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Short-Term Consolidation of Information for Episodic Memory: The Role of Attention[1]

Anısal Bellekte Bilgilerin Kısa-Süreli Konsolidasyonu: Dikkatin Rolü

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Abstract

Pieces 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 perceptual representations to a more durable form 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. Three 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 performed the attention-demanding secondary task after the presentation of the masks, whereas participants in the full attention condition were not requested to perform the secondary task after the presentation of 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.
Keywords: short-term consolidation, episodic memory, dual-task, mask.

Öz

Hızlı seri görsel sunum, dikkat kırpması, ve ikili görev bozulmaları olgularından elde edilen kanıtlar insanoğlunun kısa-süreli konsolidasyon sürecinde anlamlı bir sınırlılığı olduğunu öne sürmektedir. Kısa-süreli konsolidasyon, görsel temsillerin daha kalıcı bellek biçimlerine transfer edilmesidir. Yapılmış çalışmalar hedef uyaranlardan sonra gösterilen maskelerin bilgilerin konsolidasyonunu yarıda kestiğini göstermesine rağmen, bilgilerin anısal bellek için konsolidasyonunda dikkatin rolü hakkında yeterli kanıt yoktur. Dikkatin ve hedef uyaran ile maske arasındaki uyaran başlangıcı senkronizasyonsuzluğunun (UBS) anısal belleğe etkisini incelemek için üç 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

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bellek performansını düşürürken tam dikkatte performansı etkilememiştir. Bu bulgular kısa-süreli konsolidasyon sürecinde dikkatin gerekliliğini desteklemektedir.
Anahtar sözcükler: kısa-süreli konsolidasyon, anısal bellek, ikili görev, maske.

Introduction

People sometimes fail to remember events. One reason for forgetting is retrieval failure (Cleary, 2014), which is inability to find an existing memory trace. Another cause is storage failure, which is the inability to create a permanent memory trace (Parkin, 1993). Pieces of evidence from rapid serial visual presentation (RSVP), attentional blink (AB), masking, and dual-task paradigms have suggested that the human cognitive system has also a limitation in transferring early perceptual representations to a more stable form of memory (De Schrijver, & Barrouillet, 2017). This critical process, called short-term consolidation (Ricker & Hardman, 2017) has an important role for the successful storage of information for episodic memory.

Evidence from the Rapid Serial Visual Presentation Paradigm

Human beings have a huge capacity for storing pictorial information (Brady, Konkle, Alvarez, & Oliva, 2008). Recognition memory performance for 10,000 pictures presented for 5 seconds was very high (Standing, 1973). However, sequentially presented photographs of ordinary scenes that were shown for a brief period of time (e.g., 333 ms) were recognized very poorly (Potter, Staub, & O'Connor, 2004). Recognition memory decreased from 93% to 16% as the presentation duration of pictures was decreased from 2000 ms to 125 ms (Potter & Levy, 1969). Robinson, Grootswagers, and Carlson (2019) showed that the limits in visual processing were due to shorter SOA but not shorter presentation duration. Evidence from RSVP studies indicated that if representations activated by perception were not engaged in further processing, they were open to interference (Potter, Staub, Rado, & O'Connor, 2002).

The impairment in memory performance may be due to the 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 at the highest rates, suggesting that people had an intact perception of these pictures. Presenting a visual noise mask that did not require conceptual processing after the picture within the interstimulus interval (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 the presentation of pictures in a continuous sequence from 0 ms to 1390 ms increased recognition scores from 20% to 84%. These findings demonstrated the attention-demanding pictures 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 conceptual processing (about an additional 300 ms) after perception was interfered with by a following attended picture (Potter, 1976). In other words, if representations activated by perception were not engaged in further processing, they were open to interference (Potter et al., 2002).

Evidence from the Masking Paradigm

Evidence from the masking paradigm further supports the existence of a short-term consolidation process. In their study, Loftus and Ginn (1984) presented masks after picture targets displayed for 50 ms. They manipulated delay between pictures and masks (0 ms, 300 ms) and attention demand of masks. Increasing attentional requirements of masks by using naturalistic photographs rather than using noise patterns reduced memory performance provided that the SOA between the offset of the pictures and masks was 300 ms. These results showed that attentional demand influenced conceptual processing when masks were presented 300 ms after the onset of pictures (Loftus & Ginn, 1984).

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, 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 shapes and attended digits impaired recognition of random shapes to almost chance levels if total processing time for random shapes was between 50 ms to 150 ms. However, when the total processing time was increased, the masks were less disruptive of recognition performance. Any kind of ignored mask or the grid mask did not have an impact on memory, indicating that the meaningfulness of the 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 the 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. Participants were asked to detect if there was a change in the memory and test arrays. As the SOA between the memory array and the mask increased, performance in the change detection task improved and finally reached asymptote. Xu (2017) argues that once the consolidation process is completed, masks no longer impair performance. The larger the memory array, the more processing time was required for the 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 working memory (WM) consolidation. If the representations in WM are consolidated, they can survive long periods of time. Nevertheless, if they are not consolidated, they will decay in a few hundred milliseconds.

In order to rule out the possibility that masks impaired perception, Vogel et al. (2006) administered a visual search task. Participants were very successful in the search task, indicating that consolidation but not perception was damaged by masks. 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 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.

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. When two targets were presented among distractors in RSVP at rates of approximately ten stimuli per second, identification of the first target (T1) caused an impairment of reporting the second target (T2) if it appeared within 200–500 ms (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 AB stemmed from the attention to T1. In addition, AB was reduced or eliminated when the item immediately after T1 was replaced by a blank interval (Chun & Potter, 1995). If the second target is the last item in the stream, no AB was observed (Giesbrecht & Di Lollo,1998). This shows that visual masking of the T2 was a necessary condition for the attentional blink phenomena. Recent electrophysiological evidence suggests that masking reduces not only encoding but also engagement of attention on the target (Losier, Lefebvre, Doro, Dell'Acqua, & Jolicoeur, 2017).

Manipulations that influenced the consolidation of T1 were shown to affect AB. Christmann and Leuthold (2004) varied T1's contrast to examine the influence of the difficulty of processing the first target on the magnitude of the attentional blink. The accuracy of identifying T2 was smaller when stimulus contrast was lower. These findings indicate that when the perceptual processing of the T1 was more demanding, it was harder to consolidate this information. Since processing resources were used by T1 for a longer duration, there would be a longer delay for the consolidation of T2. As a result, T2 would have a higher probability of decay (Chun & Potter, 1995). Chun and Potter's two-stage model of the AB 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 T2 when the processing resources were used by the T1. 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.

Electrophysiological studies have provided further evidence that the consolidation bottleneck is responsible for the AB. Vogel and Luck (2002) found that the P3 wave was suppressed when the second target was followed by a mask (AB condition). On the other hand, when the second target was the last item in the stream (no AB condition), P3 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 post-perceptual stage. They reasoned that meaning could be extracted but could not be reported. Consistent with this result, many studies have shown semantic priming from the T2 words in AB experiments (Visser, Merikle, & Di Lollo, 2005). More recently, it is also argued that AB occurs due to disrupted attentional engagement to the second target (Wyble, Bowman, & Nieuwenstein, 2009; Zivony & Lamy, 2016).

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 the encoding of visual information and concurrent processing of another task when both tasks require central mental resources (Jolicoeur, 1999). A visual stimulus containing characters was presented first, followed by an auditory tone at different SOAs (Jolicoeur & Dell'Acqua, 1998). Participants were asked to make a speeded response in the auditory discrimination task and then recall the visual stimulus without any time limitation. Response times to the tones 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.

Slower RT in the tone task at short SOAs was eliminated when participants ignored the visual stimulus, indicating that the interference did not stem from the presentation of visual stimuli. These results together showed that short-term consolidation of the visual stimulus increased the RT in the auditory task because the processing of the auditory task had to wait until central mechanisms were not used any more by short-term consolidation processes. These results also suggest that the amodal bottleneck occurs even if the modalities of the two tasks are different (Marois & Ivanoff, 2005).

In another kind of dual-task paradigm, first, an auditory signal was presented, followed by a visual stimulus at varying SOAs (Jolicoeur, 1999). 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. 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.

Evidence from Induced Retrograde Amnesia

Presentation of a distinctive item in a list consisting of similar items leads to superior memory performance of the deviant item, known as the von Restorff effect (Fabiani & Donchin, 1995). On the other hand, previous research has demonstrated that facilitation of an event in a list by asking subjects to give more emphasis on it reduced long-term memory for the preceding item (Tulving, 1969). 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. When the presentation rate was increased to 2 seconds per word from 1 second per word, the impairment in memory for the preceding words disappeared. He 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). Schulz and Straub (1972) argued that high-priority events stopped continuing consolidation of the preceding item. Greater attention might be paid to the distinctive information than the others during encoding, and this might reduce the processing of surrounding items (Bireta & Mazzei, 2016). Schmidt and Schmidt (2015) demonstrated that attentional demands of the distinctive stimuli were responsible for the von Restorff effect.

It has been known for a long time that emotion enhances memory, but more recent research has demonstrated that emotion can also impair memory for preceding and succeeding neutral words (Sakaki, Ueno, Ponzio, Harley, & Mather, 2019). 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 the encoding of adjacent neutral words only when the words were presented rapidly. MacKay, Hadley, and Schwartz (2005) proposed that emotional stimuli attract attention, and consequently, there were fewer attentional resources available for the encoding of adjacent stimuli. Arousal-biased competition theory suggests that emotional stimuli are prioritized in attention and gain more limited resources in a winner-take-more manner, whereas neutral stimuli around the emotional stimuli are given low priority and use fewer resources in a loser-take-less manner (Lee, Sakaki, Cheng, Velasco, & Mather, 2014).

Purposes of the Study

Previous research has shown that masks presented after targets can interrupt the consolidation process of information in visual working memory (Vogel et al., 2006). Evidence from RSVP and masking paradigms has suggested that meaningful masks interfere with the consolidation process for episodic memory. However, there is not enough evidence for the role of attention in consolidation for episodic memory. The main goal of this study is to investigate the role of short-term consolidation on episodic memory. Specifically, the effects of attention and SOA between the onset of targets and masks on episodic memory and on secondary task RT are examined in the current study. If consolidation of information requires uninterrupted processing for some amount of time, then the 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.

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

The divided attention (DA) paradigm used in this study was 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 DA condition in this study have to perform the attention-demanding secondary task starting with the onset of the presentation of masks after the presentation of targets. Thus, participants can process the targets uninterruptedly until the presentation of masks in the DA condition. Participants in the full attention (FA) condition are not requested to perform the secondary task after the presentation of masks.

Hypotheses

It is hypothesized that reducing the SOA between targets and masks will cause a deficit in episodic memory for DA but not for FA, because the consolidation process will not be disrupted in FA conditions by mere presentation of masks. It is expected that increasing the SOA more than a sufficient amount of time for short-term consolidation (e.g., 800 ms) will not improve episodic memory.

Another set of dependent variables are accuracy and RT for the secondary tasks in DA conditions. Short-term consolidation of targets is expected to cause lengthening RT for the secondary task presented after the memory task, so RT in the secondary task should be longer in short SOA conditions compared to long SOA conditions. It is also hypothesized that accuracy in the secondary task should not be affected by the SOA manipulation.

Experiment 1

The goal of this experiment was to examine 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 people had an intact perception of the visual stimulus if the SOA between the stimulus and the 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. On the other hand, 1000 ms is long enough for the consolidation process to take place independent of attention. The independent variables were attention and 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.

Method

Participants

Forty-one undergraduate psychology students of the 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 the Departmental Review Committee (DPERC) of the Psychology Department at the 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 FA or DA conditions.

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 chosen from a free image archive (www.morguefile.com) with different content were employed in the study. All of the pictures had identical sizes. They were shown at the center of the screen against a gray background. 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 either target or distractor. The presentation order 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.

Procedure

The experiment was carried out using a PC, and participants were tested individually. Presentation of stimuli with the collection of responses was controlled by the E-prime experimental software package. At the beginning of the study, participants practiced the tasks. Subjects in the DA condition were instructed to respond to the tones as rapidly and accurately as possible. For the DA, participants were told that the memory and secondary tasks were equally important, and they were requested to put equal effort into them.

At the beginning of each block the cue, “Study” and the type of delay either short or long was presented in the middle of the screen (see Figure 1). Afterward, 24 pictures of scenes were presented for 160 ms each, followed in each case by a random noise mask in color shown for 150 ms. 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.

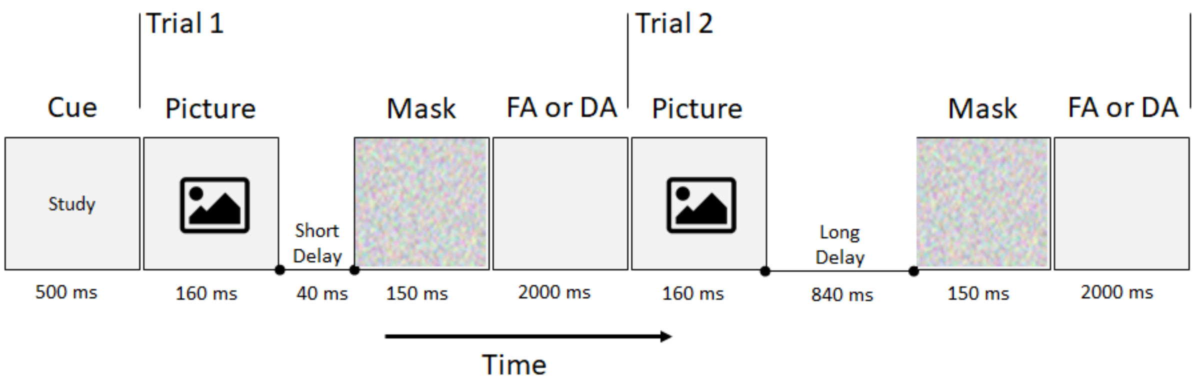

Figure 1. Schematic illustration of two study trials in Experiment 1. DA= divided attention, FA= full attention

After the onset of the mask, there was a 2000 ms delay until the presentation of the next picture. During this delay, participants in the DA condition performed a continuous auditory choice-reaction time (CRT) task, which required subjects to press one of two keys associated with either the low-frequency tone or the high-frequency tone (Naveh-Benjamin, Guez, & Marom., 2003). After the subject’s response, the next tone was presented immediately in a continuous fashion. The participants in the FA condition did not hear any tones.

After the study phase of each picture list, participants were requested to count backward by threes from a predetermined three-digit number for 12 sec to avoid responses based on primary memory. This three-digit number was different in every block. 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 scene 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.

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 the memory performance of that participant was near the chance level. Corrected recognition scores were computed by subtracting the proportion of false alarms from hits for each participant. 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 1. A 2 (attention) X 2 (SOA) factorial analysis of variance (ANOVA) was performed on corrected recognition. Effect sizes were reported as partial eta-squared (partial η^2) where 0.01, 0.06, and 0.14 were considered as small, moderate, and large effects (Cohen, 1988). The main effect of attention was significant, $F(1, 38) = 12.49$, $MSE=.035$, $p=.001$, partial $\eta^2=0.25$. The participants in the FA condition performed better than the ones in the DA condition. The main effect of SOA was also significant, $F(1, 38) = 7.27$, $MSE=.006$, $p=.01$, partial $\eta^2=0.16$. Corrected recognition performance was higher when the SOA was long than when the SOA was short. More importantly, the interaction between attention and SOA was significant, $F(1, 38) = 4.14$, $p=.04$, partial $\eta^2=0.10$, indicating that decreasing SOA impaired memory performance for the DA condition, $t(19) = 2.83$, $p=.01$, but not for the FA condition, $t(19) = .56$, $p=.58$ (see Figure 2) .

Table 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.

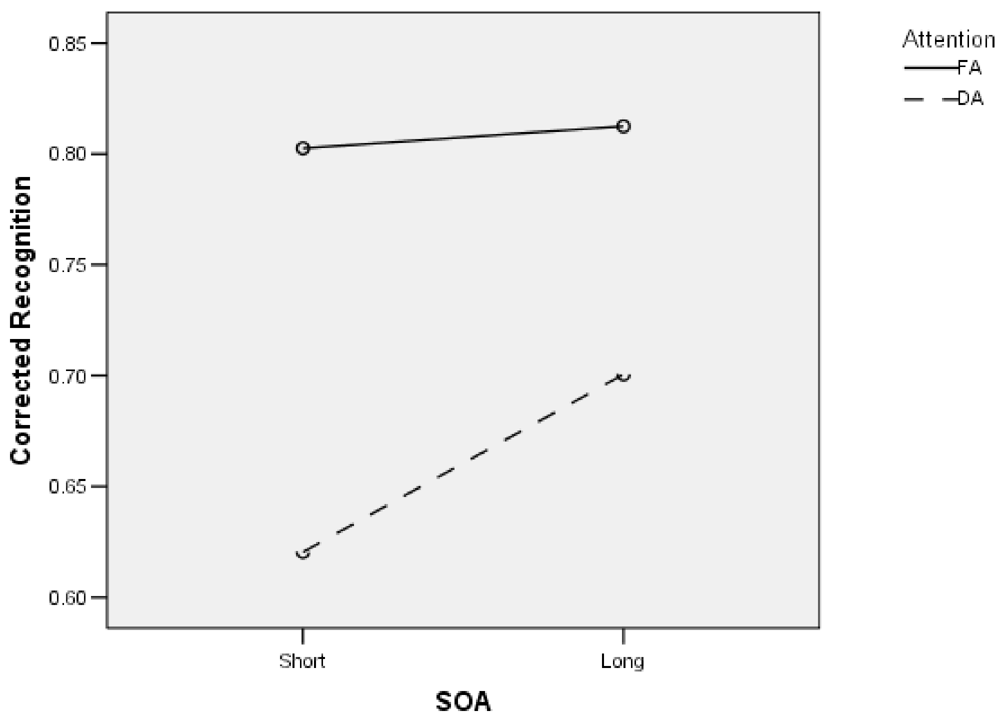

Figure 2. Mean corrected recognition performance as a function of attention and SOA in Experiment 1. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

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 ($M=.93$, $SD=.07$). The effect of SOA on RT of correct responses was not statistically significant, $t(19) = -1.25$, $p=.23$. RT in the short SOA condition

(*M*=.32, *SD*=.14) was not different from RT in the long SOA condition (*M*=.31, *SD*=.11). Similar results were found when both correct and incorrect responses to the secondary task were included in the analysis.

Discussion

The goal of the first experiment was to investigate the effect of attention and the SOA between pictures and masks 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 show that when the consolidation process was interrupted by an attention-demanding task, performance in recognition decreased significantly. These results suggest that when attentional resources were withdrawn by a secondary task, people 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. There was no significant difference on secondary task RT between short and long SOAs.

These findings also indicate that there was no trade-off between the memory task and the secondary task, such that more effort spent on 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 no slowing in the secondary task performance for the long SOA, ruling out the possibility of a trade-off between the memory and secondary tasks.

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. The hit percentage was .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. 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 people 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, words were utilized in this experiment. It is expected that memory performance will be lower when materials are words than pictures. Besides, the perceptual distinctiveness of words is very low. Using words will also enhance the generalizability of the findings.

Another goal of the current experiment was to extend the results of Experiment 1 by using different memory tests and SOAs. For this reason, in addition to the recognition test, a free recall test was administered to measure episodic memory performance. Free recall as a harder memory test has the potential to eliminate the ceiling effect. Three SOAs were used in this study: 200 ms, 400 ms, and 800 ms. It is expected that memory performance will be lower and dual-task RT is larger when attention is divided and SOA is 200 ms or SOA is 400 ms than when attention is divided and SOA is 800 ms, because prior research has suggested that at least 500 ms is needed for the consolidation process to take place. Memory performance should be similar between different SOAs for FA.

Method

Participants

The participants were 20 students of the University of Toronto (14 female and 6 male) who were between 18 and 32 years old (*M*=20.60, *SD*=3.22) 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.

Materials and procedure

The materials and procedures were similar to those in Experiment 1. Instead of pictures, words were used as stimuli. The words were selected from the MRC Psycholinguistic Database (Coltheart, 1981). Words were 4-8 in length (*M*=5.07, *SD*=1.29). Two sets each consisting of 12 lists of 12 concrete noun words were created. An additional two 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). 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. In experiment 1, SOA was manipulated between blocks which caused unequal intertrial interval (ITI) between different SOA conditions. In order to prevent this problem, 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 the 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.

Subjects were presented with each kind of attention block consequently for three times. The order of attention condition was counterbalanced across subjects. The order of word lists was constant across subjects which enabled the 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 three by pressing corresponding keys on the keyboard in 2500 ms. Participants saw a novel digit array in each trial. No auditory stimulus was presented.

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”. Afterward, 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 (see Figure 3). Next, a fixation sign was presented for 500 ms. Afterward, 16 words (12 study plus 2 filler words at the beginning of the block and 2 filler words at the end of the block) 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 the presentation of the fixation sign followed immediately by the presentation of a digit array.

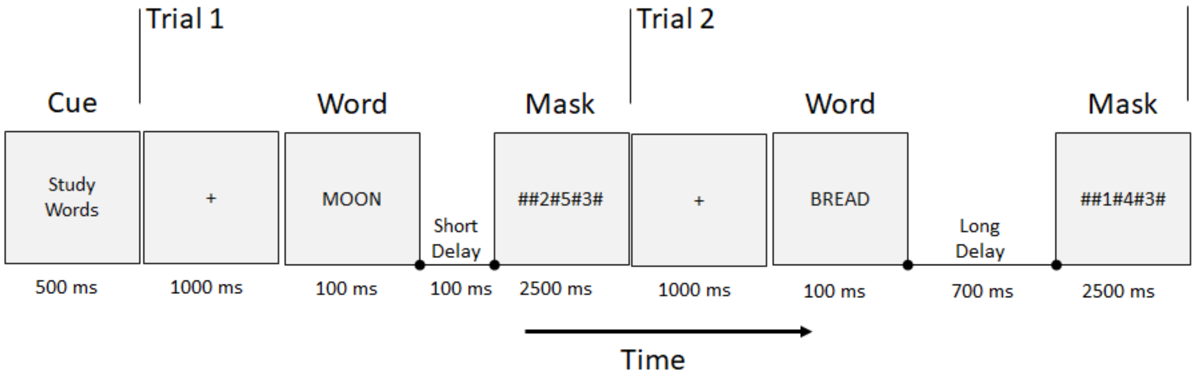

Figure 3. Schematic illustration of two study trials in a block in Experiment 2

After studying each word list, participants were asked to count backward by threes from a predetermined three-digit number for a duration of 12 sec to circumvent responses based on primary memory. In order to minimize recognition judgments based on the assessment of item familiarity, a free recall test was employed. 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 decrease memory performance after obtaining high recognition performance in the pilot work. Each word was presented for 3 sec in the test. Targets, distractors, and additional distractors were presented in random order for each participant.

Results

Memory task

Recognition memory performance in Experiment 2 can be seen in Table 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. The multivariate criterion of Wilks' lambda (Λ) was employed in ANOVA test because the sphericity assumption was violated. There were significant main effects of attention, Λ=.11, F(1, 19) = 159.541, p<.001, partial η^2=0.89; and SOA, Λ=.59, F(2, 18) = 6.30, p=.008, partial η^2=0.41; as well as a significant interaction between attention and SOA, Λ=.59, F(2, 18) = 6.15, p=.009, partial η^2=0.41. Separate ANOVAs show a significant effect of SOA on corrected recognition for DA, F(2, 38) = 9.11, MSE=.007, p=.001, partial η^2=0.32, but not for FA, F(2, 38) = 0.65, MSE=.005, p=.53, partial η^2=0.03. 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 across the three tests, Holm's sequential Bonferroni procedure was applied (Green, Salkin, & Akey, 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 4).

Table 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.

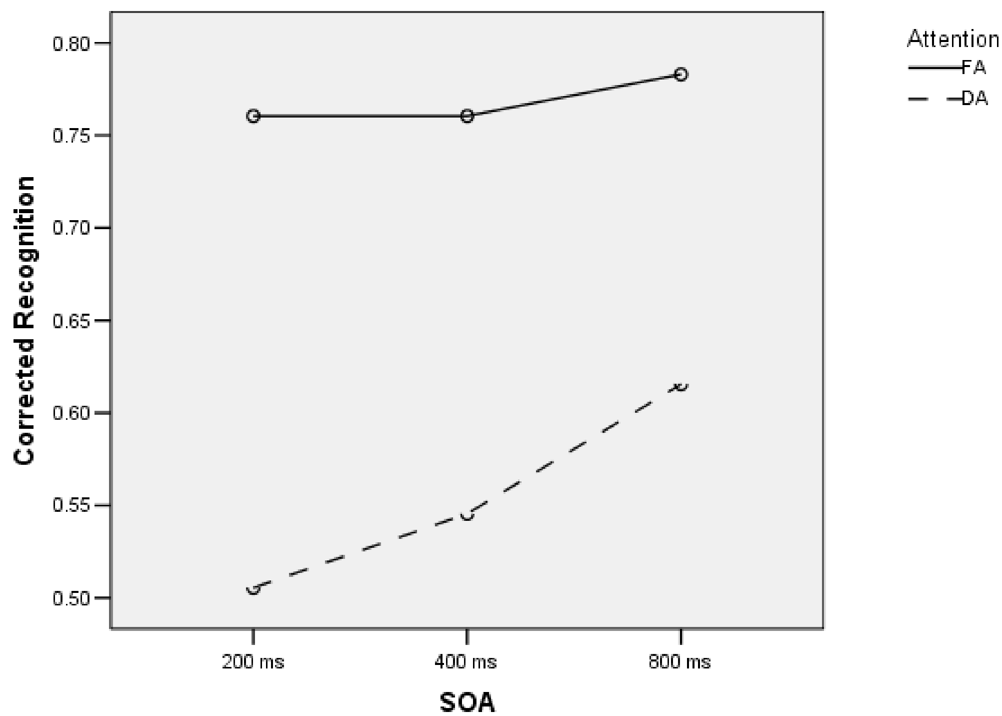

Figure 4. Mean corrected recognition performance as a function of attention and SOA in Experiment 2. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

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, $F(1, 19) = 99.09$, $MSE=.022$, $p<.001$, partial $\eta^2=0.84$, and a significant attention X SOA interaction, $F(2, 38) = 7.20$, $MSE=.048$, $p=.002$, partial $\eta^2=0.27$, but no significant effect of SOA, $F(2, 38) = 1.38$, $MSE=.007$, $p<.26$, partial $\eta^2=0.07$. Separate ANOVAs indicate a significant effect of SOA on free recall for DA, $F(2, 38) = 5.64$, $MSE=.006$, $p=.007$, partial $\eta^2=0.23$, but not for FA, $F(2, 38) = 3.32$, $MSE=.008$, $p=.047$, partial $\eta^2=0.15$. Three paired-samples *t*-tests were conducted to follow-up pairwise comparisons for the main effect of SOA for DA. 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, $t(19)= -2.38$, $p=.028$ (see Table 3). 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 5).

Table 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. 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.

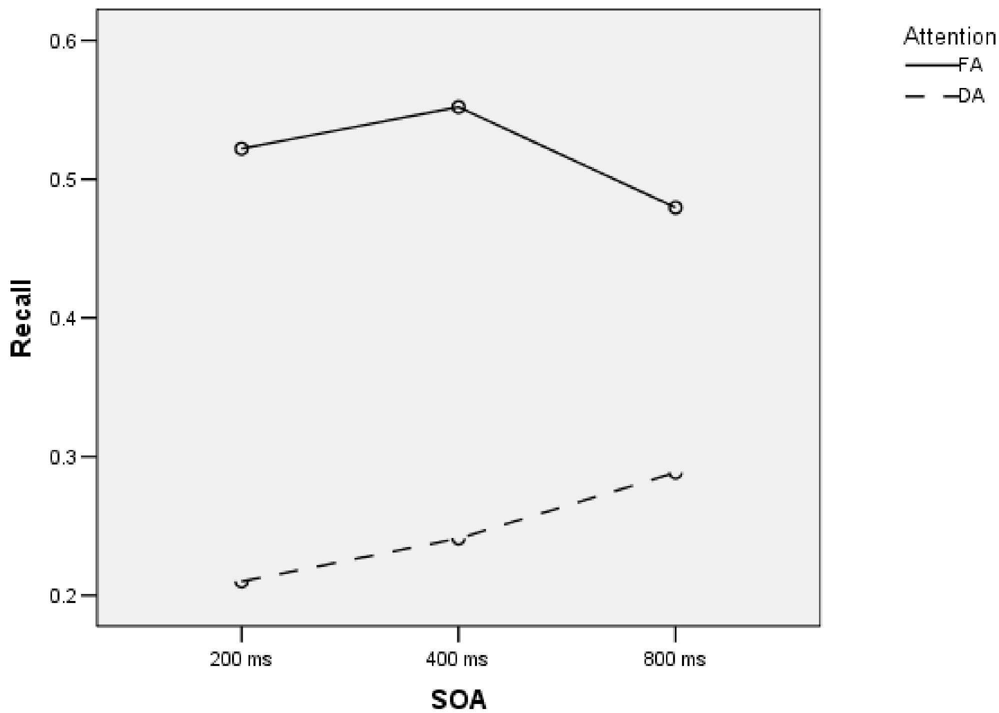

Figure 5. Mean free recall performance as a function of attention and SOA in Experiment 2. DA= divided attention, FA= full attention, SOA= stimulus onset asynchrony

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 for the ANOVA show no significant SOA effect, $F(2, 38) = 0.80$, $MSE=.007$, $p=.46$, partial $\eta^2=0.04$, 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, $t(19)= .27$, $p=.79$, 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 ANOVA was significant, $F(2, 38) = 8.13$, MSE=9567, p=.001, partial η^2=0.30. Three paired-samples *t*-tests were conducted to follow-up pairwise comparisons for the effect of SOA on secondary task RT. 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 people 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 people 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).

Discussion

The results of the second experiment replicated the results of the first experiment. The interaction between attention and SOA shows 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 people needed more than 400 ms to consolidate information. When attentional resources were consumed by another task within 400 ms, the consolidation process was interrupted, and consequently, people had poorer memory performance. A limitation of the current experiment was that administering the free recall test may affect the performance in the following recognition memory test. Thus, the results on recognition memory in Experiment 2 should be considered with caution.

A slowing was detected in the secondary task when the SOA was 800 ms. This result was in contrast to expectations. It may be due to the 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 after the memory task.

Experiment 3

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). 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 the 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 with 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 pictures than the second pictures because there would be fewer processing resources left for the first pictures.

Method

Participants

The participants consisted of 24 university students (13 female and 11 male) who were between 18 and 32 years old (*M*=22.83, *SD*=4.08).

Design

The study had a 3 (SOA between the onset of visual stimuli and mask: 400 ms, 800 ms, and 1200) X 2 (picture order: first picture, second picture) 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. In each trial, two pictures were presented, followed by a three-digit array superimposed on a gray noise mask (see Figure 6). In the secondary task, participants were shown an array that 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 three 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 the target in the test, the distractor in the test, the first picture in the study trials, and the second picture in the study trials. Targets in the recognition test were the old pictures that had been presented in the study session, whereas distractors in the recognition test were the new pictures that had not been shown in the study session. No auditory stimuli were presented. There was no FA condition.

The participants were asked to show 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 a cue to study the pictures and respond to digits. 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. Between the study and the test phase, subjects were not requested to count backward 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. 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 because the recency and primacy effects are unlikely in this experiment because the study and test blocks consist of 48 and 96 pictures, respectively.

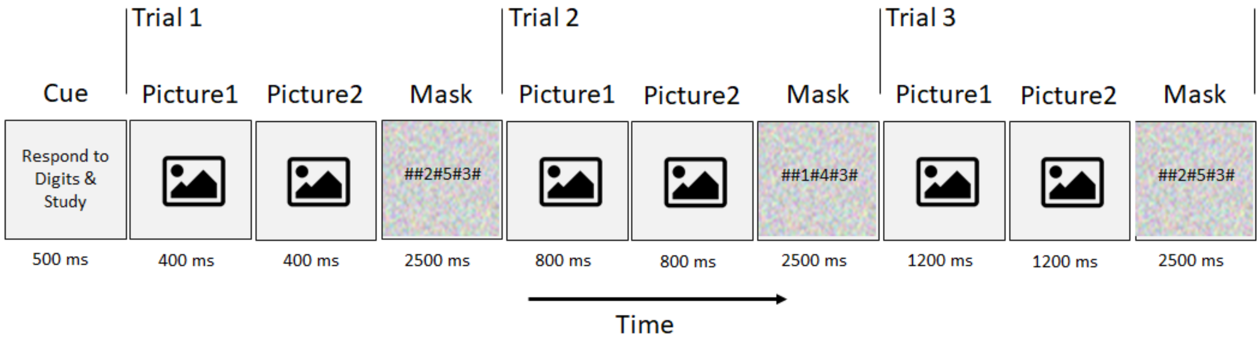

Figure 6. Schematic illustration of three study trials in a block in Experiment 3

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 picture order (first, second) on corrected recognition of pictures. Significant effects of SOA, $F(2, 46) = 11.55$, $MSE=.008$, $p<.001$, partial $\eta^2=0.33$, and order, $F(1, 23) = 10.82$, $MSE=.006$, $p<.003$, partial $\eta^2=0.32$, were found with no significant SOA X order interaction, $F(2, 46) = .79$, $MSE=.005$, $p=.46$, partial $\eta^2=0.03$. The results suggest that memory performance was higher for the second picture ($M=.41$, $SD=.16$) than for the first picture ($M=.37$, $SD=.16$).

Three paired-samples *t*-tests were performed to follow-up pairwise comparisons for the main effect of SOA. 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 it can be seen in Figure 7, 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 ($M=.42$, $SD=.17$).

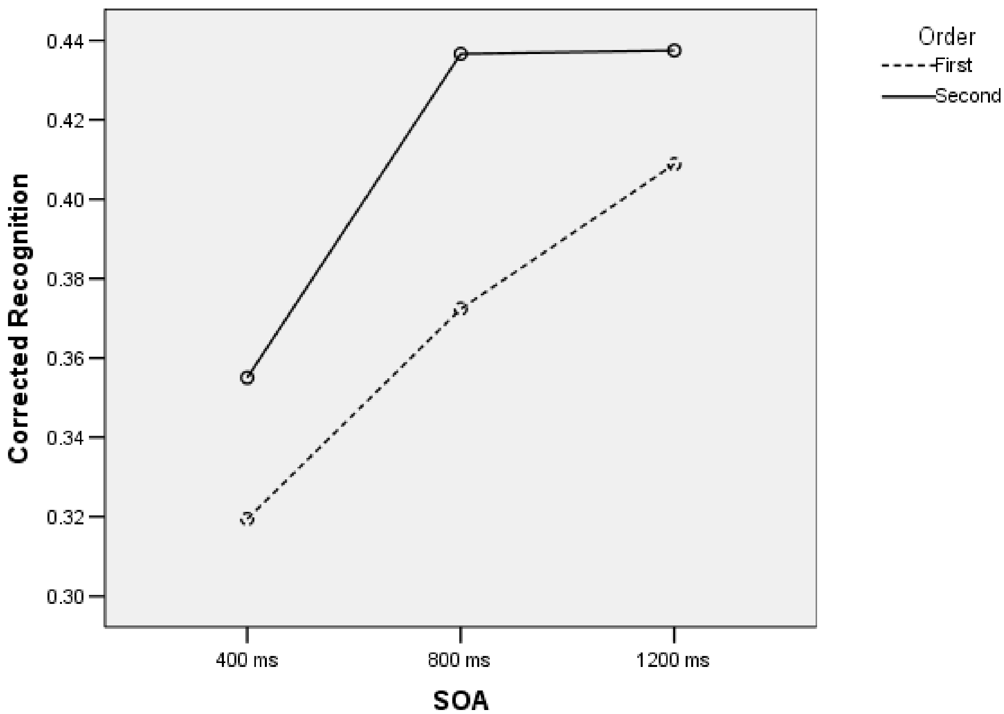

Figure 7. Mean recognition performance as a function of picture order and SOA in Experiment 3. SOA= stimulus onset asynchrony

Secondary task

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 show that the effect of SOA was not significant, $F(2, 46) = 0.90$, MSE=.003, p=.42, partial η^2=0.04. 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 the 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, partial η^2=0.15. Three paired-samples *t*-tests were performed to follow-up pairwise comparisons for the main effect of SOA. The 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, $t(23)$= -.80, p=.43, These results show that people 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),

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 representations that had not yet been consolidated" (Vogel et al., 2006). 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 suggest that the expectations of the processing hypothesis were not supported.

People were worse at 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 the second pictures because fewer attentional resources were left for the first pictures than the 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 of 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.

General Discussion

The goal of this study was to investigate the effect of attention and the SOA between targets (words, or pictures) 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 attentional resources were engaged 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 impaired when the SOA was 200 ms and 400 ms for DA, but not when the SOA was 800 ms, suggesting that the people needed more than 400 ms uninterrupted processing time for a successful memory encoding.

Two pictures were presented consecutively, followed by the digit decision task in each trial in Experiment 3 to determine whether the addition of an attention-demanding task would trigger more impairment in episodic memory. Poorer memory performance was expected for T1 than T2, because more attentional resources were withdrawn for T1 (by the second picture and the digit decision task) than for T2 (by only the digit decision task). This expectation was realized, 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 results of the analysis on secondary task RT show 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 the consolidation of the target for episodic memory. Processing of the secondary task was postponed until the short-term consolidation of the target was over.

Jolicoeur and Dell'Acqua (1998) argued that slowing in the secondary task demonstrated the existence of the 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 Experiment 3 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 pictures resulted in a 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 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.

Although the goal of this study was not to find the time course of consolidation, the results suggest that the consolidation process took more than 400 ms and less than 800 ms. This finding is consistent with RSVP, 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 (Raymond et al., 1992). Jolicoeur and Dell'Acqua (1999) demonstrated the dual-task inference on the consolidation of letters of the auditory discrimination task within 400 ms.

Taken together, these results suggest that withdrawal of attentional resources by an attention-demanding task within 400 ms after the onset of the target caused an impairment in memory performance and a slowing in secondary task performance. On the other hand, when the attentional resources were not consumed by a secondary task, the visual mask did not affect episodic memory. This shows that people needed more than 400 ms and less than 800 ms time 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. Some alternative hypotheses also can explain the results. Two hypotheses will be discussed in the next sections.

The Processing Time Hypothesis

The processing time hypothesis expects that when people have more time to process information, they will have better memory performance when SOA was1200 ms than when SOA was 800 ms. On the other hand, the consolidation hypothesis expects nearly equivalent performance in these two SOA conditions since previous research suggested that the 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. In order to test this hypothesis, performance differences in recognition memory between 400 ms, 800 ms, and 1200 ms SOA conditions were contrasted. 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 3.

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 FA 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 FA conditions may be a result of the engagement of further processing such as rehearsal, elaboration, and organization during the interval of the secondary task.

The useful encoding time hypothesis seems to explain reasonably the results of Experiment 1 and Experiment 2, but the results of Experiment 3 disconfirmed the useful encoding hypothesis. There was no FA condition in Experiment 3. 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. Supporting these findings, a study by Shaffer and Shiffrin (1972) showed that the duration of the blank post-stimulus interval had no effect on recognition memory for visual scenes. They argued that complex pictures were processed just during their exposure duration.

In sum, all these results showed that reducing SOA between targets and masks caused an impairment in memory performance for DA but not for FA, providing evidence for the necessity of attention for the short-term consolidation process.

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