participants were told to ignore T1 and to just report T2 (Chun, 1997), indicating that attentional blink stemmed from the attention to the first target. In addition, AB was reduced or eliminated when the item immediately after T1 was replaced by a blank interval (Raymond et al., 1992, Chun & Potter, 1995). If the second target was the last item in the stream, no attentional blink was observed (Giesbrecht & Di Lollo,1998), This shows that visual masking of the second target was a necessary condition for the attentional blink phenomena.

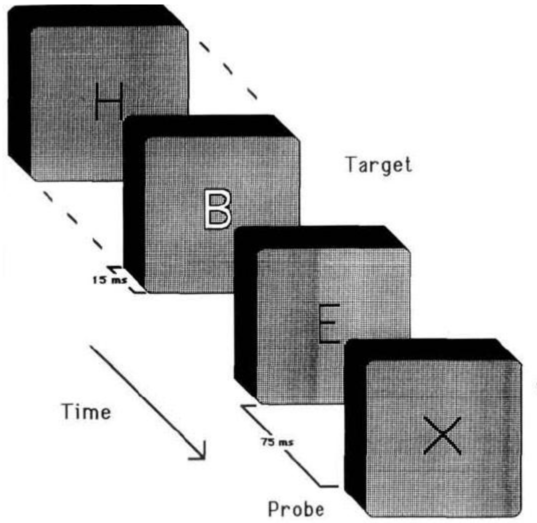

Figure 2.4. Attentional blink paradigm (Shapiro, Raymond, & Arnell, 1994)

Manipulations that influenced the consolidation of T1 were shown to affect AB. Christmann and Leuthold (2004) varied first target's contrast to examine the influence of the difficulty of processing the first target on the magnitude of attentional blink. The accuracy of identifying T2 was smaller when stimulus contrast was lower. These findings indicated that when the perceptual processing of the first target was more demanding, it was harder to consolidate this information. Increasing the duration of processing for T1 was associated with longer delay for consolidation of T2. As a result, T2 would have higher probability of decay (Chun and Potter, 1995). Chun and Potter's two-stage model of the attentional blink phenomenon proposed that the consolidation stage following the first stage of perception was limited in capacity such that only one process could be accomplished at a time. Chun and Potter suggested that the problem was a result of the lack of sufficient resources for the consolidation of the second target when the processing resources were used by the first target. More recently, Dux and Harris (2007) found that changing the orientation of T1 increased the magnitude of AB, because they reasoned that consolidation of misoriented information needed more processing resources.

Visser (2007) explicitly measured T1 processing time to examine the relationship between the difficulty of T1 and the magnitude of AB. When response times of T1 were longer because of the difficulty of the size discrimination task, AB was larger. The magnitude of AB increased with the set size of the target letters (Visser 2007). The interference of the first target on the second target was more severe when T2 required speeded responses rather than unspeeded responses (Jolicoeur, 1999b). Besides, the AB deficit was more severe when T1 required the subject to report both size and letter identity than only size or only letter identity (Jolicoeur, 1999b). Similarly, Evans and Treisman (2005) found that when participants were given a detection task instead of an identification task, the attentional blink was attenuated. The detection task included responding whether a target category (e.g. animals, vehicles) was present in the stream without reporting its identity (e.g. rabbit), whereas the identification task included reporting the name of the target they was seen. They proposed that the detection task made minimal demands on attention whereas the identification task required focused attention for binding features.

AB also occurs when subjects were given only one task. The viewers were presented photographs in a RSVP stream and asked to detect a rotated picture among upright pictures (Most, Chun, Windders, & Zald, 2005). The target was preceded by either a neutral or an emotionally negative picture. The automatic attraction of attention by irrelevant emotional pictures caused an impairment for detecting the target up to 800 ms. Dolcos and McCarthy (2007) argued that activations in amygdala and ventrolateral prefrontal cortex by emotional distractors interfered neural activity in dorsal neural structures which were responsible for maintaining task relevant information in WM.

2.3.4 Evidence from the Dual-task Paradigm

The dual-task paradigm has been frequently employed to examine whether short-term consolidation is responsible for interference between encoding of visual information and concurrent processing of another task when both tasks require central mental resources (Jolicoeur, 1999a, Jolicoeur & Dell'Acqua, 1998; Jolicoeur & Dell'Acqua, 1999; Stevanovski & Jolicoeur, 2007). A visual stimulus containing characters (letters or symbols) were presented first followed by an auditory tone at different stimulus onset asynchronies (Jolicoeur & Dell'Acqua, 1998). The two tasks were presented in different modalities to avoid peripheral limitations. Participants were asked to make a speeded response in the auditory discrimination task and then to recall the visual stimulus without any time limitation (see Figure 2.5). Response times to the tones (T2) increased as the SOA was decreased and this effect was larger when more letters had to be encoded, showing that short-term consolidation needed central resources. Response times was not affected anymore by changing the SOA between T1 and T2 after some time (about 500-700 ms), indicating that slowing was observed during the consolidation process of T1.

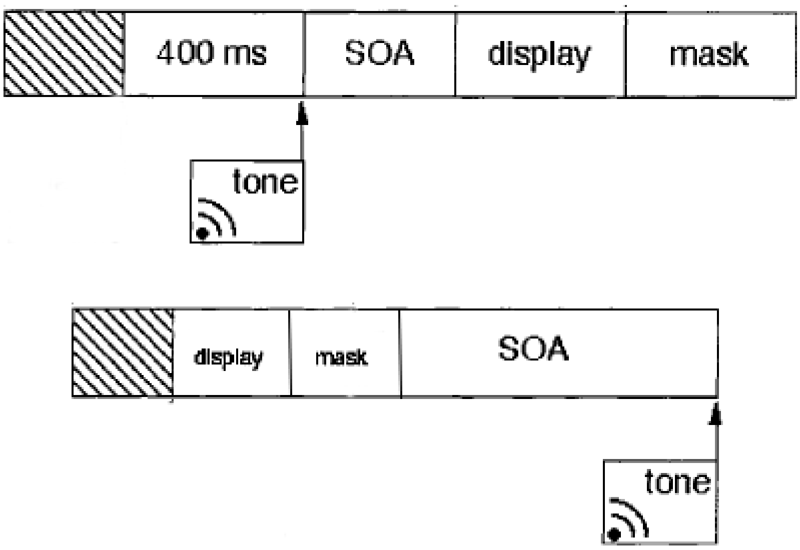

Figure 2.5. Dual-task paradigm in which tone is followed by visual stimulus and visual stimulus is followed by tone (Jolicoeur & Dell'Acqua, 1999)

Slowing of the tone task at short SOAs was not observed when participants ignored the visual stimulus. This indicated that the interference did not stem from presentation of visual stimuli. These results together showed that short-term consolidation of the visual stimulus slowed down the auditory task, because processing of the auditory task had to wait until central mechanisms were not used any more by short-term consolidation. These results also suggest that the amodal bottleneck occurs even if the modalities of the two tasks are different (Marois & Ivanoff, 2005). An electrophysiological study provided converging evidence by demonstrating that decreasing SOA produced an increase in P300 (associated with encoding information to working memory and updating contents of working memory) latency (Dell'Acqua, Jolicoeur, Vespignani, & Toffanin, 2005). A positive correlation was observed between the latency of P300 and the reaction time in the second task.

In contrast to previous studies by Jolicoeur and his colleagues, more recent research (Stevanovski & Jolicoeur, 2007) showed that short-term consolidation of larger set size of information did not create greater costs to the other task. Costs associated with consolidation of line color and orientation were not larger than consolidation of just color or orientation (Stevanovski & Jolicoeur, 2007). Minimizing verbal coding by a concurrent articulatory suppression task (i.e. repeatedly saying loudly a speech sound such as "da da da…"), or employing change detection of colored squares presented briefly rather than recall of verbal information eliminated set size effects (Stevanovski & Jolicoeur, 2007). Greater costs associated with larger set size of information in previous studies by Jolicoeur were explained by involvement of verbal coding.

In another kind of dual-task paradigm, an auditory signal was presented first followed by a visual stimulus at varying SOAs (Jolicoeur, 1999a). The shorter the SOA, the lower was the performance of subjects on recalling visual information. This pattern of results was observed only when a pattern mask was shown after the visual stimulus to prevent iconic persistence. The visual information could avoid decay if no mask was used. Jolicoeur and Dell'Acqua found that when the auditory discrimination task was harder (4 tones versus 2 tones), the memory decrement for the visual information was more severe, indicating that consolidation was again limited in capacity.

In a novel dual-task paradigm, Allan and Allen (2005) showed that retrieval of previous events interfered with simultaneous encoding of new information for about 450 ms. Memory performance improved after 450 ms and reached baseline level after about 850 ms. However, encoding was found not to interfere with concurrent retrieval. They claimed that effort associated with retrieving an existing memory trace interfered with forming new memory traces when hippocampal substrates were shared by both retrieval and encoding.

2.3.5 Evidence from Temporal Integration Paradigm

Temporal integration is the process of combining temporarily separated stimuli into an integrated representation. In a typical temporal integration task, participants are presented two dot arrays, each has different cells filled with dots. When the two images are superimposed, the dots will cover the whole space except one cell, or one cell is used twice by the images. The task of the participants is to find this cell. Jiang (2004) utilized this paradigm by manipulating the ISI between the two arrays. He found that presentation of the second array disturbed the representation for the first array when ISI was short (e.g. 250 ms) but not when ISI was long (e.g. 1000 ms). Enhancement of performance was observed as the length of ISI was increased. Asymptote was reached at 500 ms. The temporal window for the disruption of first image was decreased to 200 ms if the second image was ignored, or the second display was attended without the need to memorize it in a search task. Jiang claimed that a period of time was required for the consolidation of the first array and this process was very open to disruption by following images. This period of time was expanded if both images needed to be remembered. These results suggest that the consolidation of spatial locations takes about 200-500 ms into a stable memory representation.

Temporal integration in face perception was investigated by Anaki, Boyd, and Moscovitch (2007). They horizontally divided famous and nonfamous faces into three parts and presented these parts sequentially with varying intervals. Each face part was presented very briefly (i.e. 17 ms). Performance in the temporal integration task impaired when the interval between parts was 400 ms, but not when this duration was 700 ms, indicating that representations could be consolidated when the interval between face parts was 400 ms. However, the stimuli presented very briefly decayed and consequently a united percept could not be formed when the interval between the parts was 700 ms.

2.3.6 Evidence from Induced Retrograde Amnesia

Presentation of a distinctive item in a list consisting of similar items leads superior memory performance of the deviant item, known as von Restorff effect (1933; cited in Fabiani & Donchin, 1995). On the other hand, previous research has demonstrated that facilitation of an event in a list by making it more distinctive (Detterman, 1975) or asking subjects to give more emphasis on it reduced long-term memory for the preceding item (Tulving, 1969, Guynn & Roediger, 1995). Tulving requested subjects to give high priority to specified targets in word lists. Subjects were asked to search for names of famous people in lists that included one name of a famous person and fourteen neutral words. Interestingly, he found that one or two words immediately before the famous word were recalled at a very low rate compared to the other words. This memory impairment is called induced retrograde amnesia. Induced amnesia is “an experimental analog to clinical amnesia” (Detterman & Ellis, 1972, p. 308). When the presentation rate is reduced to 2 seconds per word from 0.5 or 1 second per word, the drop in memory for the preceding words disappears. Tulving reasoned that the high-priority event consumed processing resources and suggested that “the high-priority item prematurely terminates the encoding of the immediately preceding item and therefore impairs its trace formation" (Tulving, 2001, p. 15). Shultz and Straub (1972) argued that high-priority events stopped continuing consolidation of the preceding item.

In order to determine the role of suppression of rehearsal in induced retrograde amnesia, Detterman and Ellis (1972) gave specific instructions to participants for minimizing rehearsal. This manipulation did not influence retrograde amnesia, suggesting that the inability to rehearse the preceding item was not responsible for induced amnesia. The priority instructions themselves may be the underlying reason for this effect. Saufley and Wingrad (1970) tested this possibility by contrasting performance between groups that were given priority instructions and groups that were administered no priority instructions. Similar performance was found between these groups, supporting the view that retrograde amnesia was not caused by priority instructions, but rather "the effect is attributable to processes during list presentation" (p. 150). The critical items may interfere with the perception of the preceding item. This hypothesis was tested by inclusion of a two-choice forced detection task during list presentation (Detterman, 1975). The results showed that perception failures were minimal in the detection task.

In addition to making an item distinctive in a list, more recent research has demonstrated that emotion can also impair memory for preceding and succeeding neutral words (MacKay, Shafto, Taylor, Marian, Abrams, & Dyer, 2004; Hadley & MacKay, 2006). Hadley and MacKay presented taboo words and normal words at fast (5 words per sec) or slow rates (1 word per sec). Taboo words interfered with encoding of adjacent neutral words only when the words were presented rapidly. MacKay, Hadley, and Schwartz proposed that emotional stimuli attract attention, and consequently there was less attentional resources available for the encoding of adjacent stimuli (2005).

2.4 The Central Capacity Theory

The central capacity theory (Kahneman, 1973; cited in Johnson & Proctor, 2004) proposes that human beings have a limited amount of processing resources that can be allocated to different processes and tasks. Each task consumes some attentional resources proportional to the difficulty of the task. When the demands of the tasks on this common pool of attentional resources exceed the available capacity, performance suffers. The central capacity is shared among tasks. A difficult task will use lots of attentional resources and consequently it will leave little processing capacity for another task to be performed at the same time.

The central capacity theory suggests that attentional resources are divided among tasks that will be carried out simultaneously. Evidence from several studies supported this proposal. Naveh-Benjamin, Craik, Gavrilescu, and Anderson (2000) investigated the effects of decision difficulty and motor difficulty of the secondary task (choice reaction time task) on episodic memory. Increasing the decision difficulty by presenting six choices as opposed to three choices reduced memory performance, but motor difficulty (requiring one press or two presses) had no effect on memory, suggesting that encoding was influenced by concurrent tasks that consumed processing resources. When available the shared pool of processing resources was reduced, participants engaged in shallower levels of encoding (Craik, 1983).

Craik, Govoni, Naveh-Benjamin, and Anderson (1996) manipulated the instructions given to participants such that either the memory task, the secondary task, or both tasks equally were emphasized. The results showed that participants had strategic control of their processes and that paying less attention to the memory task resulted in poorer memory performance.

A positron emission tomography (PET) study by Shallice, Fletcher, Frith, Grasby, Frackowiak, & Dolan (1994) demonstrated that impaired performance in episodic memory by the difficult secondary task compared to the easy one was associated with inactivity in left inferior prefrontal cortex which was responsible for deep semantic processing. Divided attention reduced left prefrontal and medial-temporal activity for both young and older adults (Anderson, Iidaka, Cabeza, Kapur, McIntosh, & Craik, 2000). They reasoned that the divided attention manipulation reduced attentional resources for episodic encoding, consequently participants could not engage in elaborative processing of semantic information which was evident in diminished activity in left prefrontal cortex. Taken together, converging evidence suggested that divided attention during encoding impaired memory performance because, subjects did not have enough processing resources for deep semantic processing, so they rather shifted to shallower processing (Craik, 2001; Naveh-Benjamin, 2002).

A sign of greater necessity of attentional resources for consolidation of information compared to other encoding processes such as perception and elaboration was provided by Naveh-Benjamin, Guez, and Sorek's (2004) study. They presented the secondary task at different temporal segments either during the first, the middle, or the last 2 seconds. They found that dividing attention during each phase of encoding decreased memory performance, but the interference was greatest during the first 2 seconds.

Divided attention during encoding is associated with large reductions in memory performance (Craik, 2001). However, costs of divided attention at retrieval are minimal on memory (Anderson, Craik, & Naveh-Benjamin, 1998; see also Fernandes & Moscovitch, 2003). Memory costs are largest in free recall, intermediate in cued recall and least in recognition tests. The effects are larger on responses based on recollecting contextual detailed information related with the event than on sense familiarity without explicit recollection (Yonelinas, 2002). Divided attention decreases conceptual priming but not perceptual priming (Mulligan, 1998). These results suggest that divided attention is disruptive on controlled processes that need great amount of attentional resources but not on automatic processes.

2.5 Event-related Potentials

Imaging methods such as PET and functional magnetic resonance imaging (fMRI) have been widely used in cognitive neuroscience to reveal detailed anatomical structures associated with cognitive processes in the brain (Hillyard, 1999). However, these methods have a limitation in showing temporal properties of the cognitive operations (Hillyard & Anllo-Vento, 1998). Event-related potentials (ERPs) provide precise time resolution of brain activity in the order of milliseconds in a non-invasive way at a low cost from multiple locations in the scalp (Hillyard, Anllo-Vento, Clark, Heinze, Luck, & Mangun, 1996; Otten & Rugg, 2004; Luck 2005). On the other hand, the locations of neural activations in the brain can only be estimated in ERP, but these locations can be explicitly visualized in fMRI and PET (Hillyard & Anllo-Vento, 1998). ERPs also enable observation of covert processing without the need of any overt response (Kotchoubey, 2006).

ERPs are transient changes in electrical potentials in the brain that are time-locked with cognitive processes (Hillyard & Anllo-Vento, 1998, Picton, Lins, & Scherg, 1995). In contrast to spontaneous electroencephalography (EEG) rhythms, ERPs can be associated with physical stimuli or with endogenous physiological processes when no external stimulus is present (Picton & Stuss, 1993; Luck, 2005). These are called evoked potentials and emitted potentials, respectively. Several components are included in an ERP waveform. These waves indicate functionally different cognitive processes such as perception, comprehension, and response selection (Munksgaard, 2007). ERP components are categorized based on their polarity whether it is positive or negative and the time latency of their peak from the onset of the stimulus (Bressler, 2002). For instance, P300 is a positive wave that has a peak 300 ms after the appearance of the stimulus.

The neural sources of ERPs are postsynaptic potentials, not action potentials in neurons. Action potentials are spikes of voltage that propagate electrical impulses from beginning of the body of the nerve cell to the axon terminals. Action potentials are created one after another, so the net voltage recorded from a surface electrode is very small. If neurons don't send action potentials in parallel, potentials will not accumulate, hence will not be detected from the surface. Contrarily, postsynaptic potentials can be recorded by electrodes if they occur nearly at the same time and if the neurons are spatially aligned. The flow of ions to postsynaptic terminal as a result of release of neurotransmitters from the presynaptic terminals causes a voltage change. As a result, a dipole is created having a specific direction like a vector. A dipole has two poles, a positive and a negative electrical charge which are close to each other. The duration of a postsynaptic potential is about hundreds of milliseconds, whereas for action potentials this duration is nearly a millisecond. If several postsynaptic potentials are created in neighboring neurons at nearly the same time and if spatial orientations of dipoles are not in opposite to each other, then the dipoles of all these postsynaptic potentials will add together (Luck, 2005).

The activity in one electrode can only be measured in reference to another electrode. In order to measure the activity in one electrode, one needs at least two electrodes, an active electrode and a reference electrode, because Voltage is the potential between the active electrode and the reference electrode. The reference electrode should be at an inactive neutral site (Rippon, 2006). The earlobes, the chin, the tip of the nose, the neck, and the mastoid are widely used neutral sites for placing the reference electrode (Luck, 2005). Another method for the selection of the reference is using an average of all the electrodes (Picton, Lins, & Scherg, 1995). It is assumed that the average of all recordings is zero provided that the whole head is covered with sufficient number of electrodes (Luck, 2005).

The spontaneous EEG recordings are the source for ERPs (Munksgaard, 2007). However, it is not easy to successfully extract these small magnitude ERPs (0.1–15 mV) from relatively high amplitude (10–100 mV) EEGs because ERPs have to be distinguished from background EEG that is related with electrical activities produced by the brain while it is performing some other processes (Picton & Stuss, 1993). Averaging repeated events is used as a method to reveal signal from noise (see Figure 2.6). It is assumed that the ERP associated with the event under investigation is constant for every instance, while the noise is random across trials (Luck, 2005). The averaging operation will decrease random noise and reveal the underlying ERP waveform.

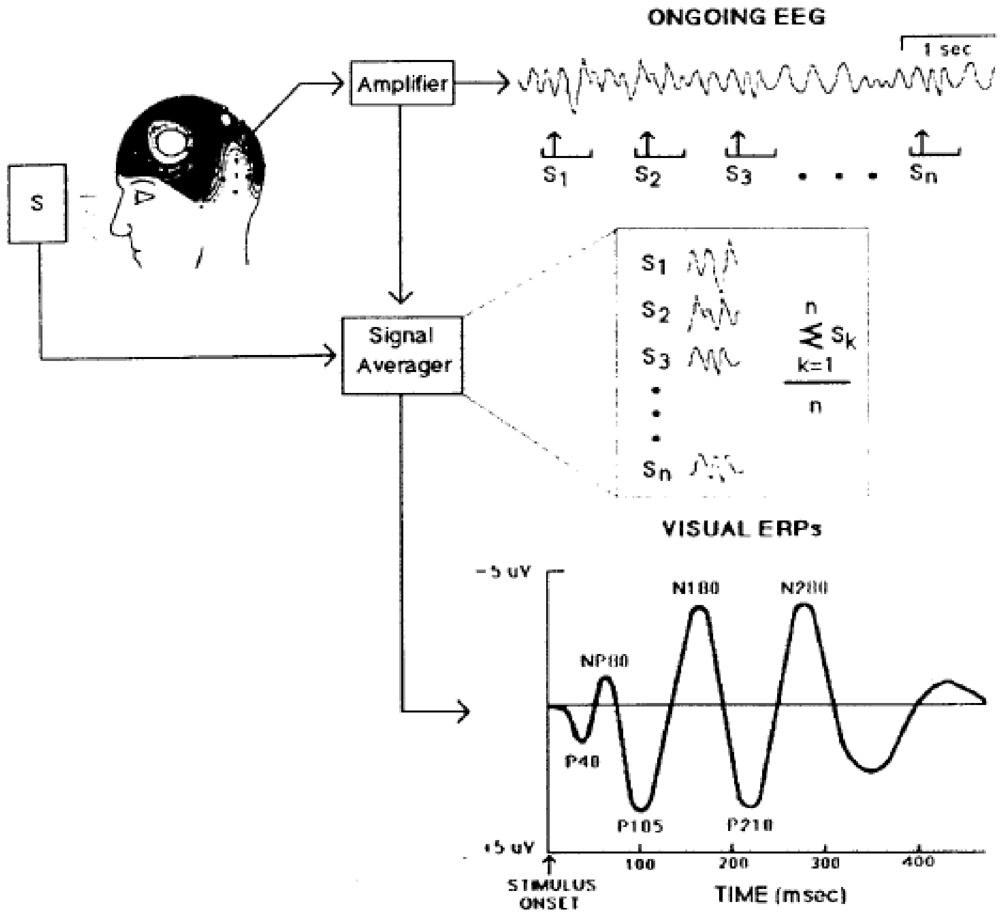

Figure 2.6. Event-related potential technique (Hillyard et al., 1996)

The voltage change that is recorded from the scalp can be contaminated by many sources of artifacts such as the eyes, the muscles of the scalp, neck, and face, electrical noise in the environment, and the skin (Picton, Lins, & Scherg, 1995). Eye movements and eye blinks are measured by placing electrodes close to the eyes

(Rippon, 2006). The distortion caused by the artifacts can be minimized by excluding contaminated trials from analysis and compensating for their influence (Luck, 2005). The procedures for cleaning data are called artifact rejection and artifact correction, respectively. The electrical noise in the environment mostly stems from AC line current and video monitors (Luck, 2005). Electrical noise can be minimized if the experiments take place in an electrically shielded chamber.

A typical ERP system consists of a computer for presenting stimuli, sending triggers, and collecting behavioral responses, a signal amplifier, a computer for recording the EEG, and electrodes (Munksgaard, 2007). Triggers are sent for ensuring when each event occurs (Luck, 2005). These triggers will be used later for averaging EEG data. The amplifier is used to receive the analogue EEG gathered from the electrodes, amplify the weak EEG signals, and convert the analogue data to digital format (Munksgaard, 2007). One computer that has high disk capacity is needed for recording EEG signals.

The electrodes should be kept in place in standard positions mechanically by elastic cap or by adhesive materials such as double-sided glued collars. The Ten-Twenty system formed by Jasper (1958; cited in Picton, Lins, & Scherg, 1995) is utilized to compensate for size and shape differences of the heads. The system is based on putting the electrodes at 10 percent and 20 percent of lines between some reference points (the nasion, the inion, and the left and right pre-auricular points). The scalp has to be prepared before placing the electrodes in order to reduce the impedance (resistance) of the scalp. Otherwise, high impedance will distort the data. The hair under the electrodes should be swept by mechanical pressure for avoiding disconnection between the electrodes and the scalp. The skin under the electrode should be abraded by a blunt needle or some abrasive paste to remove the dead skin layer on the scalp. Electrodes need to be disconnected from the skin by sponges or plastic housings in order to eliminate the contamination of data by the movement of the electrodes. These sponges or plastic housings are filled by electrolyte paste or electrolyte gel for transmission of electricity between the electrodes and the scalp (Picton, Lins, & Scherg, 1995).

Signals are collected at predefined sampling rates (Rippon, 2006). For instance if the sampling rate is 100 Hz, a new signal is gathered in every 10 ms. The higher is sampling rate, the higher will be the resolution of the signal in time domain. The analog signals are translated to digital format by analog-to-digital converter device (Luck, 2005). If the analog-to-digital converter has a resolution of 12 bits, then analog voltage fluctuations are converted to nearest integers between 0 and 2^{12}-1 (Picton, Lins, & Scherg, 1995). Amplifier gain is the amplification factor. Most ERP waveforms contains frequencies of interest between .001 Hz and 30 Hz, so the data can be cleaned by applying high-pass and low-pass filters (Luck, 2005). For instance, high-pass filter can decrease the disruptive effects of large gradual shifts in voltage attributable to skin potentials due to sweating. Sinusoidal oscillations at 50 Hz or 60 Hz due to AC line current can be attenuated by the help of low-pass filters (Luck, 2005).

2.5.1 Major ERP Components

P1. One of the most major ERP components is P1. This visual evoked potential can be best identified from lateral occipital electrodes with a peak between 100-130 ms (Luck, 2005). P1 is larger when participants are focusing their attention on the location of the stimulus than when participants are ignoring the location of the stimulus (Hillyard et al., 1998). In addition to sustained attention experiments, visual search studies showed that P1 amplitude was higher for targets distinguished by color compared to distractors (Luck, Fan, & Hillyard, 1993). The latency of P1 wave depends on stimulus contrast (Luck, 2005).

N1. N1 component generally occurs after P1 for visual stimuli. It can be best detected from occipital electrodes. Similar to P1, N1 has higher amplitude with identical waveform and scalp source in a focused attention condition compared to an ignore condition (Mangun, Hillyard, & Luck, 1993), suggesting that attention influences early sensory coding of visual stimuli (Luck & Hillyard, 1999). Sensory evoked potentials of P1 and N1 are larger when cues about the location of targets are correct than when the cues are incorrect (Mangun & Hillyard, 1991). Taken together, the results on P1 and N1 show that these early sensory evoked potentials are related to perceptual processing of visual stimuli (Luck et al, 2000).

P300. P300 component has maximum amplitude on central parietal electrodes with a latency between 300 and 600 ms after stimulus onset (Rugg, 1996). The latency of P300 increases as the task becomes harder to accomplish (Kutas & Donchin, 1978, cited in Kutas, 1988). The amplitude of this wave is larger as the participants put more effort to the current task, supporting the proposal that P300 is an indicator of mental resources allocated to the task (Isreal, Chesney, Wickens, & Donchin, 1980). P300 becomes larger for novel and infrequent targets (Luck, 2005). When a new stimulus is encountered, the current neural representational environment in the working memory is updated (Polich 2007). It is proposed that P300 indexes this contextual updating (Donchin, 1981).

P550. P550 is a late ERP component that can be observed in parietal sites. Mangels, Picton, and Craik (2001) suggest that this wave is associated with registering of information in medial temporal lobe/hippocampal complex. P550 depends on attentional resources such that when there are not enough resources for the current task, the P550 wave attenuates. Mangels et al. argued that processing of consciously comprehended information in the medial temporal lobe/hippocampal complex triggered a P550 wave.

Sustained Negativity. Sustained negativity is a late slow wave that is best identified in parietal sites. As a mental arithmetic task becomes harder, the negative sustained potential gets larger. The latency of this wave depends on the reaction time of the subject in the arithmetic task (Ruchkin, Canoune, Johnson, & Ritter, 1991). Sustained negativity is affected neither by attention paid to the task nor by stimulus duration (Stuss, Sarazin, Leech, & Picton, 1983). Taken together these results suggest that the late slow waves index working memory processes but not attentional or sensory processes (Ruchkin, Canoune, Johnson, & Ritter, 1995; Stuss et al., 1983).

2.5.2 Electrophysiological Evidence for the Short-term Consolidation Process

Electrophysiological studies have provided evidence that there exist a short-term consolidation bottleneck (e.g. more than one information can not be consolidated simultaneously). For instance, Vogel and Luck (2002) found that the P300 wave was suppressed when the second target was followed by a mask in an attentional blink condition. On the other hand, when the second target was the last item in the stream in the no attentional blink condition, P300 was delayed but not suppressed. Luck, Vogel and Shapiro (1996) demonstrated the presence of P1 and N1 components (a sign of intact perceptual processing) and an N400 peak (a sign of accessing word meaning) at a postperceptual stage. They reasoned that meaning could be extracted but could not be reported. This finding was supported by many behavioral studies, which have shown semantic priming from the second target words in AB experiments (Shapiro, Driver, Ward, & Sorensen, 1997; Martens, Wolters, van Raamsdonk, 2002; Visser, Merikle, Di Lollo, 2005)

Converging electrophysiological evidence showed that there was positive correlation between P300 lengthening and RT to the second task lengthening in a dual-task paradigm (Dell'Acqua, Jolicoeur, Vespignani, & Toffanin, 2005). P300 wave was delayed as the SOA between the first task and second task was decreased. Luck (1998) demonstrated that the amplitude of P300 wave was smaller in short SOA conditions compared to long SOA conditions. These findings confirm that the central processing postponement was responsible for the dual-task effects.

CHAPTER 3

EXPERIMENTS

Six experiments were conducted in this study. This chapter presents goals, method, results and discussion of each experiment. Participants, design, materials, and procedures of the experiments are described in the method section of each experiment. The general discussion of the current study will be provided in the next chapter.

3.1 Experiment 1

There were two tasks in Experiment 1. The primary task was to study the pictures for a subsequent memory test. The secondary task was a continuous auditory choice-reaction time (CRT) task. Participants were required to press one of two keys associated with either the low-frequency tone or the high-frequency tone in the CRT task (Naveh-Benjamin et al., 2003). After the subject's response, the next tone was presented immediately in a continuous fashion. The goal of Experiment 1 was to find out whether presenting an attention demanding secondary task during the short-term consolidation process would impair episodic memory and increase secondary task RT. Prior research suggested that participants had an intact perception of the visual stimulus if the SOA between the stimulus and a noise mask was 200 ms. Past research also showed that the uninterrupted processing of about 500 ms was critical for a successful consolidation process. Thus, 200 ms is selected to be an SOA interval that is not enough for consolidation if attention is withdrawn but is enough for an intact perception. On the other hand, 1000 ms is long enough for consolidation process to take place independent of attention. The independent variables were attention and stimulus onset asynchrony (SOA) between the onset of the pictures and masks (200 ms, 1000 ms). The dependent variables were the memory performance of subjects in a recognition test following the encoding phase and secondary task RT.

3.1.1 Method

Participants. Forty-one undergraduate psychology students of University of Toronto (23 female and 18 male) took part in the experiment for extra course credit after providing informed consent. The experiment was approved by Departmental Review Committee (DPERC) of Psychology Department at University of Toronto. All the participants reported normal or corrected-to-normal vision. They were between 17 and 25 years old (*M*=19.45, *SD*=2.00). Twenty of the subjects were randomly assigned to the full attention (FA) condition and the rest were assigned to the divided attention (DA) condition.

Design. The study had a 2 (attention: FA, DA) X 2 (SOA between the onset of visual stimuli and mask: 200 ms, 1000 ms) mixed design with the first variable as a between-subjects variable, and the second one as a within-subjects variable.

Materials. A total of 480 photographs of scenes (see Figure 3.1 for some samples) chosen from a free image archive (www.morguefile.com) with different content were employed in the study. All of the pictures had identical size. They were shown at the center of the screen against a gray background. No picture was repeated in the study phase. Four lists of pictures were used for practice. Two sets each consisting of eight lists of 24 pictures were constructed randomly from this picture pool. The sets were rotated across participants such that each picture was presented equally often as target and as distractor. The presentation order of the pictures in the lists were randomized for each subject. Auditory stimuli that were used only in the DA condition were pure tones presented for 100 ms at a frequency of 262 Hz or 524 Hz.

Figure 3.1. Samples of stimuli used in Experiment 1

<u>Procedure.</u> The experiment was carried out using a PC that had a refresh rate of 100 Hz. Participants were tested individually. Presentation of stimuli and collection of responses was controlled by the E-prime experimental software package (Schneider, Eschman, & Zuccolotto, 2002).

Each block in the experiment consisted of three phases: study, filled delay, and memory test (see Figure 3.2). The study phase included 24 trials. Each trial in the study phase included presentation of a fixation sign for 500 ms, a picture for 160 ms, and a random noise mask in color shown for 150 ms (see Figure 3.3). The noise mask was created by Adobe Photoshop 5 software (Adobe Systems, San Jose, CA). The mask was generated by adding a uniform noise filter to a blank image. At the beginning of each block the cue, “Study” and type of delay either short or long was presented in the middle of the screen. Each block was started by the participant with the press of a key. In the short SOA block, the interval between the onset of the picture and the mask was 200 ms whereas it was 1000 ms for the long SOA block. Short and long SOA were received in alternating blocks (i.e. ABAB). The order of the SOA blocks was counterbalanced across participants (i.e. ABAB, BABA). After the onset of the mask, there was a 2000 ms delay until presentation of the next picture. During this delay, participants in the DA condition performed the CRT task.

Participants heard either low or high tones and they were asked to respond to this task as accurately and quickly as possible by pressing corresponding keys on the keyboard. The next tone was presented immediately after the response of the participant in a continuous fashion for 2000 ms. The participants in the FA condition did not hear any tones.

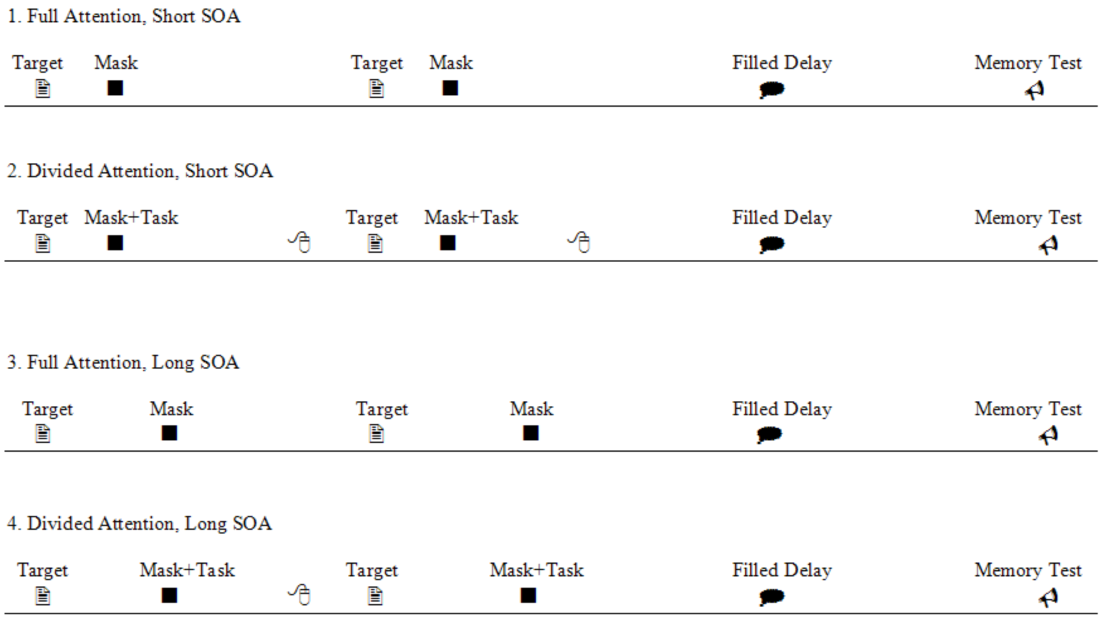

Figure 3.2. General paradigm of the study

After the study phase of each picture list, participants were requested to count backwards by threes from a predetermined three-digit number for 12 sec. Participants were not asked to remember this number. This three-digit number was different in every block. The goal of this filled delay phase was to avoid responses based on primary memory.

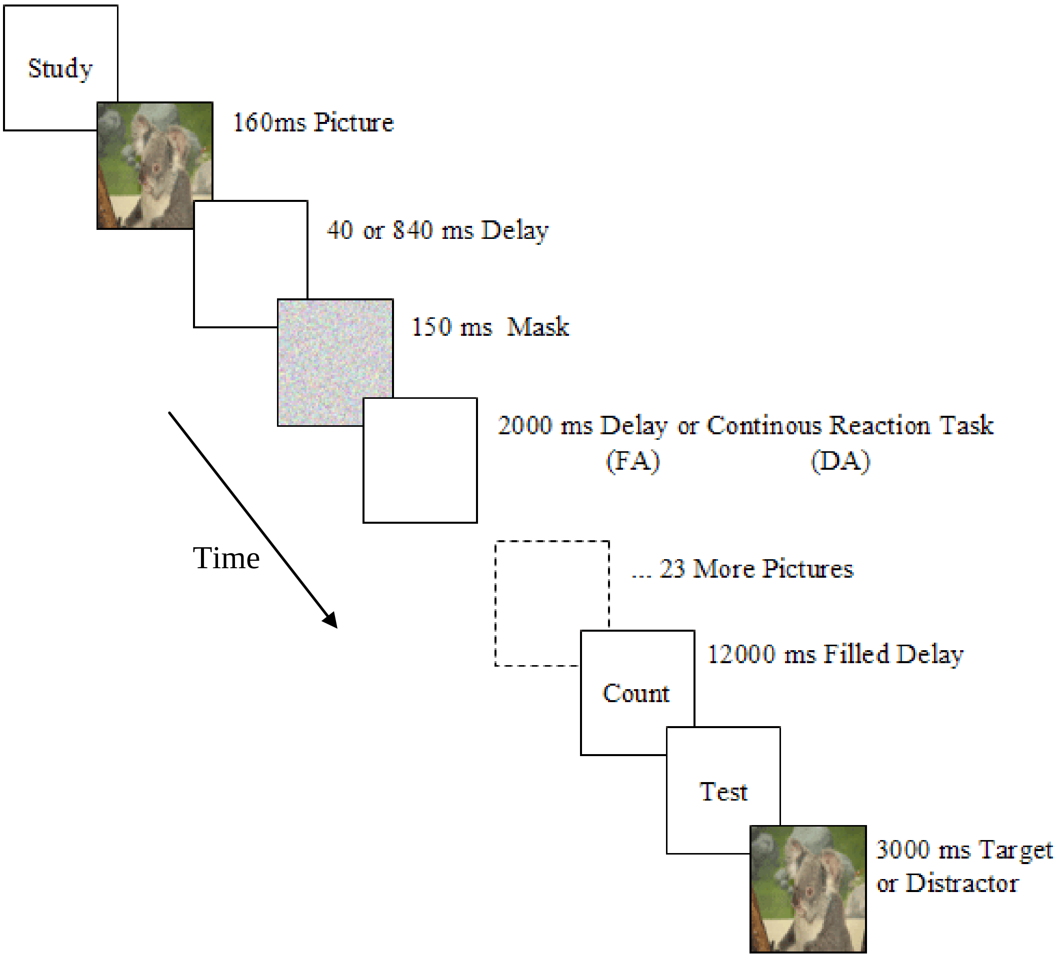

Figure 3.3. Schematic illustration of one block in Experiment 1

In the test phase of the experiment, subjects were shown 48 pictures for 3 sec each. They were asked to indicate whether they recognized the picture or not by pressing one of the two specified keys on the keyboard. Half of the pictures were distractors. Targets and distractors were presented randomly for each subject in the recognition test. The first and the last two pictures from the study list were not taken into account in the data analysis for the recognition test in order not to be influenced by primacy and recency effects.

Prior to the experiment, participants were given two blocks as practice. One of them was a short SOA block and the other was a long SOA block. The practice blocks were identical to the experimental blocks with the exception that after each block in the practice session, participants were given feedback about their performance. Additionally, participants in the DA condition were given 50 practice trails for the CRT task. The practice for the CRT task was administered again if the performance of the subject on this task was lower than 80%. After the practice session, subjects in the DA condition were instructed to respond to the tones as rapidly and accurately as possible. They were told that the memory and secondary tasks were equally important and they were requested to put equal effort into them.

3.1.2 Results

Memory task. Of the 41 subjects who participated in this study, the data of one subject from the DA group was excluded from the analysis because memory performance of that participant was near chance level. Corrected recognition scores were computed by subtracting proportion of false alarms from hits for each participant. A hit is a true positive (pressing "yes" to a target) and a false alarm is a false positive (pressing "yes" to a distractor) response in the recognition test. The chance level performance was at 0, and perfect level performance was at 1.0 for corrected recognition. Average percentages of hits, false alarms and corrected recognition are displayed in Table 3.1. A 2 (attention) X 2 (SOA) mixed factorial analysis of variance (ANOVA) was performed on corrected recognition. The main effect of attention was significant, $F(1, 38) = 12.49$, $MSE=0.035$, $p=.001$. The participants in the FA condition ($M=.81$, $SD=.11$) performed better than the ones in the DA condition ($M=.66$, $SD=.16$). The main effect of SOA was also significant, $F(1, 38) = 7.27$, $MSE=0.006$, $p=.01$. Corrected recognition performance was higher when the SOA was long ($M=.76$, SD=.14) than when the SOA was short ($M=.71$, $SD=.18$). More importantly, the interaction between attention and SOA was significant, $F(1, 38) = 4.14$, $p=.04$, indicating that decreasing SOA impaired memory performance for the DA condition, $t(19) = 2.83$, $p=.01$, but not for the FA condition, $t(19) = 0.56$, $p=.58$ (see Figure 3.4).

Table 3.1. *Recognition Memory Performance in Experiment 1*

Attention	SOA	Hits	False Alarms	Corrected Recognition
Full	Short	.86 (.07)	.06 (.05)	.80 (.12)
Full	Long	.88 (.07)	.07 (.05)	.81 (.11)
Divided	Short	.74 (.09)	.12 (.09)	.62 (.19)
Divided	Long	.80 (.07)	.10 (.09)	.70 (.14)

Note. Standard deviations are shown in parentheses next to means.

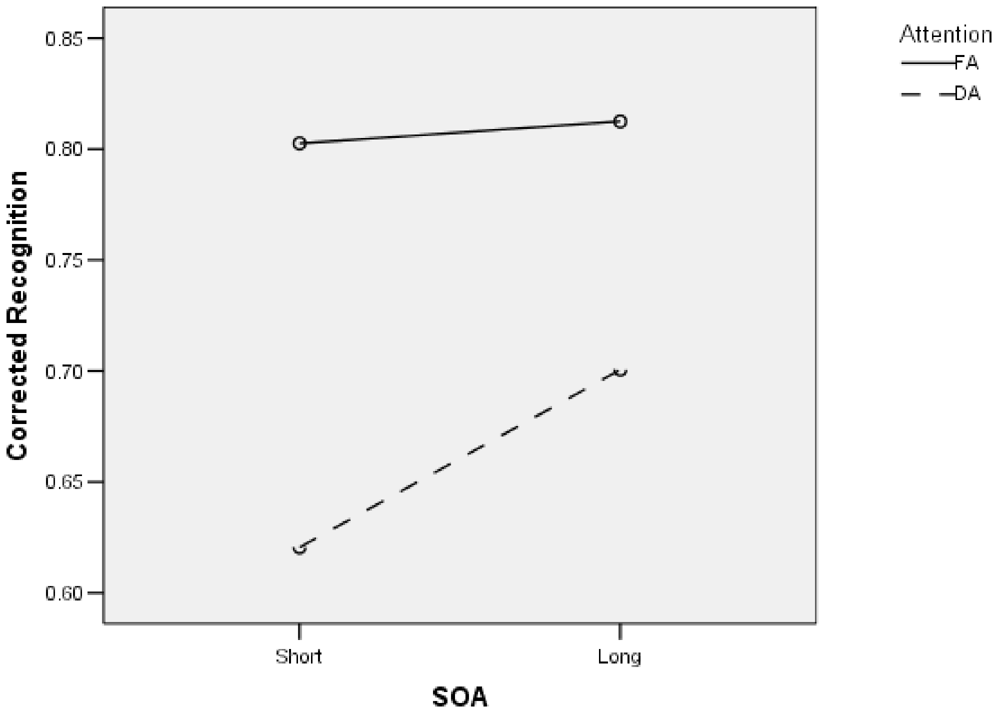

Figure 3.4. Mean corrected recognition performance as a function of attention and SOA in Experiment 1. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

Secondary task. A paired samples *t*-test was performed to examine whether there was a difference in secondary task accuracy between the two SOA conditions. The delay between the picture and mask affected secondary task accuracy, $t(19) = 2.75$, $p=.01$. The average accuracy of responses was only 1% higher in the long SOA condition (M=.94, SD=.07) than in the short SOA condition (M=.93, SD=.07). Although the effect of SOA on RT of correct responses was not statistically significant, $t(19) = -1.25$, $p=.23$, the trend was towards slower RT in the short SOA condition ($M=.322$, $SD=.140$) compared to long SOA condition ($M=.308$, $SD=.112$). Similar results were found when both correct and incorrect responses to the secondary task were included in the analysis.

3.1.3 Discussion

The goal of the first experiment was to investigate the effect of attention and the SOA between the onset of pictures and mask on recognition memory. Attention and SOA interacted, indicating that there was a disruption in memory performance when the interval between pictures and masks was short and subjects had to perform the secondary task after the presentation of the mask. However, presenting the masks earlier had no disruptive effect on memory when subjects were paying full attention to the pictures. The results of the current experiment showed that when the consolidation process was interrupted by an attention-demanding task, performance in recognition decreased significantly. These results demonstrated that when attentional resources were withdrawn by a secondary task (DA conditions), participants had poorer recognition memory in the 200 ms SOA condition compared to the 1000 ms SOA condition as a result of interrupted and intact short-term consolidation in 200 ms and 1000 ms SOA conditions, respectively.

Although the differences were not statistically significant, decreasing SOA was associated with slower responses to the secondary task. Slower RTs in the secondary task can be regarded as a sign of consolidation of information for episodic memory. When the attentional resources are in use by the short-term consolidation of pictures, the secondary task may not be processed immediately and there may be a delay in processing of the secondary task.

These findings also indicated that there was no trade-off between the memory task and the secondary task such that better performance in a task caused a cost on the other. For the current experiment, it can be argued that more effort was spent on the memory task in the long SOA conditions than in the short SOA conditions because of the superior memory performance for the long SOA. However, there was not a slowing in the secondary task performance for the long SOA, ruling out the possibility of a trade-off between the memory and secondary tasks.

3.2 Experiment 2

Recognition memory performance did not increase as the SOA was increased from 200 ms to 1000 ms in the FA conditions in Experiment 1. This may be due to a ceiling effect. Percentages of hits were .86 and .88 in short and long SOA conditions, respectively. Reducing the SOA between pictures and masks in DA decreased memory performance in Experiment 1. However, the percentage of disruption in memory was very low. This may be due to the perceptual distinctiveness of pictures (Nelson, Reed, & Walling, 1976). In order to eliminate these problems, words were utilized as stimuli instead of pictures in Experiment 2. It was expected that memory performance would be lower when materials were words than pictures (Nelson et al., 1976). Using words will also enhance the generalizability of the findings.

Another goal of Experiment 2 was to extend the results of Experiment 1 by using different memory tests and SOAs. For this reason, in addition to a recognition test, a different memory test was administered to measure episodic memory performance. In order to minimize recognition judgments based on assessment of item familiarity (Yonelinas, 2002), a free recall test was employed. Three SOAs were used in this study: 200 ms, 400 ms, and 800 ms. It was expected that memory performance would be lower and dual-task RT would be longer when attention was divided and SOA was 200 ms or SOA was 400 ms than when attention was divided and SOA was 800 ms, because prior research suggested that at least 500 ms was needed for the consolidation process to take place. Memory performance should be similar between different SOAs for FA.

3.2.1 Method

Participants. The participants were 20 students of University of Toronto (14 female and 6 male) students. Half of them were paid and the rest were given extra course credits. An informed consent form was obtained from the subjects. The participants were between 18 and 32 years old (*M*=20.60, *SD*=3.22) and native English-speakers.

Design. The study had a 2 (attention: FA, DA) X 3 (SOA between the onset of visual stimuli and mask: 200 ms, 400 ms, 800 ms) within-subjects design.

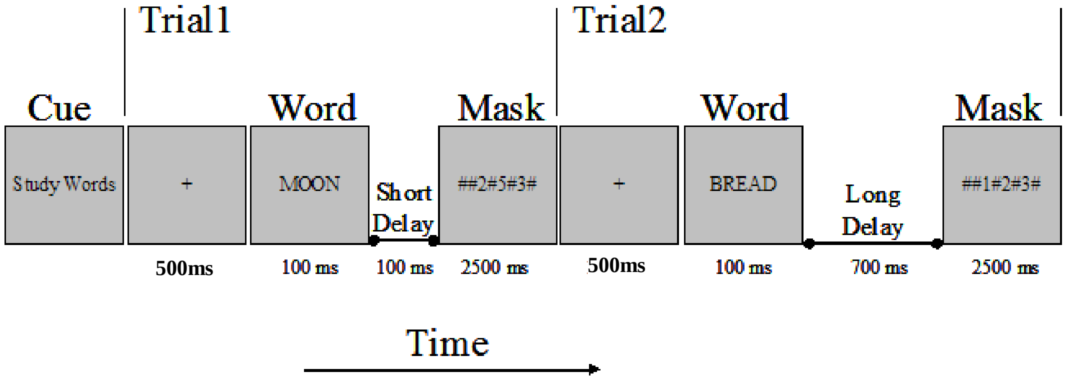

Figure 3.5. Schematic illustration of two trials in a block in Experiment 2

Materials and procedure. The materials and procedure were similar to those in Experiment 1. Instead of pictures, words were used as stimuli in order to decrease the contribution of perceptual details of pictures on recognition memory. The words were selected from the MRC Psycholinguistic Database (Coltheart, 1981). Words were 4-8 letters in length (M=5.07, SD=1.29). Two sets each consisting of 12 lists of 12 concrete noun words were created. An additional 2 lists of words were used for practice. The sets were rotated across participants so that each word was shown equally often as either target or distractor. Word lists were matched for length and Kucera-Francis written frequency (Kucera & Francis, 1967). Written frequency of the word lists were checked by using frequency information of the British National Corpus (BNC) (Burnard, 2000). The BNC is a 100 million words corpus of contemporarily written and spoken British English. The correlation between

Kucera-Francis written frequency and frequency of words in the BNC was significant and the correlation coefficient was high, r=.84, p<.001. Additionally, ANOVA tests were run to examine whether frequency of the word lists was similar or not. The results indicated that there was no significant difference in frequency of words between word lists when Kucera-Francis and BNC frequency data was used, all ps>.92. Two filler words were added to the beginning and end of each list. These 4 filler items were not presented in the in the recognition test to reduce the total duration of the experimental sessions and to minimize primacy and recency effects. The words were shown against a gray background in the middle of the screen.

Three SOAs were randomly intermixed within each block for each participant in order to eliminate subject anticipation and employment of specific strategies (Tversky & Sherman, 1975). In Experiment 1, SOA was manipulated between blocks which caused unequal intertrial interval (ITI) between different SOA conditions. Intertrial interval is the time between two trials. Unequal ITIs might have contaminated the results. In order to prevent these problems, the SOA was varied within a block rather than between blocks. In addition, in order to set up baseline task performance, subjects were required to perform only the secondary task without presentation of words in each DA block. As a result, each DA block consisted of 4 trials with 200 ms SOA, 4 trials with 400 ms SOA, 4 trials with 800 ms SOA, and 4 secondary task only trials intermixed randomly.

Attention was a between-subjects variable in Experiment 1. In the current experiment, attention was manipulated within subjects in order to minimize individual differences across conditions, so each participant was given both FA and DA conditions. Subjects were presented each kind of attention block consequently for three times. The order of attention condition was counterbalanced across subjects. Thus, half of the subjects were given the blocks in either "FA, FA, FA, DA, DA, DA, FA, FA, FA, DA, DA, DA" or "DA, DA, DA, FA, FA, FA, DA, DA, DA, FA, FA, FA" order. The order of word lists was constant across subjects which enabled presentation of each word list equally often in FA and DA conditions.

In the secondary task, participants were shown an array which included three digits between 0 to 6 (e.g. ##1#4#3##). Subjects were asked to decide whether the sum of the digits was divisible by 3 by pressing corresponding keys on the keyboard in 2500 ms. A total of 280 different three digit array was created so that participants saw a novel digit array in each trial. No auditory stimulus was presented.

A PC that had a refresh rate of 100 Hz was used to test each subject individually. The E-prime experimental software package controlled presentation of stimuli and collection of responses. Participants were given the following instructions at the beginning of the study: "Please give higher priority to the digit decision task than to the memory task. Try to respond to the digit decision task as accurately and rapidly as possible. Try to memorize the words, as well". Afterwards, participants were given the opportunity to practice the tasks. At the beginning of each block the cue, "Study Only Words" or "Study Words and Respond to Digits" was presented depending on whether the attention condition of that block was FA or DA, respectively. Each block was initiated by the press of a key. Next a fixation sign was presented for 500 ms. Afterwards 16 words (12 study plus 2 filler words at the beginning of the block and 2 filler words at the end of the block) were presented for 100 ms each, followed by a digit array shown for 2500 ms. The delay between the offset of the word and onset of the digit array was 100 ms, 300 ms, or 700 ms for 200 ms, 400 ms, or 800 ms SOA conditions, respectively. No word was presented in the secondary task only trials. This type of trial included presentation of the fixation sign followed immediately by presentation of a digit array.

After studying each word list, participants were asked to count backwards by threes from a predetermined three-digit number for a duration of 12 sec to circumvent responses based on primary memory. Subjects were given 1 minute for the free recall test. The responses of the participants were recorded by a tape-recorder. Next, the recognition test was administered. The recognition test consisted of 12 targets and 12 distractors plus 4 additional distractors. Additional distractors were used to reduce corrected recognition after obtaining high memory performance in the pilot work. Increasing the number of distractors was expected to increase false alarm rates and consequently decrease corrected recognition. Each word was presented for 3 sec in the test. Targets, distractors, and additional distractors were presented in random order for each participant.

3.2.2 Results

Memory task. Recognition memory performance in Experiment 2 can be seen in Table 3.2. A two-way within-subjects ANOVA was performed to examine the effect of attention (FA, DA) and SOA (200 ms, 400 ms, 800 ms) on corrected recognition. There were significant main effects of attention, $F(1, 19) = 159.54$, $MSE=1.36$, $p<.001$, and SOA, $F(2, 18) = 7.72$, $MSE=0.046$, $p=.002$, as well as a significant interaction between attention and SOA, $F(2, 18) = 3.21$, $MSE=0.019$, $p=.05$. Separate ANOVAs showed a significant effect of SOA on corrected recognition for DA, $F(2, 38) = 9.11$, $MSE=0.007$, $p=.001$, but not for FA, $F(2, 38) = 0.65$, $MSE=0.005$, $p=.53$. Three paired-samples t tests were performed to follow-up pairwise comparisons for the main effect of SOA for DA. In order to control Type I error (rejecting true null hypothesis) across the three tests, Holm's sequential Bonferroni procedure was applied (Green et al., 2000). Differences in mean corrected recognition were significant between 200 ms SOA and 800 ms SOA, $t(19)= -3.35$, $p=.003$, and between 400 ms SOA and 800 ms SOA, $t(19)= -3.09$, $p=.006$. However, there was no significant difference in mean corrected recognition between 200 ms SOA and 400 ms SOA, $t(19)= -1.19$, $p=.25$ (See Figure 3.6).

Table 3.2. *Recognition Memory Performance in Experiment 2*

Attention	SOA	Hits	False Alarms	Corrected Recognition
Full	200 ms	.80 (.13)		.76 (.15)
Full	400 ms	.80 (.15)	.04 (.04)	.76 (.16)
Full	800 ms	.82 (.13)		.78 (.14)
Divided	200 ms	.58 (.17)		.51 (.19)
Divided	400 ms	.62 (.18)	.08 (.06)	.55 (.19)
Divided	800 ms	.69 (.17)		.62 (.18)

Note. Standard deviations are shown in parentheses next to means. Since SOA was manipulated within a block and the recognition test was given after each block, there is only one false alarm rate for the FA condition and one for the DA condition.

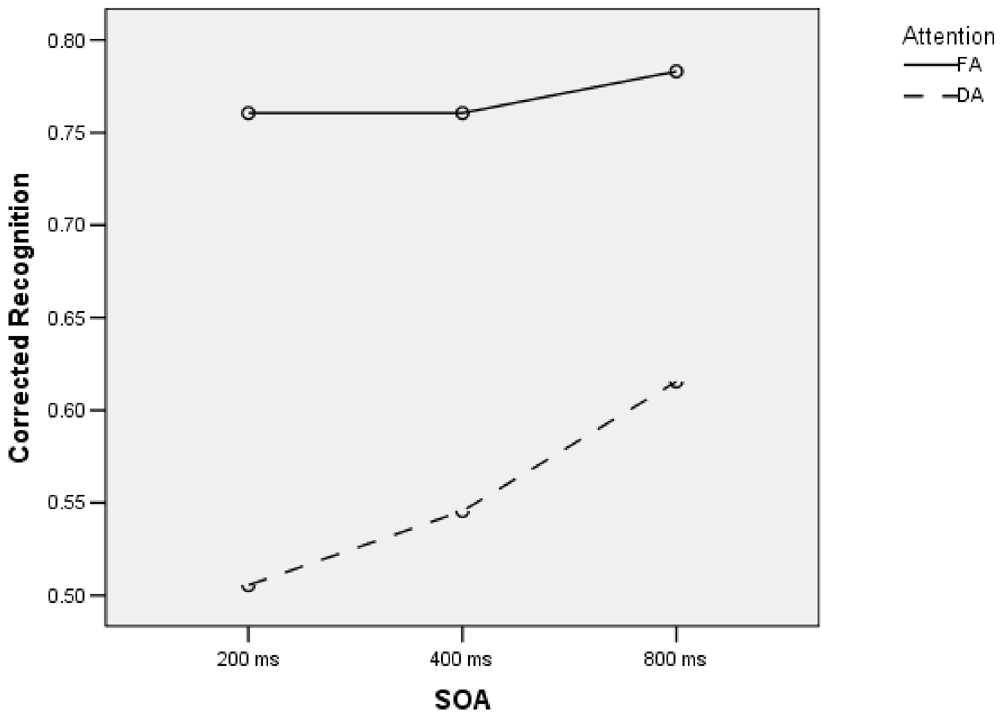

Figure 3.6. Mean corrected recognition performance as a function of attention and SOA in Experiment 2. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

Another two-way within-subjects ANOVA was run to examine the effect of attention and SOA on free recall performance. Results confirmed a significant effect of attention, $F(1, 19) = 99.09$, MSE=0.022, p<.001, and a significant attention X SOA interaction, $F(2, 38) = 7.20$, $MSE=0.048$, $p=.002$, but no significant effect of SOA, $F(2, 38) = 1.38$, $MSE=0.007$, $p<.26$. Separate ANOVAs indicated a significant effect of SOA on free recall for DA, $F(2, 38) = 5.64$, $MSE=0.006$, $p=.007$, but not for FA, $F(2, 38) = 3.32$, $MSE=0.008$, $p=.047$. Three paired-samples *t* tests were conducted to follow-up pairwise comparisons for the main effect of SOA for DA. In order to control Type I error across the three tests, Holm's sequential Bonferroni procedure was applied again. Differences in mean recall were significant between 200 ms SOA and 800 ms SOA, $t(19)= -3.85$, $p=.001$, and between 400 ms SOA and 800 ms SOA, $t(19)= -2.38$, $p=.028$. However, there was no significant difference in mean recall performance between 200 ms SOA and 400 ms SOA, $t(19)= -1.07$, $p=.30$ (see Figure 3.7).

Table 3.3. *Recall Performance in Experiment 2*

Attention	SOA	Recall
Full	200 ms	.52 (.21)
Full	400 ms	.55 (.23)
Full	800 ms	.48 (.20)
Divided	200 ms	.21 (.17)
Divided	400 ms	.24 (.19)
Divided	800 ms	.29 (.15)

Note. Standard deviations are shown in parentheses next to means.

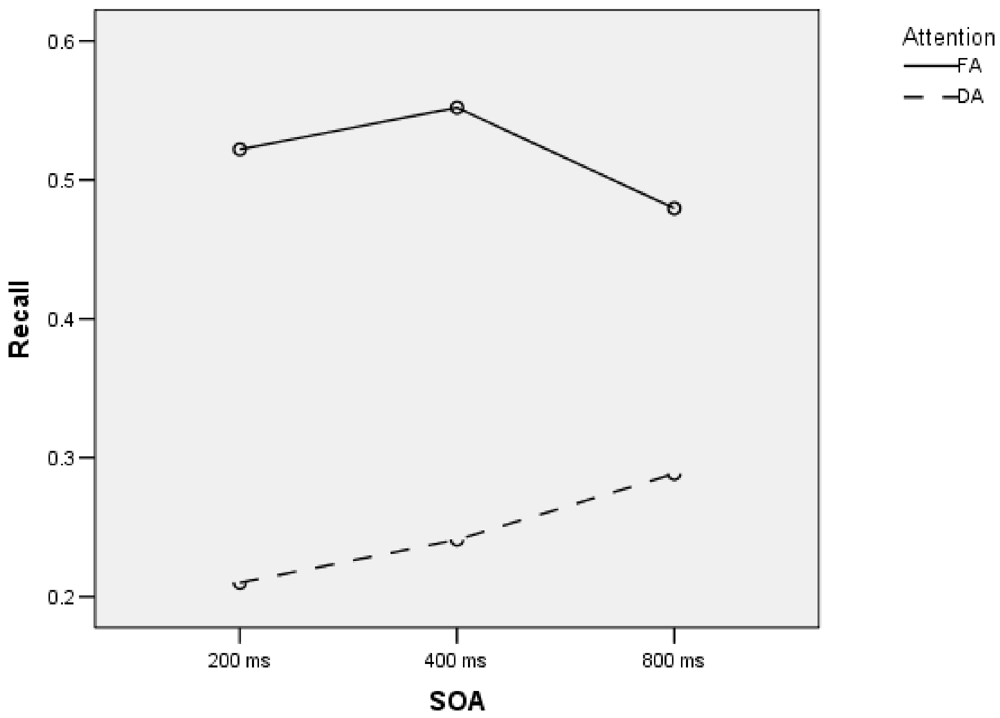

Figure 3.7. Mean free recall performance as a function of attention and SOA in Experiment 2. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

Pearson's correlation coefficients were computed between recognition and recall performance of subjects in each experimental condition. To control Type 1 error across the 6 correlations, a *p* value of less than .008 (.05/6) was considered to be significant with the Bonferroni approach. The correlation was significant between recognition and recall for the 200 ms SOA with FA condition, *r* (18)=.80, *p*< .001, for the 400 ms SOA with FA condition, *r* (18)=.65, *p*= .002, for the 800 ms SOA with FA condition, *r* (18)=.65, *p*= .003, for the 200 ms SOA with DA condition, *r* (18)=.70, *p*= .001, for the 400 ms SOA with DA condition, *r* (18)=.72, *p*< .001, for the 800 ms SOA with FA condition, *r* (18)=.65, *p*< .002. In general, the results suggested that performance in the different episodic memory tests (recognition and recall) used in the current experiment were highly correlated with each other.

Secondary task. A one-way within-subjects ANOVA was conducted in order to assess the effect of SOA on accuracy in the secondary task. The results showed no significant SOA effect, *F*(2, 38) = 0.80, *MSE*=0.007, *p*=.46, indicating that accuracy performance was not different for 200 ms SOA (*M*=.77, *SD*=.15), 400 ms SOA (*M*=.79, *SD*=.17), and 800 ms SOA (*M*=.81, *SD*=.13). A paired samples *t*-test was performed to see whether accuracy in the secondary task when it was done alone (baseline) was different from when it was done with the memory encoding task (mean of three SOAs). The *t*-test was not significant, *t*(19)= 0.27, *p*=.79, indicating that accuracy in the secondary task when it was done alone (*M*=.80, *SD*=.11) was not different from when it was done with the memory encoding task (*M*=.79, *SD*=.13).

In order to examine the influence of SOA on RT in the secondary task, a one-way within-subjects ANOVA was performed. The effect of SOA was significant, *F*(2, 38) = 8.13, *MSE*=9567, *p*=.001. Three paired-samples *t* tests were conducted to follow-up pairwise comparisons for effect of SOA on secondary task RT. In order to control Type I error across the three tests, Holm's sequential Bonferroni procedure was applied again. Differences in mean RT were significant between 200 ms SOA and 800 ms SOA, *t*(19)= 3.44, *p*=.003, and between 400 ms SOA and 800 ms SOA, *t*(19)= 2.63, *p*=.016. However, there was no significant difference in mean RT between 200 ms SOA and 400 ms SOA, *t*(19)= 1.93, *p*=.069. These results imply that subjects were slower in the digit decision task when the SOA was 800 ms (*M*=1642, *SD*=183) than when the SOA was 400 ms (*M*=1576, *SD*=151 or 200 ms (*M*=1517, *SD*=180). A paired samples *t*-test was performed to see whether RT in the secondary task when it was done alone (baseline) was different from when it was done with the memory encoding task (mean of three SOAs). The *t*-test was marginally significant, *t*(19)= -1.83, *p*=.08, indicating that participants were faster in the secondary task when it was done alone (*M*=1515, *SD*=158) compared to when it was done with the memory encoding task (*M*=1578, *SD*=152).

3.2.3 Discussion

The results of the second experiment replicated the results of the first experiment. The interaction between attention and SOA showed that SOA influenced memory performance when attention was withdrawn by the secondary task but not when attention was fully devoted to the memory task. Impairment in memory was evident just for 200 ms SOA and 400 ms SOA for DA but not 800 ms SOA, indicating that participants needed more than 400 ms time to consolidate information. When attentional resources were consumed by another task within 400 ms, consolidation process was interrupted and consequently subjects had poorer memory performance.

A slowing was detected in the secondary task in the 800 ms SOA condition with respect to the other SOA conditions. This result was in contrast to the short-term consolidation hypothesis which expects dual-task slowing for the short SOA condition when the central processing resources are occupied by short-term consolidation of words. It may be due to presentation of secondary task only trials within a block intermixed randomly with 200 ms, 400 ms, and 800 ms SOA trials. These secondary task only trials were shown in 25% of trials in a block. Because of these infrequent trials, participants may not concentrate on the normal secondary tasks.

Similar results were found when the episodic memory was measured by the recognition test and recall test, suggesting that the findings did not depend on the test that was used in the experiments. The obtained results could be generalized to a different memory test used for measuring episodic memory such as recall.

3.3 Experiment 3

The results of Experiment 1 and Experiment 2 suggested that short-term consolidation of information for episodic memory was limited in capacity and needed attentional resources. Withdrawal of attention in the short SOA conditions might influence the early perceptual processing of words. Alternatively, it might influence post-perceptual processes. The goal of Experiment 3 was to examine which processes were responsible for this effect by using ERPs, which "provide a continuous measure of processing between a stimulus and a response and can therefore be used to pinpoint the time at which attention begins to influence processing" (Vogel et al., 1998; p.1657). If the effect results from impairment of sensory processing, there should be suppression of P1 and N1 components (Luck, Woodman, & Vogel, 2000). Other components in the ERPs such as P300, N400, and P550 can show whether registering information in WM, processing semantic information, and processing information in the medial temporal lobe was responsible for the impaired memory performance, respectively (Luck, 2005).

Specific hypotheses for the ERP measurements are

(i) N1 and P1, associated with perceptual processing of words, will not be influenced by attention and SOA manipulations.

(ii) P300 for digits, associated with encoding the digit array in WM, will occur for divided attention (DA) but not for full attention (FA).

(iii) Sustained negativity of digits, associated with mental calculations of digits, will appear in DA but not for FA.

(iv) P300 for words will not occur when attention is divided and SOA is short. In the other three conditions, P300 will be present.

(v) P550, associated with processing of words in medial temporal lobe, will be absent when attention is divided and SOA is short. This wave will be found for the other three conditions.

3.3.1 Method

Participants. Fourteen participants (10 female, 4 male) took part in the experiment after providing informed consent. This experiment was approved by the Research Ethics and Scientific Review Committee at the Baycrest Centre. The average age was 27.8 years (*SD*= 3.75). The participants had a mean of 18.86 (*SD*= 3.01) years of education. All the participants were native speakers of English, right-handed, and reported no neurological disorder. All the subjects had normal or corrected-to normal vision.

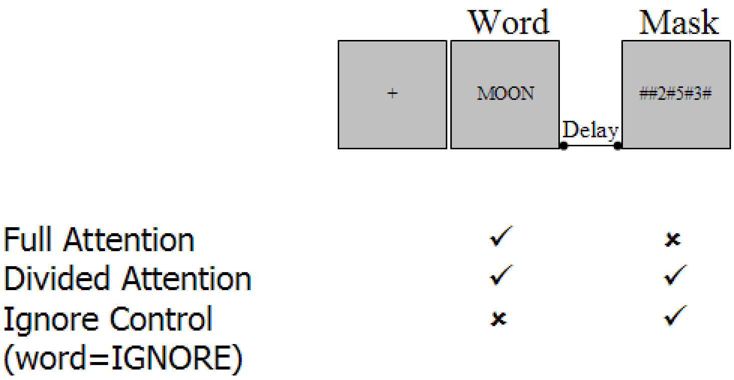

Figure 3.8. Schematic illustration a trial depending on the attention conditions. Participants (i) only study the words in the full attention condition, (ii) both study the words and respond to the digit arrays in the divided attention condition, (iii) and only respond to the digits in the ignore control condition.

<u>Materials.</u> Two sets each consisting of 14 lists of 16 concrete noun words were created. Word lists were matched for length and Kucera-Francis written frequency The sets were rotated across participants so that each word was presented equally often as either target or distractor. The order of words in the lists were randomized for each participant. Two filler words were added to the beginning and end of each list. These 4 filler items were not presented in the recognition test to reduce the total duration of the experimental sessions and to eliminate primacy and recency effects. Two SOAs were randomly intermixed within each block in order to eliminate subject's anticipation and using specific strategies. In addition, in order to set up baseline secondary task performance for ERP analysis, subjects were required to perform only the secondary task without studying words in an Ignore condition. In this condition the word "Ignore" was always presented. For the secondary task, participants were shown an array included three digits between 0 to 6 (e.g. ##1#4#3##) and requested to decide whether or not the sum of the digits was divisible by 3 by pressing one of the two keys within the 2500 ms following the onset of numerical stimulus. No auditory stimuli were presented.

Procedure. First, participants were prepared for EEG recordings in a preparation room. The preparation of a subject included the following procedures. The distances from the nasion to the inion, and from preauricular point to preauricular point over the top of head and the circumference of the head were measured. Next, 5% of the circumference measurement on each side of forehead was marked with a wax crayon. These measurements and markings were done for putting the 65-channel cap in appropriate position in the head. A chest band was put under the armpits across the chest of the participant. A prep pad that included alcohol and pumice was used to clean the areas where drop-down electrodes would be placed. The drop down electrodes were attached to LO1, LO2, IO1, IO2, F9, F10, FT9, FT10, TP9, and TP10 positions. The straps on the cap was attached to the snaps on the chest band so that the cap will preserve its fixed placement in the head. The electrode gel was applied by using a syringe with a blunt needle. After preparing the subject, the amplifier was calibrated. In order to decrease the impedance that can cause noisy data, a sharp needle was used very carefully. By the help of the sharp needle, dead skins under the electrodes were removed. Before and after the experiment, an ocular artifact rejection procedure (Picton et al., 2000) was employed to remove eye movement and eye blinks artifacts from EEG data. In each session of this procedure, participants were required to make eye movements (up, down, left, and right) and eye blinks.

After these preparations, participants practiced the tasks. Subjects were instructed to answer questions as rapidly and accurately as possible. Participants were told to give higher priority to the digit decision task (secondary task) than to the memory task. They were also instructed to be as rapid and accurate as possible on the decision task.

The experiment took place in a sound-proof EEG experiment room. An LCD display that had a 60 Hz refresh presented stimuli. The E-prime software package was used to present stimuli and collect behavioral data. The distance between the eyes of the subject and the center of the screen was adjusted to 75 cm.

At the beginning of each block, participants were presented one of the following cues according to the experimental condition: “Only Study Words”, “Study the Words and Respond to Digits”, “Only Respond to Digits”. The order of condition (FA, DA, and Ignore) block was counterbalanced across participants. The order of word lists was constant across subjects so that each word list was presented equally often presentation in FA and DA conditions.

Each block was started by the press of a key. Next, a fixation sign was presented for 1000 ms. Afterwards 20 words were presented for 100 ms each, followed in each case by a the digit array for 2500 ms. In the short SOA block, the interval between the onset of the word and the digit array was 200 ms whereas it was 800 ms for the long SOA block.

After the presentation of each study block, subjects were shown 32 words for 3 sec each in the test phase of the experiment. No count backwards procedure was applied, because articulation could have created too much noise for EEG recordings. Participants were asked to indicate whether they recognized the word or not by pressing one of the two specified keys on the keyboard. Half of the words were distractors. Targets and distractors were shown randomly for each participant. After running the first four participants, the results showed that subjects were very successful in the memory test. In order to decrease their performance and to prevent ceiling effects, the recognition test was given at the end of all study blocks in the subsequent 10 subjects. Electrophysiological data was collected from all of the 14 subjects.

<u>Electrophysiological recordings.</u> EEG activity was recorded continuously from a 64-channel EEG cap (Electro-Cap international, 10-10 system) using a Neuroscan

Synamps (El Paso, TX, U.S.A.) amplified (DC to 100 Hz sampled at 250 Hz) and referenced to Cz with a ground at AFz. The channel configuration were as follows: Frontal, AF3, AF4, AF7, AF8, F1, F2, F3, F4, F5, F6, F7, F8, Fz, Fp1, Fp2, Fpz; Fronto-central, FC1, FC2, FC5, FC6, FCz; Central, C1, C2, C3, C4, C5, C6; Parieto-central, CP1, CP2, CP5, CP6, CPz; Parietal, P1, P2, P3, P4, P5, P6, P7, P8, Pz; Parieto-occipital, PO3, PO4, POz; Occipital, O1, O2, Oz; Temporal, T7, T8; Temporo-parietal, TP7, TP8; Posterior channels CB1, CB2 and Iz. The following channels were placed manually on the face and back of the ears: eye channels, IO1, IO2, LO1, LO2; mastoid, TP9, TP10; frontal, F9, F10; and fronto-temporal, FT9, FT10. All impedances were kept under 5 kOhms. Recordings of blinks, horizontal and vertical eye movements prior to the experiment allowed to compensate for ocular artifacts using source components (Picton et al., 2000).

ERP Preprocessing and Analysis. Continuous EEG files for each subject were evaluated using the Brain Electromagnetic Source Analysis software of BESA 5 (BESA; MEGIS Software, Munich, Germany). In order to have more trials in averages, a liberal artifact rejection procedure was applied. A high threshold was selected to reject trials with large voltage deflections, resulting in about 1% reduction of trials. The data were re-referenced to an average reference, epoched into 4300 ms segments (1000 ms pre-stimulus interval), baseline-adjusted to the 200 ms pre-stimulus interval and averaged separately for each experimental condition. Average file of each participant was corrected for eye artifacts. Eye artifact correction was done in BESA using source components derived from the recordings made immediately before the experimental session. Since compensation near the eyes may not be perfect (Picton et al., 2000), the eye channels (IO1, IO2, LO1, LO2) were excluded from subsequent analyses. The grand mean waveforms were created by combining data of all 14 subjects contributing equally to the grand mean. No filtering was applied on the data, but for displaying cleaner plots, a digital high-pass-filter (zero phase shift) of 8 Hz was employed. ERP components were identified by using mean or peak amplitude measure by calculating the mean or peak voltage in a predefined time window. The main effects of attention (FA, DA, Ignore) and SOA (short, long) were assessed by ANOVAs on mean or peak amplitudes on the midline parietal electrode (Pz) or parietal-temporal electrodes (P7, P8). All ERP analyses except for the sensory evoked potentials of words were done separately for the short SOA and the long SOA, because the onset of the mask and the duration of a trial were different between short SOA and long SOA conditions.

3.3.2 Results

Memory task. Descriptive data for recognition memory performance in Experiment 3 is shown in Table 3.4. A 2 (attention) X 2 (SOA) within-subjects ANOVA was performed on corrected recognition. The main effect of attention was significant, $F(1, 13) = 5.76$, $MSE=0.027$, $p=.03$. The participants in the FA condition ($M=.50$, $SD=.31$) performed better than the participants in the DA condition ($M=.40$, $SD=.31$). The main effect of SOA was also significant, $F(1, 13) = 16.30$, $MSE=0.002$, $p=.001$. Corrected recognition performance was higher with long SOA ($M=.47$, $SD=.30$) than with short SOA ($M=.42$, $SD=.29$). More importantly, the interaction between attention and SOA was significant, $F(1, 13) = 5.39$, $p=.04$, indicating that decreasing the SOA impaired memory performance for DA, $t(13) = -4.202$, $p=.001$, but not for FA, $t(13) = -0.32$, $p=.75$ (see Figure 3.9).

Table 3.4. *Recognition Memory Performance in Experiment 3*

Attention	SOA	Hits	False Alarms	Corrected Recognition
Full	200 ms	.71(.18)	.21	.50 (.30)
Full	800 ms	.71 (.20)		.50 (.33)
Divided	200 ms	.55 (.23)	.20	.35 (.32)
Divided	800 ms	.64 (.22)		.44 (.30)

Note. Standard deviations are shown in parentheses next to means. Since SOA was manipulated within a block and the recognition test was given after each block, there is only one false alarm rate for the FA condition and one for the DA condition.

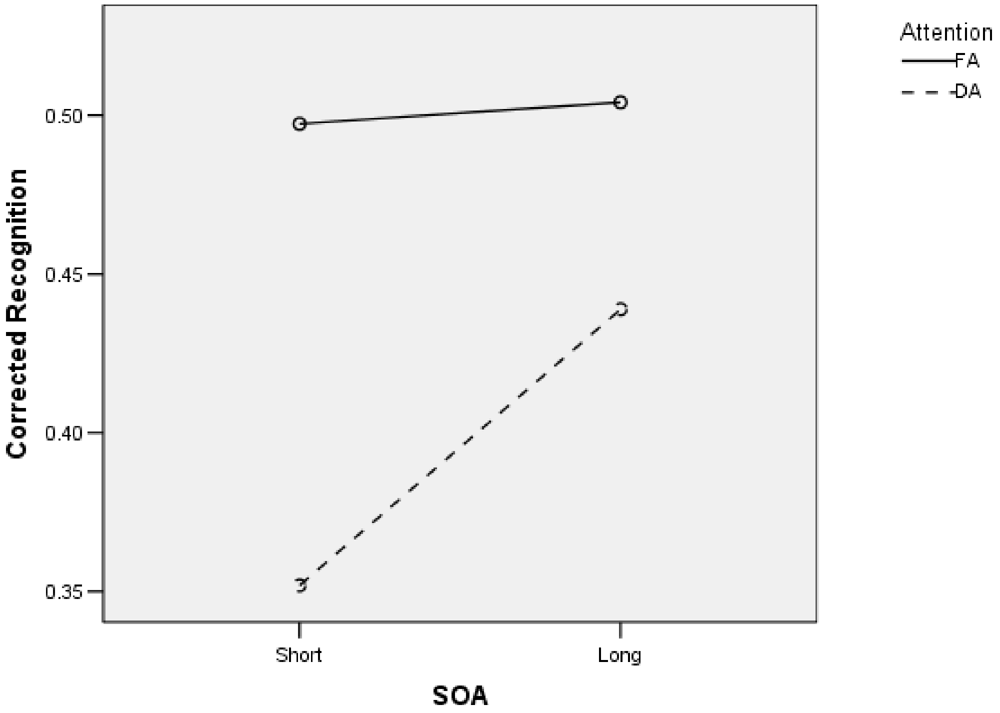

Figure 3.9. Mean corrected recognition performance as a function of attention and SOA. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

Secondary task. A two-way within-subjects ANOVA was performed to examine if accuracy in the secondary task (digit decision task) was influenced by condition (Ignore, DA) and SOA (200 ms, 800 ms). The results showed that the effect of condition was significant, $F(1, 13) = 5.01$, MSE=0.002, p=.04. Accuracy in the secondary task was lower when participants were studying the words (M=.92, SD=.05) than when they were just looking at the same "Ignore" word (M=.95, SD=.03). There was neither a significant effect of SOA, $F(1, 13) = 1.71$, MSE=0.001, p=.21, nor an interaction between condition and SOA, $F(1, 13) = 0.21$, MSE=0.001, p=.66.

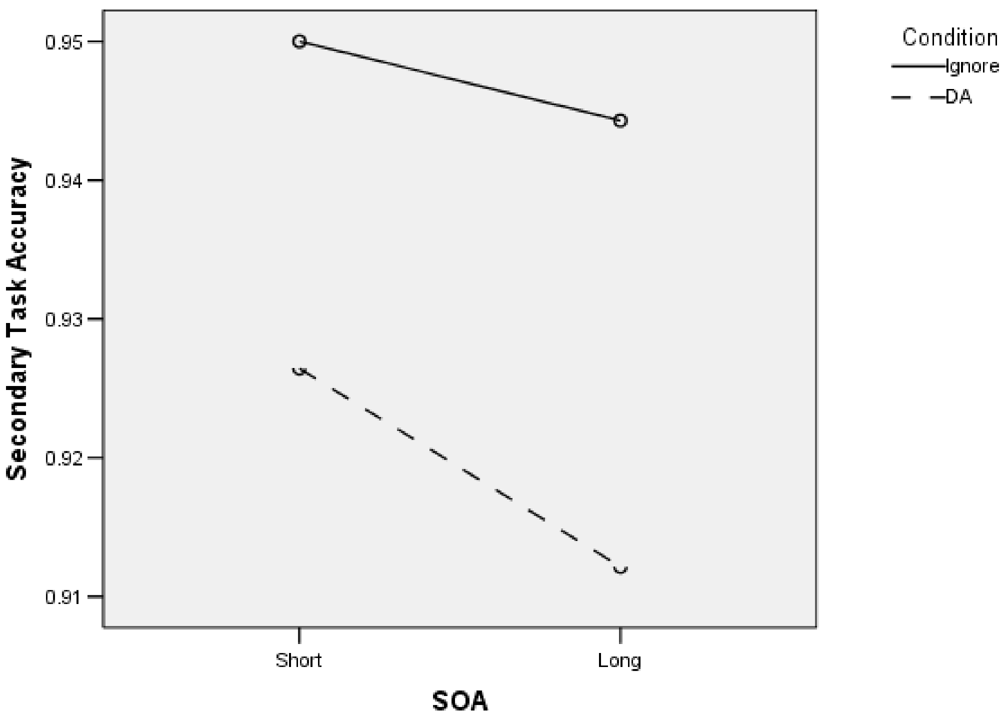

Figure 3.10. Mean secondary task accuracy as a function of condition and SOA. DA= divided attention, SOA= stimulus onset asynchrony

In order to examine the influence of condition (Ignore, DA) and SOA on the secondary task response time (RT) of correct responses, a two-way within-subjects ANOVA was conducted. The results revealed that secondary task RT was affected by condition, $F(1, 13) = 12.75$, $p=.003$, and SOA, $F(1, 13) = 11.05$, $p=.005$. Accordingly, participants were slower to respond to the secondary task in the DA condition (M=1446, SD=181) than in the Ignore condition (M=1304, SD=218). Participants were slower to respond to the secondary task with the short SOA condition (M=1395, SD=196) than with the long SOA condition (M=1354, SD=203). However, the interaction between condition and SOA was not significant, $F(1, 13) = 2.22$, $p=.16$.

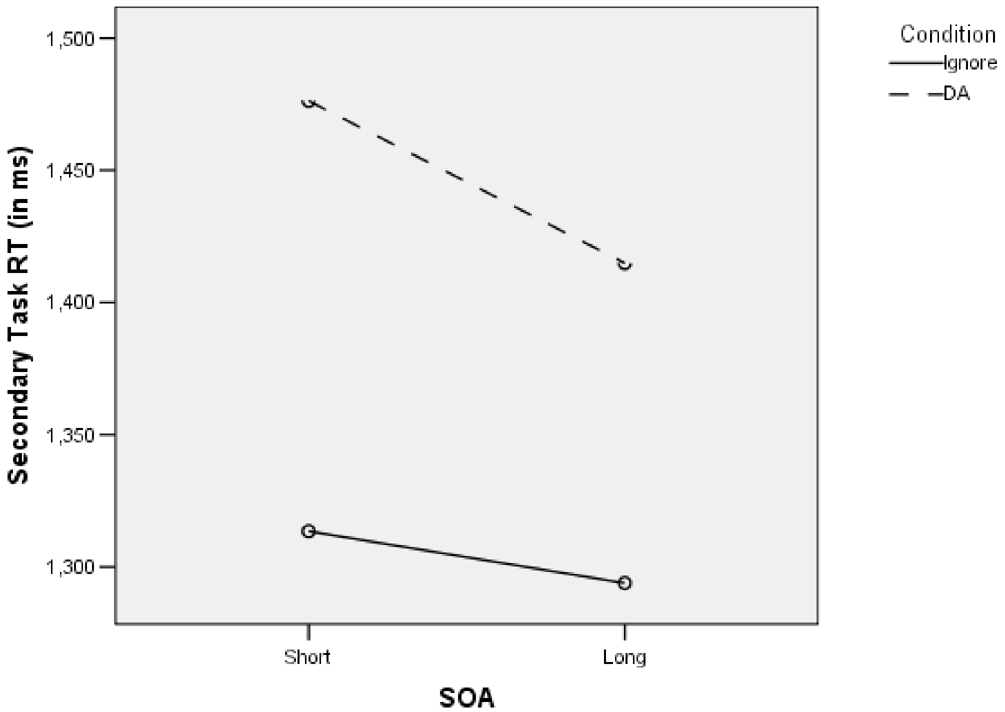

Figure 3.11. Mean secondary task response time as a function of condition and SOA. DA= divided attention, SOA= stimulus onset asynchrony, RT=response time

Electrophysiology. Based on the electrophysiology literature (Luck, 2005; Luck, Woodman, & Vogel, 2000; Mangels et al., 2005; Vogel et al., 1998; Vogel & Luck, 2002), some critical components were identified on specific electrodes by using peak or mean amplitude measurements. All the time windows were measured after word onset. For instance, 100-200 ms time window starts after 100 ms word onset and ends at 200 ms after word onset.

In order to measure P1, the latency of the positive peak within 0-150 ms time window recorded laterally in the parietal-temporal region (P7 and P8 electrodes) was found. P7 was on the left hemisphere, whereas P8 is on the right hemisphere. For N1, the latency of the negative peak within 0-250 ms time window recorded laterally at the parietal-temporal region was measured. These early peaks are associated with perceptual processing of words (Mangels et al.,2001). P300 for digits was obtained by finding the mean amplitude within 450-800 ms and 1050-1400 ms time window recorded at the centro-parietal region (Pz electrode) for short and long SOA conditions, respectively. P300 for words in long SOA conditions were acquired by getting the mean amplitude within 250-400 ms time window recorded at centro-parietal region. P300 was related with updating information in WM (Donchin, 1981; Vogel et al., 1998). P550 for words in long SOA conditions were obtained by finding the mean amplitude within 450-700 ms time window recorded at centro-parietal region. P550 is associated with registering of information by the medial temporal lobe/hippocampal complex (Mangels et al., 2001). Sustained negativity, following the P300 of digits, was calculated by finding the mean amplitude within 1100-2500 ms and 1800-3200 ms time window at centro-parietal region for the short and the long SOA conditions, respectively. Sustained negativity is associated with mental calculation of digits (Ruchkin, Johnson, Canoue, & Ritter, 1991; Ruchkin, Johnson, Mahaffey, & Sutton, 1988).

N1 and P1 for words. A 2 (hemisphere: left, right) X 3 (attention: FA, DA, Ignore) X 2 (SOA: short, long) within-subjects ANOVA was conducted on early positive peaks at the parietal temporal electrodes (P7 and P8). There were no significant main effects of hemisphere, attention, and SOA, all ps>.46. The interactions were not significant, all ps>.10. These results suggested that early positive peaks (P1), which are associated with perception of words were not influenced by attention and SOA (see Figure 3.12).

A 2 (hemisphere: left, right) X 3 (attention: FA, DA, Ignore) X 2 (SOA: short, long) within-subjects ANOVA was performed on early negative peaks at the parietal temporal electrodes (P7 and P8). Main effects of hemisphere, attention, and SOA were not significant, all ps>.25. Besides, the interactions were also non-significant, all ps>.11. These results together indicated that perceptual processes of the words were similar between different experimental conditions because of similar peak latencies for P1 and N1 (see Figure 3.12).

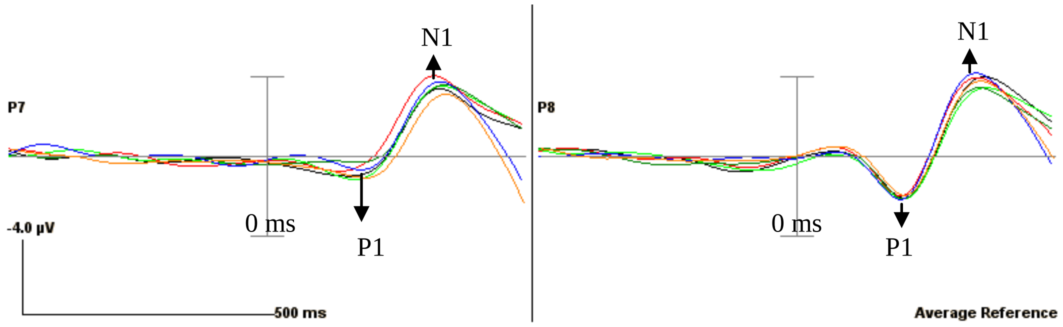

Figure 3.12. The early peaks, P1 and N1, at left (P7) and right (P8) parietal-temporal electrodes in different conditions

P300 for digits in Short SOA. The effect of attention on P300, which is associated with updating of working memory by digits was significant, $F(2, 26) = 4.66$, MSE=1.42, p=.04. Three separate one-sample t tests were conducted to test if the mean amplitude was bigger than 0 for each attention condition. Holm's sequential Bonferroni procedure was utilized to control Type I error across the three tests. The t tests showed that the mean amplitude was bigger than 0 for DA, $t(13)$= 4.99, p<.001, for Ignore, $t(13)$= 3.37, p=.005, but not for FA, $t(13)$= 1.73, p=.11. A paired-samples t tests was run for the planned comparison between DA and Ignore. Difference in the mean amplitude was not significant between DA and Ignore, $t(13)$= 1.27, p=.23. These results demonstrated that the manipulation of attention was successful such that the working memory was updated by digits in DA and Ignore conditions but not in the FA condition (see Figure 3.13). The magnitude of P300 component was similar between DA and Ignore conditions.

Sustained Negativity for Digits in Short SOA. Sustained negativity which was associated with mental calculation of digits was influenced by the manipulation of attention, $F(2, 26) = 13.41$, MSE=1.73, p=.001. For each attention condition, a separate one-sample t test was conducted to test if the mean amplitude was smaller than 0. The t tests showed that the mean amplitude was smaller than 0 for DA, $t(13)$= -4.05, p=.001, for Ignore, $t(13)$= -3.60, p=.003, but not for FA, $t(13)$= -0.50, p=.63. A paired-samples t test was run for planned comparison between DA and Ignore. Difference in mean amplitudes was not significant between DA and Ignore, $t(13)$= 0.85, p=.41.

These results demonstrated that participants really performed the digit decision task in DA and Ignore conditions (see Figure 3.13). It seems like that there was no qualitative difference in performing the secondary task between DA and Ignore conditions.

P300 for digits in Long SOA. P300 which is associated with updating of working memory by digits was influenced by attention, $F(2, 26) = 21.76$, $MSE=1.27$, $p<.001$. Three separate one-sample t tests were conducted to test if the mean amplitude was bigger than 0 for each attention condition. The t tests showed that the mean amplitude was bigger than 0 for Ignore, $t(13)= 3.69$, $p=.003$, but not for DA, $t(13)= 0.60$, $p=.56$. Mean amplitude was smaller than 0 for FA, $t(13)= -4.81$, $p<.001$. Although t test was not significant, mean amplitude was positive for DA. These results showed that the contents of the WM was updated in the Ignore condition, but not in FA condition. Contextual updating was slightly present in the DA condition (see Figure 3.12).

Sustained Negativity for Digits in Long SOA. Sustained negativity which was related with mental calculation of digits was also affected by attention, $F(2, 26) = 24.17$, $MSE=0.88$, $p<.001$. Three separate one-sample t tests were run to examine whether mean amplitudes were negative. The t tests showed that the mean amplitude was negative for Ignore, $t(13)= -3.04$, $p=.01$, for DA, $t(13)= -2.86$, $p=.01$, but not for FA, $t(13)= 0.75$, $p=.47$. A paired-samples t test was conducted for planned comparisons between DA and Ignore. Difference in mean amplitudes was not significant between DA and Ignore, $t(13)= 0.84$, $p=.42$. These results showed that negative sustained potentials arose in DA and Ignore conditions but not in the FA condition. There was no significant difference in the magnitude of these slow negative waves between DA and Ignore conditions.

P300 for words. It was nearly impossible to identify P300 for words in the short SOA, because P300 waves of words were contaminated by sensory evoked potentials of digits which were presented 200 ms after the onset of words. In other words, overlapping of P300 for words with P1 and N1 of digits made it hard to isolate P300 for words. Because of this problem, only P300 for words in the long SOA could be examined. The effect of attention on P300 for words was not significant, $F(2, 26) = 1.54$, $MSE=0.80$, $p=.24$. Three separate one-sample *t* tests were performed to test if the mean amplitude was bigger than 0 for each attention condition with Holm's sequential Bonferroni procedure. The *t* tests showed that the mean amplitude was bigger than 0 for Ignore, $t(13)= 2.67$, $p=.019$, for DA, $t(13)= 2.51$, $p=.026$, and for FA, $t(13)= 2.41$, $p=.031$. Three paired-samples *t* tests were run for follow-up pairwise comparisons for the main effect attention. There were no differences in mean amplitudes between these conditions, all $ps>11$. These results demonstrated that similar P300 was present in FA, DA, and Ignore conditions when the SOA was long (see Figure 2.12). Most importantly, the present paradigm could not show P300 when the SOA was short because of the succeeding sensory evoked potentials of digits.

P550 for words. It was also very hard to identify P550 for words in the short SOA because of the overlap with sensory evoked potentials of digits. Only P550 for words in the long SOA were investigated for this reason. The effect of attention on P550 for words was significant, $F(2, 26) = 6.40$, $MSE=1.29$, $p=.008$. Three separate one-sample *t* tests were conducted to see if the mean amplitudes were bigger than 0. The *t* tests showed that the mean amplitude was bigger than 0 for FA, $t(13)= 4.50$, $p=.001$, but not for DA, $t(13)= 1.72$, $p=.10$. On the other hand, the mean amplitude for Ignore was negative. These results showed that P550 existed in the FA condition (see Figure 2.12). Even if the *t* test is not significant, a P550 wave for DA could be identified in the grand averages. This wave is smaller than the one in the FA condition.

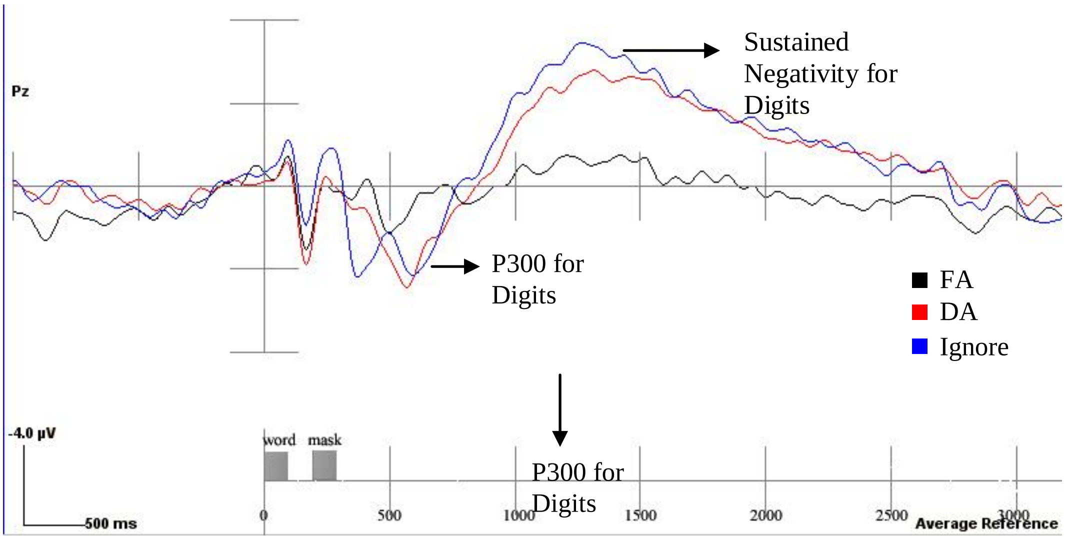

Figure 3.13. ERPs at centro-parietal electrode in full attention, divided attention, and ignore conditions when the SOA is short

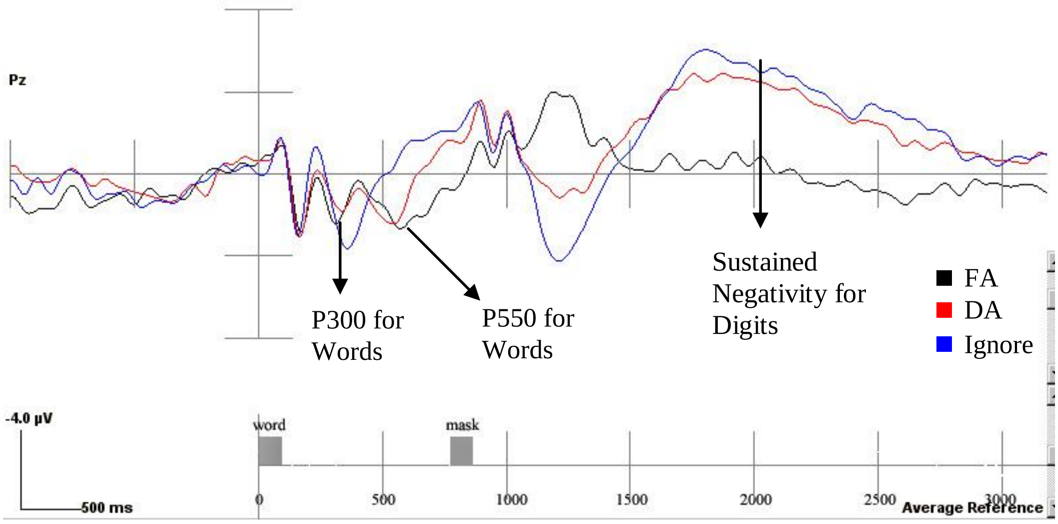

Figure 3.14. ERPs at centro-parietal electrode in full attention, divided attention, and ignore conditions when the SOA is long

3.3.3 Discussion

The goal of this experiment was to investigate the effect of attention and SOA between the onset of pictures and masks on recognition memory. Attention and processing time interacted, indicating that the disruption in memory performance was highest when the SOA was short and attention was divided. The results of the current experiment showed that when the short-term consolidation process was interrupted by an attention-demanding task, performance in recognition decreased significantly.

The results on secondary task performance suggested that costs to the secondary task RT were greater when subjects were required to study the words than when they were requested to just look at the "Ignore" word without episodic encoding. Participants were slower to respond to the secondary task when they were studying words for a future memory test. Besides, it took more time to respond to the digit decision task in the short SOA condition than in the long SOA condition. These results suggest the existence of a bottleneck for consolidation of information such that processing of the secondary task has to wait the short-term consolidation of the word.

The electrophysiological data demonstrated that perception of words was intact in all the conditions, because N1 and P1 waves which were associated with perceptual processing of words were influenced neither by attention nor by SOA. The results also showed that the manipulation of attention was effective and participants really performed the secondary task immediately when they were required to do, since P300 and sustained negativity related with digits was intact in DA and Ignore conditions but not in the FA condition. One limitation of the current experiment was the inability to examine the effects of attention on P300 and P550 of words in the short SOA conditions. Sensory evoked potentials made it impossible to separate these potentials. However, it was feasible to explore these waves for long SOA conditions. Consistent with expectations, P550 occurred in the FA condition, indicating that further processing of words in the medial temporal lobe could only happen in the FA condition. Although the statistics were not significant, a P550 wave that was weaker than the one in FA could be identified in the DA condition.

ERP results provided evidence that participants did not employ specific strategies (e.g. performing the memory task and the secondary task simultaneously) in the DA condition, because P300 for digits and sustained negativity for mental calculation of digits was similar in DA and Ignore conditions. It was apparent from P300 and sustained negative waves that subjects started performing the secondary task immediately when they were asked to do, so participants did not start performing the secondary task with some delay for studying the words longer.

3.4 Experiment 4

Decreasing the SOA between pictures and masks in DA impaired episodic memory performance in Experiment 1. Nevertheless, the drop in memory was very small. It is possible that participants use perceptual distinctiveness of pictures to recover from the disruptive effects of reducing the SOA in the DA condition (Nelson, Reed, & Walling, 1976). It is also possible that participants recognize pictures by "detecting disjunctive set of unbound features of target category and then us[ing] these to discriminate between scenes that do or do not contain the target without necessarily fully identifying it" (Evans & Treisman, 2005, p.1477). For instance, low level features of picture of an animal such as feathers, fur, and scales might provide necessary information about the superordinate category such as bird, mammal, and fish, respectively. In order to eliminate the contamination on recognition from the possibility of using perceptual details or unbound features of stimuli, figures of stickmen were utilized in this experiment. Stick figures have the same set of parts such as a head, two legs, and two arms. No stick figure includes an additional perceptual detail. The disjunctive set of features of all the stick figures are the same, but the spatial arrangement of these body parts enable the creation of different figures with different meanings.

3.4.1 Method

Participants. Participants were 20 University of Toronto students (12 female, 8 male) who received course credits or monetary compensation. The average age was 21.65 years (*SD*=5.10). Informed consent was obtained from the participants prior to testing. All participants reported normal or corrected-to normal vision.

Design. The present experiment used a two-factor within-subjects design. The independent variables were attention with two levels (FA, DA) and SOA between the onset of the visual stimulus and the mask with three levels (400 ms, 800 ms, 1200 ms).

Materials. Instead of photographs of scenes as in Experiment 1, figures of stickmen were used in the current experiment. A total of 360 stickman figures with different content were created. Examples of 9 different stick figures can be seen in Figure 3.15. The sizes of the pictures were identical. All the figures were made by using the same reference figure, so all the figures had identical parts (the head, legs, and arms) with same size, but for some figures few parts of the stickman were occluded by other parts. The orientations of the head, legs, and arms were changed to create figures with different conceptual meanings. The stick figures were shown against a white background. Two sets each consisting of six lists of 15 pictures were constructed randomly from the stickmen figures pool. Two additional lists of figures were used for practice. The sets were rotated across participants such that each figure was presented equally often as either target or distractor and equally often under DA and FA conditions. Trials were blocked by attention type. The order of figures in the study lists or test lists were randomized for each participant.

Procedure. Prior to testing, practice trials were administered to acquaint participants with the tasks. Subjects were instructed to answer questions as rapidly and accurately as possible. For the DA conditions, participants were told to give higher priority to the digit decision task than to the memory task.

At the beginning of each block, one of the following cues was presented in the middle of the screen. For FA blocks, the cue was "Study Only Stickmen", whereas for DA blocks the cue was "Study Stickmen and Respond to Digits ". The blocks were initiated by the press of any key on the keyboard. Afterwards, 15 study trials were presented. Each trial consisted of a fixation sign shown for 500 ms, the figure shown for 200 ms, either 200 ms, 600 ms, or 1000 ms delay depending on the SOA condition, and the digit array shown for 2250 ms. The SOA between the figure and the digit array was varied randomly within a block.

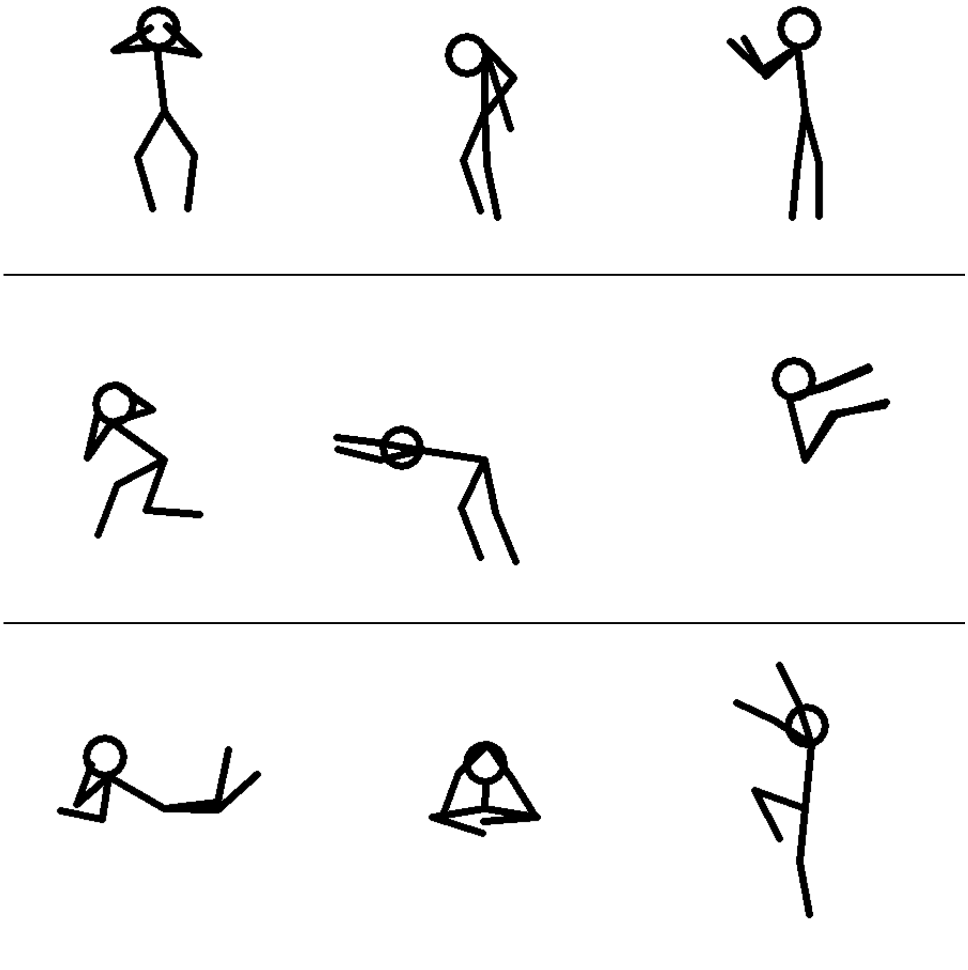

Figure 3.15. Nine different stickmen figure used in Experiment 4

Subjects were requested to perform the secondary task in the DA condition, whereas in the FA condition the mask "########' was presented instead of a digit array; participants were not required to do the mental calculation. After the study block, participants were shown a predefined random number and requested to count backwards by threes from that number for 12 sec. Afterwards, participants were presented the message, "Recognition Test" and they were reminded which keys they would use for "Yes" and "No" in the memory test. In the test block, 30 figures

(15 targets and 15 distractors) were presented for 3 sec in random order for each participant. Subjects were told to press a predetermined key on the keyboard if they recognized studying the stickman figure on that study block and to press another key if they did not recognize it.

3.4.2 Results

Memory task. A two-way within-subjects ANOVA with attention (FA, DA) and SOA (400 ms, 800 ms, 1200 ms) as factors was administered on corrected recognition. There were significant main effects of attention, $F(1, 19) = 45.81$, $MSE=0.035$, $p<.001$, and SOA, $F(1, 19) = 7.36$, $MSE=0.006$, $p=.002$. No significant interaction between attention and SOA was present, $F(2, 38) = 0.55$, $p=.58$ (see Figure 3.16). Three paired-samples *t* tests were performed to follow-up pairwise comparisons for the main effect of SOA by applying Holm's sequential Bonferroni procedure. Difference in mean corrected recognition was significant between 400 ms SOA and 1200 ms SOA, $t(19)= -4.12$, $p=.001$, but mean corrected recognition was not significantly different between 400 ms SOA and 800 ms SOA, $t(19)= -1.87$, $p=.08$ and between 800 ms SOA and 1200 ms SOA, $t(19)= -1.85$, $p=.08$.

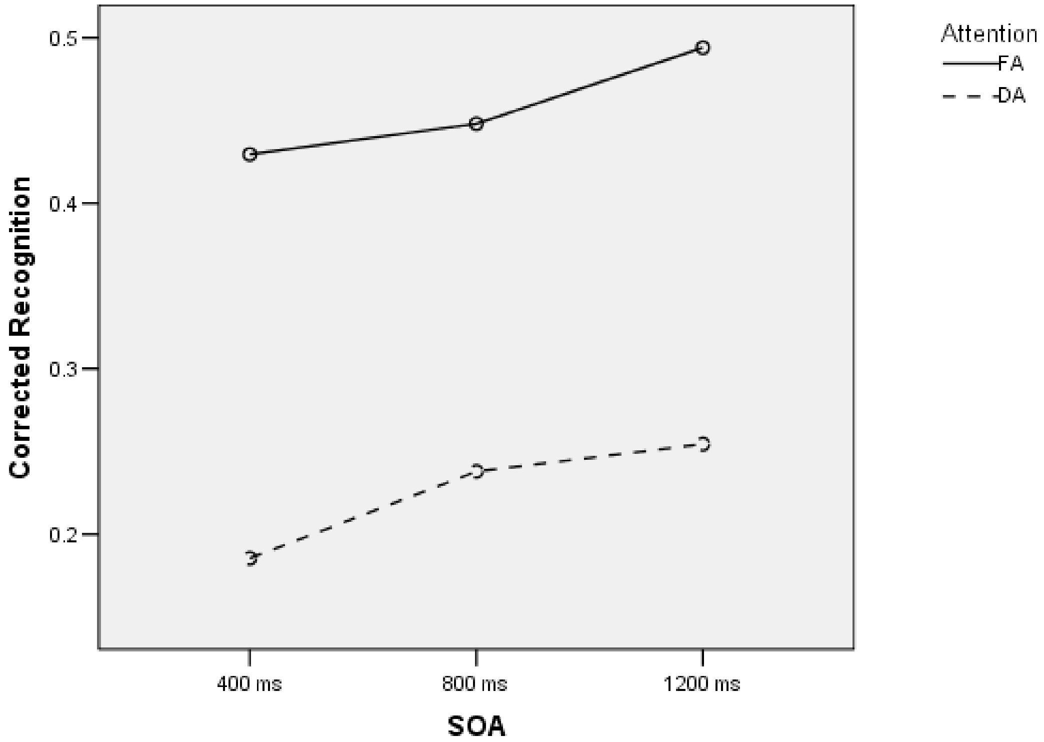

Figure 3.16. Mean corrected recognition performance as a function of attention and SOA in Experiment 4. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony.

Secondary task. In order to examine the influence of SOA on accuracy in the secondary task, a one-way within-subjects ANOVA was performed. The results showed no significant SOA effect, $F(2, 38) = 0.06$, $p=.97$, indicating that participants' accuracy in the digit decision task was not different between 400 ms SOA ($M=.87$, $SD=.09$), 800 ms SOA ($M=.86$, $SD=.08$), and 1200 ms SOA ($M=.87$, $SD=.12$).

The influence of SOA on RT in the secondary task was examined by a one-way within-subjects ANOVA. The results demonstrated a significant effect of SOA, $F(2, 38) = 16.81$, $MSE=6726$, $p<.001$. Three paired-samples t tests were conducted to follow-up pairwise comparisons on secondary task RT by applying Holm's sequential Bonferroni procedure. Differences in mean RT were significant between 400 ms SOA and 1200 ms SOA, $t(19)= 6.53$, $p<001$, and between 400 ms SOA and 800 ms SOA, $t(19)= 4.12$, $p=.001$. On the other hand, the difference in mean RT between

800 ms SOA and 1200 ms SOA was not significant, $t(19)= 1.37$, $p=.19$. These results indicated that participants were slower in the digit decision task when the SOA was 400 ms (M=1303, SD=121) than when the SOA was 800 ms (M=1222, SD=121) or when the SOA was 1200 ms (M=1191, SD=95). However, participants' speed of responses to the secondary task was not reduced by increasing the SOA from 800 ms (M=1222, SD=121) to 1200 ms (M=1191, SD=95).

3.4.3 Discussion

The results suggested that performance on episodic memory was better when participants were paying full attention to the stick figures than when they were in a divided attention condition. Subjects were more successful in recognizing these figures in the 1200 ms SOA condition compared to the 400 ms SOA condition. The interaction between attention and SOA was not significant, indicating that the effect of attentional load was not different for different SOAs. These results do not support the short-term consolidation hypothesis. Performance of the participants was relatively lower in remembering stick figures compared to remembering words or pictures. Informal interviews with the participants at the end of experiments suggested that participants had difficulty in discriminating old and new stick figures.

Jolicoeur and Dell'Acqua (1998) argued that slowing in the secondary task demonstrated the existence of short-term consolidation process, because the involvement of central processing mechanisms for consolidation of information will produce a postponement in the other task requiring the same central processing. The results of the current experiment are consistent with the findings reported by (Jolicoeur & Dell'Acqua, 1998; 1999) such that response times to the secondary task were slower in the 400 ms SOA condition compared to the 800 ms SOA condition and the 1200 ms SOA condition. However, there was no difference in secondary task RT between 800 ms SOA and 1200 ms. As a result, the engagement of the consolidation of stick figures resulted in slowing in the response times to the digits when SOA was 400 ms or 800 ms. On the other hand, when this consolidation process was finished as in 1200 ms SOA, there was no more slowing in the secondary task performance.

The results on the secondary task RT of this experiment were consistent with the ones in Experiment 3. However, the effect of SOA on secondary task was not significant in Experiment 1. The secondary task in Experiment 1 was a continuous reaction time task. Participants made several responses within the secondary task duration (2 sec). Although the interference of the ongoing consolidation was on just response in the secondary task, multiple responses were collected from the secondary task in one trial. For this reason, the disruptive effect of the consolidation process on secondary task RT was divided among several responses. Although SOA did not significantly influence secondary RT in Experiment 1, the trend was towards slower RT in the short SOA condition compared to long SOA condition. This pattern was consistent with the results of Experiment 4. A significant dual task slowing was observed in the long SOA (800 ms) condition in Experiment 2 which was in contrast to expectations and the results of the third experiment. This unexpected result may be due to infrequent secondary task only trials in Experiment 2. In secondary task only trials, subjects were given only the digit decision secondary task without presenting words. Participants may not concentrate on normal secondary tasks that included presentation of both words and digits when secondary task only trials were presented rarely.

3.5 Experiment 5

The results of the first and second experiment showed that when attention was withdrawn by a secondary task within at least 400 ms, there was an impairment in episodic memory. These results provided evidence for the consolidation hypothesis. On the other hand, these results can also be explained by the processing time hypothesis (Hulme & Merikle, 1976; Mewhort, Merikle, & Bryden, 1969). The processing time hypothesis expects better memory performance as people have more processing time for the memory task. If the consolidation hypothesis is correct, recognition memory will not change as the SOA is increased from 800 ms to 1200 ms, because the consolidation of information will be successfully done for these SOAs (800 ms and 1200 ms). On the other hand, the processing time hypothesis expects better performance in the 1200 ms SOA condition than in 800 ms SOA condition, because more processing time in the 1200 ms SOA condition would lead to better episodic memory unless processing has hit an asymptote.

Another goal of this experiment was to examine whether there would be greater impairment in episodic memory if attentional resources were withdrawn by two events compared to one event. Participants were presented two consecutive pictures (targets) instead of only one picture as in Experiment 1. The second picture served as both a mask and an attention-demanding secondary task for the first picture, because it had to be encoded for a later memory test. If the consolidation of visual information needs attention, participants should be less successful at remembering the first targets than the second targets, because there would be fewer processing resources left for the first targets.

3.5.1 Method

Participants. The participants consisted of 24 university students (13 female and 11 male) who were paid to take part in the study. Informed consent form was obtained from the subjects. The participants were between 18 and 32 years old (*M*=22.83, *SD*=4.08) and had normal or corrected-to normal vision.

Design. The study had a 3 (SOA between the onset of visual stimuli and mask: 400 ms, 800 ms, and 1200) X 2 (target order: first target, second target) within-subjects design.

Materials and Procedure. A total of 576 black and white pictures were used in this study. The pictures used in the previous experiments were converted to grayscale in the present experiment to decrease memory performance. The sizes of the pictures were the same and they were displayed at the center of the screen with a gray background. In each trial, two pictures were presented consequently followed by a three digit array superimposed on a gray noise mask. In the secondary task, participants were shown an array included three digits between 1 to 5 (e.g. ##1#4#3##) and requested to decide whether the sum of the digits was divisible by 3 by pressing corresponding keys on the keyboard in 2500 ms.

Four sets each consisting of 6 lists of 24 pictures were created. The sets were rotated across participants such that each picture was presented equally often as target in the test, distractor in the test, the first picture in the study trials, and the second picture in the study trails. No auditory stimuli were presented. There was no full attention condition.

Prior to testing, participants were given a practice session. The participants were asked to give more priority to the digit decision task than to the memory task. Subjects were not informed about the type of delay. They were just presented with a cue to study the pictures and respond to digits. With the press of a key, the blocks started to run. No fixation sign was presented. The SOA between the two pictures and the one between the second picture and the mask was always the same. The SOA between the pictures and between the second picture and the mask was either 400 ms, 800 ms, or 1200 ms. Different SOA conditions were administered in alternating blocks (i.e. ABCABC). The order of SOA blocks was counterbalanced across participants (i.e. ABCABC, BCABCA, CABCAB). Between the study and the test phase, subjects were not requested to count backwards in order to decrease the duration of the experiment. After the study phase, participants were warned about the memory test by the "Recognition Test" cue and were reminded of the keys that would be used in the test. The pictures were presented 4 sec each in the recognition test. Targets and distractors were presented in random order for each subject. After the response of the participant, the next picture was presented with a 500 ms blank

ISI. All the pictures from the study list were taken into account in the data analysis for the recognition test.

3.5.2 Results

Memory task. A two-way within-subjects ANOVA was conducted to examine the influence of SOA (400 ms, 800 ms, and 1200 ms) and target order (first, second) on corrected recognition of pictures. Significant effects of SOA, $F(2, 46) = 11.55$, $MSE=0.008$, $p<.001$, and order, $F(1, 23) = 10.82$, $MSE=0.006$, $p<.003$, were found with no significant SOA X order interaction, $F(2, 46) = 0.79$, $MSE=0.005$, $p=.46$. The results suggested that memory performance was higher for the second target ($M=.41$, $SD=.16$) than for the first target ($M=.37$, $SD=.16$).

Three paired-samples *t* tests were performed to follow-up pairwise comparisons for the main effect of SOA. Holm's sequential Bonferroni procedure was utilized to control Type I error across the three tests. Differences in mean corrected recognition were significant between 400 ms SOA and 1200 ms SOA, $t(23)= -4.48$, $p<.001$, and between 400 ms SOA and 800 ms SOA, $t(23)= -3.39$, $p=.003$. However, there was no significant difference in mean corrected recognition between 800 ms SOA and 1200 ms SOA, $t(23)= -1.08$, $p=.29$. These results showed that memory performance in recognizing pictures was better when the SOA was 1200 ms ($M=.42$, $SD=.17$) than when the SOA was 400 ms ($M=.34$, $SD=.14$). As can be seen in Figure 3.17, recognition memory for pictures was superior with the 800 ms SOA condition ($M=.40$, $SD=.18$) than with the 400 ms SOA condition ($M=.34$, $SD=.14$). However, there was no significant difference between 800 ms SOA pictures ($M=.40$, $SD=.18$) and 1200 ms SOA pictures ($M=.42$, $SD=.17$).

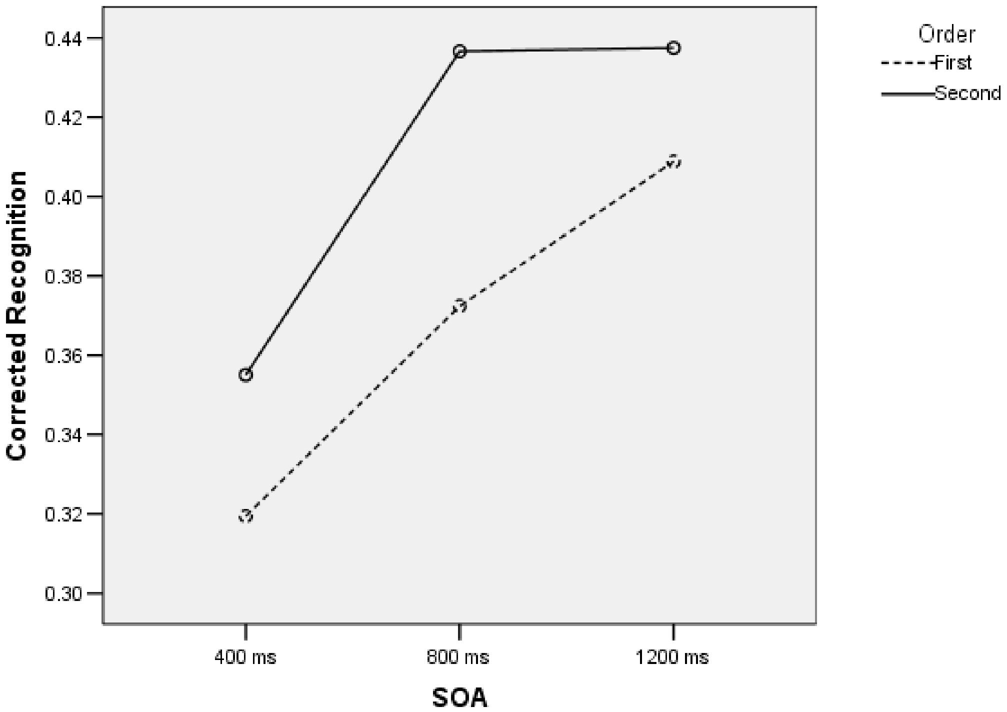

Figure 3.17. Mean recognition performance as a function of target order and SOA in Experiment 5. SOA= stimulus onset asynchrony

<u>Secondary task.</u> A within-subjects ANOVA was performed to examine if accuracy in the secondary task (digit decision task) was influenced by SOA (400 ms, 800 ms, 1200 ms). The results showed that the effect of SOA was not significant, $F(2, 46) = 0.90$, $MSE=0.003$, $p=.42$. Accuracy in the secondary task was nearly equal when the SOA was 400 ms ($M=.90$, $SD=.08$), 800 ms ($M=.90$, $SD=.09$), and 1200 ms ($M=.92$, $SD=.05$).

Another ANOVA was run to determine whether secondary task (digit decision task) RT was influenced by SOA. The results showed that the effect of SOA was significant, $F(2, 46) = 3.92$, $p=.03$. Three paired-samples t tests were performed to follow-up pairwise comparisons for the main effect of SOA. Difference in mean RT was significant between 400 ms SOA and 800 ms SOA, $t(23)= 2.50$, $p=.02$. However, there was no significant difference in mean RT between 400 ms SOA and 1200 ms SOA, $t(23)=2.01$, $p=.06$, and between 800 ms SOA and 1200 ms SOA, $t(23)= -0.80$, $p=.43$, These results showed that participants were slower to respond to the secondary task when the SOA was 400 ms (*M*=1544, *SD*=.186) than when the SOA was 800 ms (*M*=1497, *SD*=.182). On the other hand, there was no significant difference in secondary Task RT between 400 ms SOA pictures (*M*=1544, *SD*=.186) and 1200 ms SOA pictures (*M*=1510, *SD*=190), and between 800 ms SOA pictures (*M*=1497, *SD*=.182) and 1200 ms SOA pictures (*M*=1510, *SD*=190),

3.5.3 Discussion

The results of the current experiment favor the consolidation hypothesis such that there was no more increase in memory performance as the SOA was increased from 800 ms to 1200 ms. This shows that 800 ms is enough for the short-term consolidation process. The attention-demanding task disrupted early representations that were not successfully consolidated (Vogel et al., 2007). The processing time hypothesis expects better memory performance as people have more processing time for the memory task. However, recognition memory was not statistically different between 800 ms and 1200 ms SOA conditions. These results suggested that the expectations of the processing hypothesis was not supported.

Participants were worse in remembering the first pictures than the second pictures. There was further impairment in episodic memory if attentional resources were withdrawn by an additional event, providing converging evidence for the necessity of attention for the consolidation process. Poorer recognition memory was observed for the first pictures than second pictures, because fewer attentional resources were left for the first pictures than second pictures.

The results of the secondary task RT further supported the short-term consolidation hypothesis since dual-task slowing was greatest in the 400 ms SOA condition. The slowing in the secondary task performance was evidence for the bottleneck in the short-term consolidation process. Accordingly, the digit decision task could not be performed until the consolidation process was over and attentional resources were free.

3.6 Experiment 6

The nature of processes whether they are continuous or all-or-none is a topic of interest in cognitive science. The debate on whether memory retrieval is all-or-no or continuous is a good example for this (Slotnick, Dodson, & Chad, 2005; Yonelinas, 2005). The short-term consolidation process may occur in an all-or-none manner or a continuous manner that is influenced by the depth of processing involved at than instance. The goal of this experiment was to examine how episodic memory was influenced by orienting task and presentation duration. The short-term consolidation hypothesis expects better memory until the sufficient time for a successful consolidation process (e.g. 800 ms). In other words, no increment in memory performance was anticipated after people had enough time for consolidation of these information (e.g. after 800 ms). If consolidation is an all-or-none process, memory performance should not be affected by the depth of processing during consolidation.

Words were shown in a rapid serial visual presentation sequence with a presentation duration of either 200 ms, 400 ms, 800 ms, or 1200 ms in this experiment. Participants were asked to engage in 4 different orienting tasks for each for these sequences. In each block, they were asked to count the number of words that were in uppercase, that had one syllable, or that were living. In the forth condition, subjects were requested to study the words intentionally for a later memory test without any counting.

3.6.1 Method

<u>Participants.</u> A total of 32 students (19 female and 13 male) from the University of Toronto participated in the experiment after providing informed consent. All received monetary compensation. The participants were native English-speakers. They were between 19 and 30 years old (*M*=23.88, *SD*=2.15).

Design. The current experiment used a 4 (orienting task: orthographic, phonological, semantic, and intentional) X 4 (presentation duration of words: 200 ms, 400 ms, 800 ms, and 1200 ms) within-subjects design.

Materials. A total of 400 concrete nouns were used in the experiment. Sixteen lists of 15 words were created for the encoding session of the experiment. Four lists each consisting of 80 words were generated for the recognition tests. The first three and the last two words in each list at encoding were not used in the recognition test in order to eliminate primacy and recency effects. Encoding and test lists were matched for length and Kucera-Francis written frequency. Test lists were also matched for number of words that were in uppercase, that had one syllable, and that were living at encoding, For each encoding task a test list was generated by using all presentation durations. As a result, 40 words (4 presentation durations X 10 word in each encoding list) were targets, whereas 40 words were new words serving as distractors for each recognition test. The lists were created so that the correct answer of one particular list for all of the levels of processing tasks was the same having a value between 6 and 9. The possibly of having each of these value is the same (25% of 6, 25% of 7, 25% of 8,. 25% of 9, 25% of 10) in order to balance correct answers (i.e. 6, 7, 8, 9) in the orienting task. The words in the recognition test were presented in title case (e.g. Shrimp) in order to minimize orthographic priming from the encoding session.

Procedure. Participants were given the following instructions: "You will be presented with lists of words. With each list of words you will perform one of the following tasks. Case: Count the number of words that are in uppercase (capital letters). Syllable: Count the number of words that have one syllable. Animacy: Count the number of words that are names of living things (butterfly). An example of a non-living word is pipe. Memorize: Study the words for a later recognition test. Please note that the words under the memorization condition must be remembered for a memory test that will follow the presentation of all the word lists. Please note that words may be presented very rapidly in some blocks. If you could not count all the words, please make your best guess. There is no time limitation to indicate your response”. At the beginning of each block, subjects were presented a cue in the middle of the screen requesting them to count the number of either uppercase words, one syllable words, or living words depending on whether the encoding task was orthographic, phonological, or semantic, respectively. The blocks were initiated by the press of a key on the keyboard. Afterwards, all of the 15 words in the encoding block were presented for either 200 ms, 400 ms, 800 ms, or 1200 ms depending on the presentation duration condition. For one participant the order of tasks was like that: orthographic-200 ms, phonological-200 ms, semantic-200 ms, intentional-200 ms, orthographic-400 ms, phonological-400 ms, semantic-400 ms, intentional-400 ms, orthographic-800 ms, phonological-800 ms, semantic-800 ms, intentional-800 ms, orthographic-1200 ms, phonological-1200 ms, semantic-1200 ms, intentional-1200 ms. The order of conditions (encoding task X presentation duration) was counterbalanced across participants. The order of encoding and test lists was fixed across participants which enabled rotated assignment of word lists to experimental conditions so that that each word list was presented equally often in all the conditions of the experiment.

After presentation of the 16 encoding lists, the participants were administered a recognition test for all the words that they had seen including orthographic, phonological, semantic, and intentional tasks. The recognition test can be considered as a surprise test for the words presented in the incidental (orthographic, phonological, and semantic) conditions, because participants were told that they would have a test just for the words presented in the intentional condition In the recognition test, the words in each test list were presented in random order for each subject. Participants were told to press the “Z” key if they recognized studying the word and to press the “M” key if the word was a new word, not presented in the experiment. Each word was presented for a maximum duration of 10 sec in the test.

After the response of the participant, the next test word was shown immediately in order to decrease the total duration of the experiment.

3.6.2 Results

Memory task. A two-way within-subjects ANOVA with orienting task (orthographic, phonological, semantic, and intentional) and presentation duration (200 ms, 400 ms, 800 ms, and 1200 ms) as factors was run on corrected recognition. There were significant effects of orienting task, $F(3, 93) = 13.30$, $MSE=0.058$, $p<.001$, and of presentation duration, $F(3, 93) = 33.04$, $MSE=0.026$, $p<.001$, and a significant interaction between orienting task and presentation duration, $F(9, 279) = 3.78$, $p<.001$. Six paired-samples t tests were conducted to follow-up pairwise comparisons for effect of orienting task on corrected recognition. Differences in mean accuracy were significant between case and semantic tasks, $t(31)= 5.17$, $p<.001$, between semantic and intentional tasks, $t(31)= 4.93$, $p<.001$, between orthographic and phonological tasks, $t(31)= -2.87$, $p=.007$, and between phonological and semantic tasks, $t(31)= 2.82$, $p=.008$, but not significant between phonological and intentional tasks, $t(31)= -2.09$, $p=.045$, and not significant between orthographic and intentional tasks, $t(31)= -1.56$, $p=.13$. These results suggest such a pattern for episodic memory: Semantic > Phonological >Orthographic., which is consistent with previous findings (e.g. Craik & Tulving, 1975)

Separate ANOVAs showed significant effects of presentation duration on corrected recognition when the orienting task was phonological, $F(3, 93) = 14.70$, $MSE=0.026$, $p<.001$, when the orienting task was semantic, $F(3, 93) = 29.52$, $MSE=0.020$, $p<.001$, and when the participants were intentionally asked to study the words for a later memory test, $F(3, 93) = 4.89$, $MSE=0.025$, $p=.003$. On the other hand, the separate ANOVA indicated no effect of presentation duration when the participants engaged in the orthographic task, $F(3, 93) = 1.55$, $MSE=0.025$, $p=.21$.

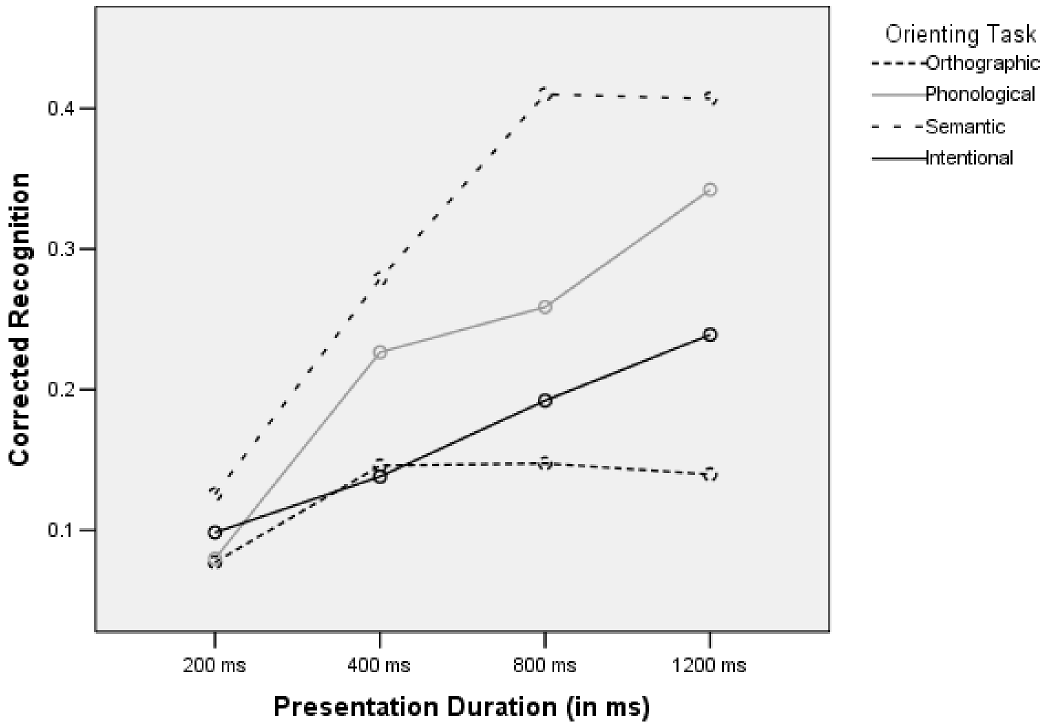

Figure 3.18. Mean corrected recognition performance as a function of orienting task and presentation duration

Planned comparisons were conducted for contrasting means of corrected recognition for the phonological task when presentation duration was 200 ms versus 400 ms, 400 ms versus 800 ms, and 800 ms versus 1200 ms by applying Holm's sequential Bonferroni procedure. Planned comparisons based on the goal of the current experiment (to examine whether performance increased as SOA was increased until 800 ms) were carried out instead of all possible comparisons in order to decrease Type I error rate. Differences in mean corrected recognition for the phonological task were significant between 200 ms and 400 ms, $t(31)= -3.57$, $p=.001$, and between 800 ms and 1200 ms, $t(31)= -2.30$, $p=.028$, but there was no significant difference in for the phonological task between 400 ms and 800 ms, $t(31)= -0.76$, $p=.46$, indicating that corrected recognition was higher at 1200 ms (*M*=.34, *SD*=.22) than at 800 ms (*M*=.26, *SD*=.22), higher at 400 ms (*M*=.23, *SD*=.24) than at 200 ms (*M*=.08, *SD*=.1), but performance was not different between 800 ms (*M*=.26, *SD*=.22), and 400 ms (*M*=.23, *SD*=.24).

Planned comparisons were carried out for comparing means of corrected recognition for the semantic task when presentation duration was 200 ms versus 400 ms, 400 ms versus 800 ms, and 800 ms versus 1200 ms by applying Holm's sequential Bonferroni procedure. Differences in mean corrected recognition for the semantic task were significant between 200 ms and 400 ms, $t(31)= -5.09$, $p<.001$, and between 400 ms and 800 ms, $t(31)= -4.34$, $p<.001$, but not between 800 ms and 1200 ms, $t(31)= 0.10$, $p=.92$, showing that corrected recognition increased significantly as presentation duration was increased from 200 ms ($M=.13$, $SD=.14$) to 400 ms ($M=.28$, $SD=.15$), from 400 ms ($M=.28$, $SD=.15$) to 800 ms ($M=.41$, $SD=.19$), but there was no more increase in memory performance after 800 ms. Corrected recognition was not different between 800 ms ($M=.41$, $SD=.19$) and 1200 ms ($M=.41$, $SD=.20$).

In order to examine means of corrected recognition for the intentional task when presentation duration was 200 ms versus 400 ms, 400 ms versus 800 ms, and 800 ms versus 1200 ms, planned comparisons were done. There was no difference in mean corrected recognition for the intentional task between 200 ms and 400 ms, $t(31)= -1.09$, $p=.28$, and between 400 ms and 800 ms, $t(31)= -1.43$, $p=.16$, and between 800 ms and 1200 ms, $t(31)= -1.32$, $p=.20$, showing that corrected recognition performance was not better when presentation duration was lengthened from 200 ms ($M=.10$, $SD=.14$) to 400 ms ($M=.14$, $SD=.17$), from 400 ms ($M=.14$, $SD=.17$) to 800 ms ($M=.19$, $SD=.18$), and from 800 ms ($M=.19$, $SD=.18$) to 1200 ms ($M=.24$, $SD=.24$). On the other hand, corrected recognition was higher for 1200 ms ($M=.24$, $SD=.24$) than 200 ms ($M=.10$, $SD=.14$), $t(31)= -3.00$, $p=.005$, when Holm's sequential Bonferroni procedure was applied to follow-up post hoc comparisons (see Figure 3.18).

Orienting task. A two-way within-subjects ANOVA was conducted in order to examine the how performance in the orienting task was influenced by presentation duration (200 ms, 400 ms, 800 ms, and 1200 ms) and task (orthographic, phonological, and semantic). The error in the orienting task was determined by the absolute difference between the value of the subject's response and the value of the correct answer for that task. For instance, if the participant counts 5 uppercase words and presses the "5" key and the correct answer is 8, the error for that task is calculated as 3 (|5-8|=3). Smaller value of the error in the orienting task is associated with better performance. The results for the ANOVA suggested a significant effect of orienting task, $F(2, 62) = 13.38$, $MSE=3.324$, $p<.001$, a significant effect of presentation duration, $F(3, 93) = 25.52$, $MSE=1.875$, $p<.001$, but no interaction between orienting task and presentation duration, $F(6, 186) = 1.12$, $p=.35$.

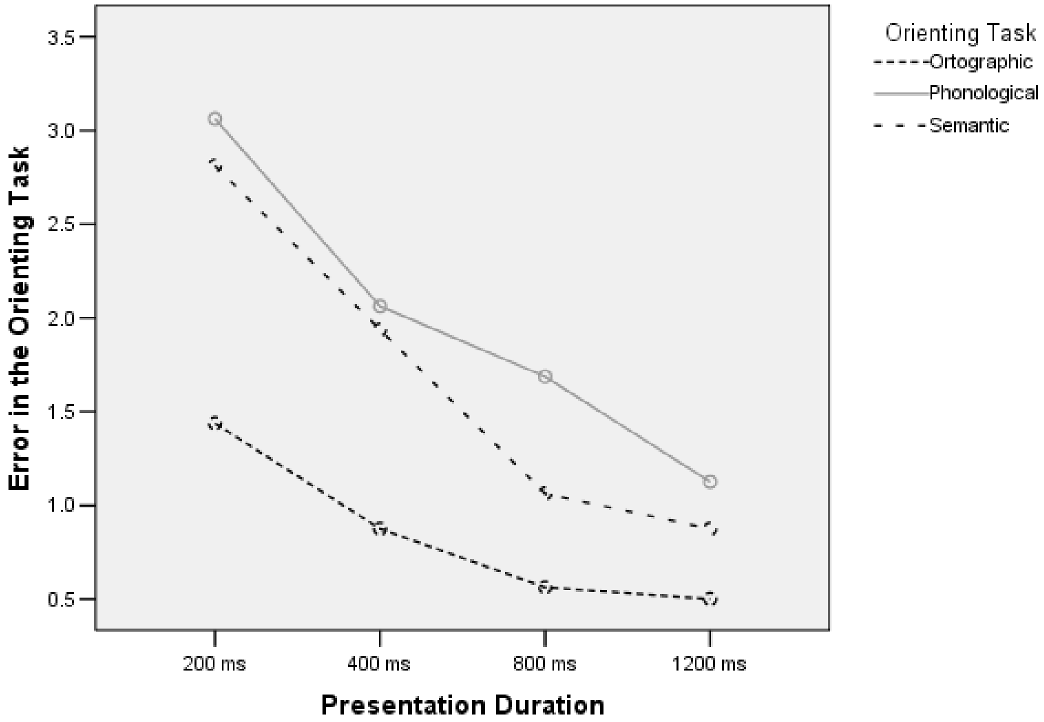

Figure 3.19. Mean accuracy in the orienting tasks s a function task and presentation duration. Smaller values are associated with better performance.

Three paired-samples *t* tests were conducted to follow-up pairwise comparisons for effect of orienting task on accuracy. Differences in mean accuracy were significant between orthographical task and phonological task, $t(31)= -5.12$, $p<.001$, and between orthographical task and semantic task, $t(31)= 3.92$, $p<.001$, but not significant between orthographical task and semantic task. As can be seen in Figure 3.19, subjects were less accurate in the orthographic task ($M=.84$, $SD=1.02$) than both in the phonological task ($M=1.98$, $SD=1.25$) and in the semantic task ($M=1.67$, $SD=1.10$).

Three planned comparisons were carried out for contrasting means of accuracy in the orienting tasks when presentation duration was 200 ms versus 400 ms, 400 ms versus 800 ms, 800 ms versus 1200 ms. Differences in mean accuracy were significant between 200 ms and 400 ms, $t(31)= 3.60$, $p=.001$, and between 400 ms and 800 ms, $t(31)= 2.24$, $p=.033$, but not between 800 ms and 1200 ms, $t(31)= 1.22$, $p=.23$. These results indicated that participants performed better in the orienting tasks when the presentation duration of words was 800 ms (M=1.10, SD=1.15) than when it was 400 ms (M=1.63, SD=1.17) and when the presentation duration of words was 400 ms (M=1.63, SD=1.17) than when it was 200 ms (M=2.44, SD=1.00), but subjects did not outperform when they words were shown for 1200 ms (M=.83, SD=1.03) than 800 ms (M=1.10, SD=1.15).

3.6.3 Discussion

The goal of the current experiment was to examine the effects of levels of processing and presentation duration of words on episodic memory performance. The results partially supported the levels of processing framework (Craik & Lockhart, 1972). Performance in the recognition test depended on the depth of processing (Craik & Tulving, 1975). Deeper processing of the words yielded better memory performance. However, episodic memory for intentionally studied words were lower than the ones studied under semantic task. This may be due to inability of participants to employ appropriate processing in the intentional condition when words were presented rapidly.

Most importantly, performance improved as presentation time was increased from 200 ms until 800 ms in the semantic task. There was no further enhancement of memory after 800 ms. These results supported the short-term consolidation hypothesis. On the other hand, such a pattern was not observed in phonological task. The results indicated that the average accuracy in the phonological task did not reach asymptote when presentation duration was 1200. Participants might need more than 1200 ms for deciding whether words had one syllable or not. Episodic memory increased linearly as people viewed the words longer.

These results suggest that the short-term consolidation is not an all-or-none process. The depth of processing influenced the consolidation process, and consequently affected memory performance. The results of the current experiment can be also considered as a sign that consolidation involves conceptual processing, because accuracy in the orienting task and corrected recognition reached asymptotic level just for the semantic task. As can be seen in Figure 3.18, the pattern of results in previous experiments for the short-term consolidation process is most similar to the pattern of results in the semantic task in the current experiment. In other words, memory performance increased as SOA increased and performance reached asymptotic level about 800 ms for the short-term consolidation. A similar pattern is observed only when the orienting task is semantic.

CHAPTER 4

GENERAL DISCUSSION

The goal of this study was to investigate the effect of dividing attention and the SOA between targets (words, pictures, or stickmen figures) and masks on episodic memory. Results of Experiment 1 showed that decreasing the SOA from 1000 ms to 200 ms between pictures and masks impaired recognition memory when central attentional resources were engaged during mask presentation by a secondary task (continuous auditory choice-reaction time), but episodic memory was intact by the manipulation of SOA when attentional was fully paid to pictures. Experiment 2 extended the findings from Experiment 1 to a different memory test (free-recall), stimulus type (words), secondary task (digit decision task) and SOAs (400 ms, 800 ms). Memory performance was lower when the SOA was 200 ms and 400 ms for DA compared to FA but not when the SOA was 800 ms, suggesting that the participants needed more than 400 ms uninterrupted processing time for a successful memory encoding.

Experiment 3 provided converging evidence for the important role of attention in the short-term consolidation process by demonstrating impaired recognition memory when the SOA was too short for a successful consolidation and attention was divided by a secondary task. On the other hand, SOA did not influence memory performance when no secondary task consumed common attentional resources necessary for the consolidation process. Electrophysiological results obtained in Experiment 3 demonstrated that impaired memory performance did not stem from disrupted perception of targets. N1 and P1 waves, associated with perceptual processes of words were unaffected by attention and SOA. These results showed that presentation of the noise mask immediately after the stimulus to be remembered did not impair perception of the stimulus in the short SOA conditions

There was no difference in P300 and sustained negative waves in parietal lobes between DA and Ignore conditions in Experiment 3. These components were associated with registering information to working memory and performing arithmetical calculations. These results showed that participants did not engage in qualitatively different mental operations after the onset of digits between DA and Ignore conditions. There was no delay in the time course of P300 and sustained negativity, so it seems that participants performed the secondary task immediately when they saw the digits on the screen. Participants did not employ specific strategies such as performing the memory task and the secondary task simultaneously or performing the secondary task with some delay for studying the words longer in the DA condition.

P550 component, which was associated with registering information in the hippocampal complex, was intact when attention was full and SOA was long. Although the *t* test was not statistically significant, one can visually identify a P550 component in the DA condition. This wave was smaller than the one in DA condition. Accordingly, medial temporal lobes may be proposed to be more active in the FA condition compared to the DA condition. No P300 in the DA short SOA condition, but intact P300 waves were expected in the other three conditions. However, P300 of words were overlapped by the sensory evoked potentials of digits in the short SOA conditions. For this reason, it was not possible to identify individual P300 waves in these conditions.

The interaction between attention and SOA was not significant when stick figures were used as stimuli in Experiment 4. The non-significant interaction may be as a result of difficulty of the memory task. It may be very hard for the participants to discriminate between targets and distractors in the recognition text since the figures were very similar to each other.

Two pictures were presented consecutively followed by the digit decision task in each trial in Experiment 5 to determine whether the addition of an attention-demanding task would trigger more impairment in episodic memory. Poorer memory performance was expected for the first target than the second target, because more attentional resources were withdrawn for the first target (by the second picture and the digit decision task) than for the second target (by only the digit decision task). This expectation was confirmed, indicating the important role of attention for the consolidation process. According to the short term consolidation hypothesis, memory performance was lower for the first pictures than the second pictures in the recognition test, because fewer attentional resources were left to the first pictures when attentional resources were consumed by both the digit decision task and processing of the second picture.

The goal of Experiment 6 was to examine whether short-term consolidation process was an all-or-none process or a continuous process that was influenced by the depth of processing. Levels of processing had an effect on memory performance. As participants engaged in deeper processing, their performance increased. These results could be considered as evidence for the continuous nature of the short-term consolidation process. Consolidation is not an all-or-none process.

The results of analysis on secondary task RT in general showed that a dual-task slowing occurred in the short SOA conditions. Slower performance in the secondary task is a sign of the bottleneck for the short-term consolidation. Accordingly, when the SOA was short, the secondary task could not be processed during the time course of consolidation of the target for episodic memory. Processing of the secondary task was postponed until short-term consolidation of the target was over.

A dual-task slowing was present in the long SOA condition in Experiment 2. This result was in contrast to the short-term consolidation hypothesis. However, the consolidation hypothesis expects a slowing in the secondary task for the short SOA condition when the processing resources are busy with the consolidation of the stimulus in the memory task. This may be as a result of having secondary task only trials within a block intermixed with normal trials that include memory and secondary tasks. Participants may not concentrate on the secondary tasks in the normal trials because of these infrequent randomly presented trials.

The findings do not show a sign of a trade-off between the memory task and the secondary task. A trade-off is a cost on a task when more emphasis is given on the other task. If there is a trade-off a between memory and secondary tasks, then there should be a slowing in the secondary task for the long SOA conditions when more effort is spent on the long SOA conditions in which memory performance is superior. However, the results suggested that although participants were more successful in the long SOA, their secondary task RT was not longer in the long SOA conditions than short SOA conditions. These results rule out the trade-off hypothesis.

Although the goal of this study was not to find the time course of consolidation, the results suggested that the consolidation process took more than 400 ms and less than 800 ms. This finding is consistent with rapid serial visual presentation, attentional blink, and dual-task interference literature. Potter (1976) suggested that 400 ms was needed for a successful consolidation of a scene in a RSVP stream. Attentional blink occurs when the interval between the first and the second target was within 200–500 ms (Broadbent & Broadbent, 1987; Weichselgartner & Sperling, 1987; Raymond, Shapiro, & Arnell, 1992). Jolicoeur and Dell'Acqua (1999) demonstrated the dual-task inference on the consolidation of letters of the auditory discrimination task within 400 ms. However, the time course of consolidation in visual-short term memory was suggested to be 50 ms per item (colored squares), which is slower than the one proposed in this study. Vogel et al. argued that the reason for their fast consolidation was their use of simple colored objects, and utilization of simple-task procedure rather than dual-task procedure.

4.1 The Processing Time Hypothesis

Alternative to the consolidation hypothesis, these results can be explained by a processing time hypothesis such that when people have more time to process information, they will have better memory performance. In order to test this hypothesis, performance differences in recognition memory between 400 ms, 800 ms, and 1200 ms SOA conditions were contrasted. The processing time hypothesis expects better performance for 1200 ms than 800 ms, because people will have more processing time for 1200 ms SOA. On the other hand, the consolidation hypothesis expects nearly equivalent performance in these two SOA conditions, since previous research suggested that consolidation process was over after 500 ms. Moreover, the consolidation hypothesis expects worse performance when the SOA is 400 ms than when the SOA is 800 ms, because consolidation will be interrupted when attentional resources are used by another task within 500 ms. The results supported the consolidation hypothesis such that no more increment was observed as the SOA was increased from 800 ms to 1200 ms in Experiment 5. Such a pattern was also present in Experiment 6 for the animacy task.

4.2 The Useful Encoding Time Hypothesis

Another possible account for the interaction between attention and SOA is that participants who are ignoring the secondary task in full attention conditions can keep processing each stimulus to some extent during the secondary task interval. Thus, in such conditions participants have “useful encoding time” of SOA between the targets and masks plus secondary task interval. The useful encoding time hypothesis holds the view that longer total amount of encoding time, that is, the exposure time plus the uninterrupted post-stimulus interval, will result in better memory (Hines & Smith, 1977). Better performance of subjects in full attention conditions may be a result of engagement of further processing such as rehearsal, elaboration, and organization during the interval of secondary task.

The useful encoding time hypothesis seems to explain reasonably the results of Experiment 1 and Experiment 2, but the results of Experiment 5 (2 pictures per trial) disconfirmed the useful encoding hypothesis. There was no full attention condition in Experiment 5, thus the finding of no more increase in memory performance as the SOA was increased from 800 ms to 1200 was problematic for useful encoding hypothesis, because it expects better performance as people have more useful encoding time. On the other hand, the useful encoding hypothesis may assume that subjects can continue to process the second picture during the secondary task for an estimate of 300-500 ms of extra useful encoding time than the first picture. Accordingly, participants will have 400, 800, 1200 ms of useful encoding time for the first pictures, whereas participants will have (say) 900, 1300 and 1700 ms of useful encoding time for the second pictures.

However, if this assumption were true, then the reaction time of the subjects in the secondary task should have been about 500 ms greater than the ones in the second experiment. However, RT was nearly the same (about 1500 ms) between Experiment 2, Experiment 5, and Experiment 3. Electrophysiological results also demonstrated that participant did not engage in different processes in the DA and Ignore conditions. There was no delay in P300 for digits and sustained negativity associated with calculating the digits in the DA condition compared to the Ignore condition. Besides, subjects were told that the secondary task (digit decision task) was more important than the memory task and they were told to give more priority to the secondary task than to the memory task.

A study by Shaffer and Shiffrin (1972) showed that duration of the blank post-stimulus interval had no effect on recognition memory for visual scenes (see also Proctor, 1983). They argued that complex pictures were processed just during their exposure duration. Haber (1970, cited in Weaver, 1974) argued that recognition memory for pictures did not involve verbal rehearsal of these visual stimuli. Contrary to results of experiments that utilized visual information, the exposure duration of verbal information did not determine memory performance (Atkinson & Shiffrin, 1968; cited in Tversky & Sherman, 1975). Moreover, Intraub (1979) demonstrated that better memory performance for the words that were shown longer in rapid serial presentation paradigm was not due to more time for verbal coding.

In addition to these experiments, the results of Experiment 6, which examined the effects of levels of processing and exposure duration of words, showed that performance did not improve anymore when exposure duration was increased from 800 ms to 1200 ms for the animacy task. On the other hand, performance linearly increased in the intentional memory task. This showed that when participants did not need to process information (like rehearsing) after the present task as in animacy task, memory did not improve after some time. The results of the Experiment 6 are also problematic for the useful encoding time hypothesis.

4.3 Impaired Perception Hypothesis

The drop in episodic memory could not be explained by the impairment of perception when the SOA between targets and masks was short, because episodic memory was intact for short SOA conditions when participants paid full attention to the memory task. No independent measurement of perception has been made in this study. However, the exposure durations of targets were not less than the ones used by Potter (1976) and Vogel et al. (2006). These studies showed that perception was unimpaired for brief presentations. Besides, N1 and P1 waves, which are associated with perceptual processing of words were not influenced by attention and SOA in Experiment 3.

4.3 Limitations of the Study

The current study has some limitations that should be addressed. The first limitation is the small sample size of the individual experiments. This problem has an influence on statistical power and generalizability of the results. Another limitation is the validity and reliability of the measures that were employed in this study to capture episodic memory performance.

An array of three digits between 0 and 6 or 1 and 5 were presented randomly in the digit decision task. The difficulty of the trials in this task is not equal. For instance a trial is easier if the digit array is "##1#1#1##" than it is "##6#3#5##". Therefore, the difficulty of digit decision task may be unequal between different SOA conditions, because random presentation of trials do not guarantee even distribution of difficulty of digit decision task within different SOA conditions. This problem can contaminate secondary task RT.

Although the participants were instructed to give higher priority to the secondary tasks in order to stop studying the targets and to process the secondary task immediately, there is a possibility that subjects did not follow these instructions. Moreover, participants may employ specific strategies to cope with different experimental conditions. For instance, participants may delay performing the secondary task while they are studying the targets.

Another limitation of the study was the inability to identify P300 and P550 components of words in the short SOA conditions. The digits were presented 200 ms after the words, so the strong sensory evoked potentials (N1 and P1) of digits overlapped with the components for words. Therefore, ERP analyses could not be performed on P300 and P550 components for short SOA conditions.

4.4 Conclusions

Taken together, these results suggested that withdrawal of central attentional resources by an attention-demanding task within 400 ms after the onset of the target caused an impairment in memory performance. On the other hand, when the attentional resources were not consumed by a secondary task, the visual mask did not affect episodic memory. Presenting an attention-demanding task after the completion of the short-term consolidation process (e.g. after 800 ms) did not reduce episodic memory performance, showing that people needed some amount of uninterrupted processing time (e.g. more than 400 ms and less than 800 ms) to consolidate words or pictures. This process is very vulnerable to interference such that if the consolidation process is interrupted by an attention-demanding task, the memory trace will be lost.

The drop in episodic memory in short SOA conditions might be due to impairment of perception in brief presentations. Electrophysiological data showed that ERP waves related with perception of information was intact when SOA was short, demonstrating that memory impairment did not result from perceptual processes but rather post-perceptual processes.

When the SOA between targets and masks was shorter than the necessary time for the short term consolidation process, a slowing in secondary task performance was observed. This was a sign of the short-term bottleneck such that processing of the secondary task could not be carried out until the consolidation of the target was completed.

In sum, visual input received from the eyes is initially stored in the visual sensory register (Dick, 1969). After this sensory encoding stage, patterns are recognized (Jolicoeur & Dell'Acqua, 1998). Recognition of patterns activates conceptual representations when relevant information from the long-term memory is retrieved (Potter, 1999). However, these early conceptual representations are vulnerable to decay or interference if they are not further processed (Potter, 1993). These early representations need to be transferred into more permanent form. This process, called short-term consolidation, needs attentional resources. When attention is withdrawn before information is fully consolidated, the conceptual representations will be lost.

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