EPISODIC MEMORY RECONSOLIDATION AND STRENGTHENING

Thesis by

Kai Rong Tay

A thesis submitted to the University of Birmingham

For the degree of

DOCTOR OF PHILOSOPHY

UNIVERSITY OF BIRMINGHAM | COLLEGE OF LIFE AND ENVIRONMENTAL SCIENCES

School of Psychology

September 2018

Abstract

Episodic memories are not always accurate, subject to false recollection due to the process of memory reconsolidation (Loftus, 2005). Memory reactivation places memory to a labile state and can lead to two phenomena: memory updating/reconsolidation with possibility of having inaccurate memories (Hupbach et al. 2007) and memory strengthening. By replicating Hupbach et al. (2007, 2008) study, Study 1 aimed to investigate the impact of music upon memory reconsolidation whereas Study 2 explored whether exposure to original learning context is sufficient to trigger reconsolidation. Study 1 found out that reconsolidation process may not be as reliable as suggested in existing reconsolidation studies. Study 2 discovered dissociation between updating of list memory and resistance to the memory-weakening effect of interference, suggesting reactivation-induced reconsolidation can maintain or even strengthen memories. Study 3 tested directly the capacity of memory reactivation to facilitate memory strengthening. An idea of implementing 6 hours interval in between Day 2 sessions was suggested, aimed to determine whether or not the learning effect is mediated by reconsolidation processes. The common effects of retrieval-relearning, relearning-retrieval, relearning-relearning, retrieval-6 hours-relearning, relearning-6 hours-retrieval to strengthen episodic memory may reflect different underlying processes, one or more of which might be related to memory reconsolidation.

Acknowledgements

I would like to thank those who helped made it possible. First and foremost I want to thank my supervisor, Dr Jonathan Lee, and co-supervisor, Dr Maria Wimber. It has been an honour to be their PhD student for the past three years. I appreciate all their contribution of time and ideas to provide me with tremendous support and useful advice. Their extreme levels of professionalism has guided me to become a better and more confident researcher. I consider myself very blessed to have them as my supervisors.

To the wonderful people in Psychology department at University of Birmingham - Miss Denise and the other professors, administrators, and colleagues, I thank you for your assistance throughout this journey of mine.

To my wonderful research subjects, I am grateful for their unselfish sharing of their time with me by attending the experimental sessions.

To my research assistants, I would like to express my sincere gratitude for helping me throughout the whole recruitment process.

To all my friends and colleagues at University of Birmingham that has been a home to me for the past three years, thank you.

Most importantly, I would like to thank my family for all their love and encouragement. To my dearest parents who raised me and supported me in all my pursuits, thank you. And my utmost gratitude goes to my little sister, Serena for being physically by my side through ups and downs in this journey and pampering me with love and words of wisdom.

Last but not least, I would like to dedicate my love and thank you to my loving husband, David who has been so wonderfully encouraging and faithfully

supportive throughout my PhD adventure, especially during the final stages of this difficult journey. Thank you. To them, I dedicate this work.

Contents

1 Chapter 1

2 Study 1: Music and episodic memory processing

3 Study 2: Reconsolidation of episodic memory processing

4 Study 3: Episodic memory strengthening

Lists of Figures

Lists of Tables

Chapter 1

1.1 Introduction

According to Sternberg (1999), memory is defined as the process on which allowing us to encode, store and retrieve various information and existing experience for the present or future uses. In other words, memory is what we remember, which gives us the opportunities to learn and adapt from previous experiences; what we recall, the ability to recall past experiences or previously learned facts and skills; what we store, the ability to store the things learned from our daily activities.

Memory involves different mechanisms in information processing, which engaged in the storage and retrieval of information. Psychologists discovered three essential aspects on how memory works, i.e. memory encoding (placing the information into memory), storage (retaining information in memory over a period of time) and retrieval (ability to access the information out of memory whenever you require it) (Melton, 1963; see Figure 1). In studying memory, researchers have implemented various tasks (e.g. recall or recognition) that require participants to remember “arbitrary information”. In recall memory task, you would be asked to give a word, a fact, or an item from memory whereas in recognition memory task, you would be asked to identify from various things the correct word, fact, or item. Among these three memory processes, the most important is encoding because you must pay attention to the information that you want to place into your memory to create a brand-new memory.

A successful remembering requires encoding, storage and retrieval to be intact with each other. However, two types of errors can be occurred throughout the stages, i.e. forgetting: where you met the person on the street, but you could not recall his name at all; and misremembering: where you see someone, who look familiar like David on the street and call that person by that name.

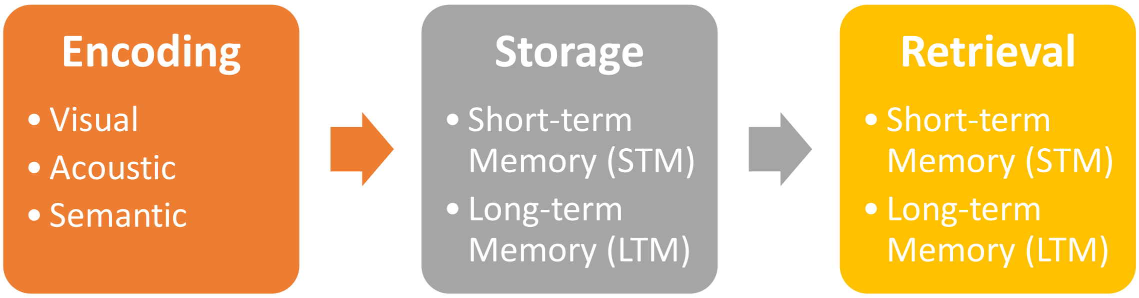

Figure 1. Stages of memory: encoding, storage and retrieval

Memory encoding allows information to enter our memory system through sensory input (i.e. visual encoding, acoustic encoding and semantic encoding) and convert into a form that memory system can handle with and can be stored within our brain (Melton, 1963). Fergus Craik and Robert Lockhart (1972) proposed three levels of encoding information. The first level is structural processing, i.e. encode the physical qualities of information (e.g. typeface of a word). The second level is phonemic processing, which we encode its sound. Last but not least, the third level which requires deep processing is semantic processing, which we encode the meaning of a word or relate it to similar words with similar meaning. The levels of processing model imply the idea of how information is encoded affects how well it is remembered, i.e. the deeper the level of processing, the easier the information is to recall. In their study (1972), Craik and Lockhart presented a series of 60 words to their participants and required them to process the words in one of three ways, i.e. structural (‘Is the word in capital letters or small letters?’) or phonemic (‘Does the word rhyme with…?’) or semantic (‘Does the word go in this sentence…?’). Participants were then given a long list of 180 words, mixed with the original words, and were asked to pick out the original words. Results showed that participants recalled more words that were semantically processed compared to phonemically and visually processed words. Semantically processed words which involved elaboration rehearsal and deep processing resulted in more accurate recall. This implied the deeper the processing of information, the better the memory. This definitely benefits the students especially; more materials will be remembered, and better exam results should be achieved. However, this model focuses on the processes involved in memory, and ignores the structures. The concept of depth is vague and cannot be observed or objectively measured.

Memory encoding process often involves recoding, in which the information that delivered to us are converted into a form that memory system can handle with it. Several psychologists have proposed different recoding strategies to improve retention during study. For example, Craik and Lockhart (1972) proposed that association should be formed between new event and the information that we have already comprehend. This association could help to retrieve information easily. Besides that, creating imagery can also make the memory more memorable and make the retrieval process later easier (Bower &

Reitman, 1972). However, recoding can easily insert information that was not even seen or heard during the encoding stage (Deese, 1959; Roediger & McDermott, 1995).

The second stage will be memory storage and this phenomenon emphasises on how the way we store information affects the way we retrieve it, i.e. where the information is stored, how long does the memory last for (duration), how much information can be stored at any time (capacity) and what kind of information is held. It is believed that a total of five to nine items can be stored in short-term memory (STM) and can be readily recalled. Miller (1956) suggested the magic number 7 for the storage capacity of short-term memory due to certain number of slots in which items could be stored in short-term memory. However, Miller could not specify the amount of information that can be stored in each slot. In contrast, the storage capacity of long-term memory (LTM) is suggested to be unlimited. Psychologists proposed that our experiences leave memory traces through consolidation process (McGeoch, 1932).

The third stage is retrieval stage, which explains how information can be retrieved from storage. Tulving (1993) argued the main key process of memory is retrieval. There are two main method of accessing memory, i.e. recognition, the association of an event with previous experiences which involves a process of comparison; and recall, involves remembering a fact, or event that requires the direct revealing of information from memory. There are clear differences between short-term memory and long-term memory in term of retrieval. Short-term memory is stored and retrieved by sequence. For example, if a person was asked to memorise a list of words, and then asked to recall the fifth word on the list, he or she will go through the whole list, starting from the beginning to retrieve the information (fifth word). On the other hand, long-term memory is stored and retrieved by association. This can explain why you can remember what you went down to kitchen for if you go to the fridge. Most importantly, the way of organising information can help retrieval process. You can choose to organise information by sequences (such as alphabetically or by time). For example, if a doctor gives a clear instruction in order (in time sequence) to a patient who involved various treatments and taking different kind of pills at different times, this will help the patient remember them. Most of the important memories move from short-term memory to long-term memory. There are several ways to make this transfer more permanent. This movement can happen through repetition, for example, studying for an exam or repeatedly cycling until riding a bicycle can be performed without extra learning, or by association, for example, trying to remember your best friend’s birthday by associating with World War II start date. Besides that, motivation can promote this transfer. For example, your beloved sport game is football and this interest will strongly encourage you to remember the footballers’ names or their football tactics.

The main principle that explains the effectiveness of retrieval process is encoding specificity principle (Tulving & Thomson, 1973). This principle emphasised that once a retrieval cue overlaps the memory trace of past experience, the cue will be effective in inducing the memory. A classic experiment by Godden and Baddeley (1975) on encoding specificity principle, participants were asked to memorise a word sets in a testing room. After that, participants were tested on the set of words, either in the same testing room they learned the words or a different testing room. Results showed that students who took the test in the same place they learned the words recalled more words compared to those who took the recall test in a new environment, which also showed that physical context itself provided cues for retrieval. In order to improve learning and memory, it is essential to construct meaningful cues that remind us the original experience, and distinctive cues which do not associated with other existing memories (Nairne, 2002).

1.2 Categories of human memory

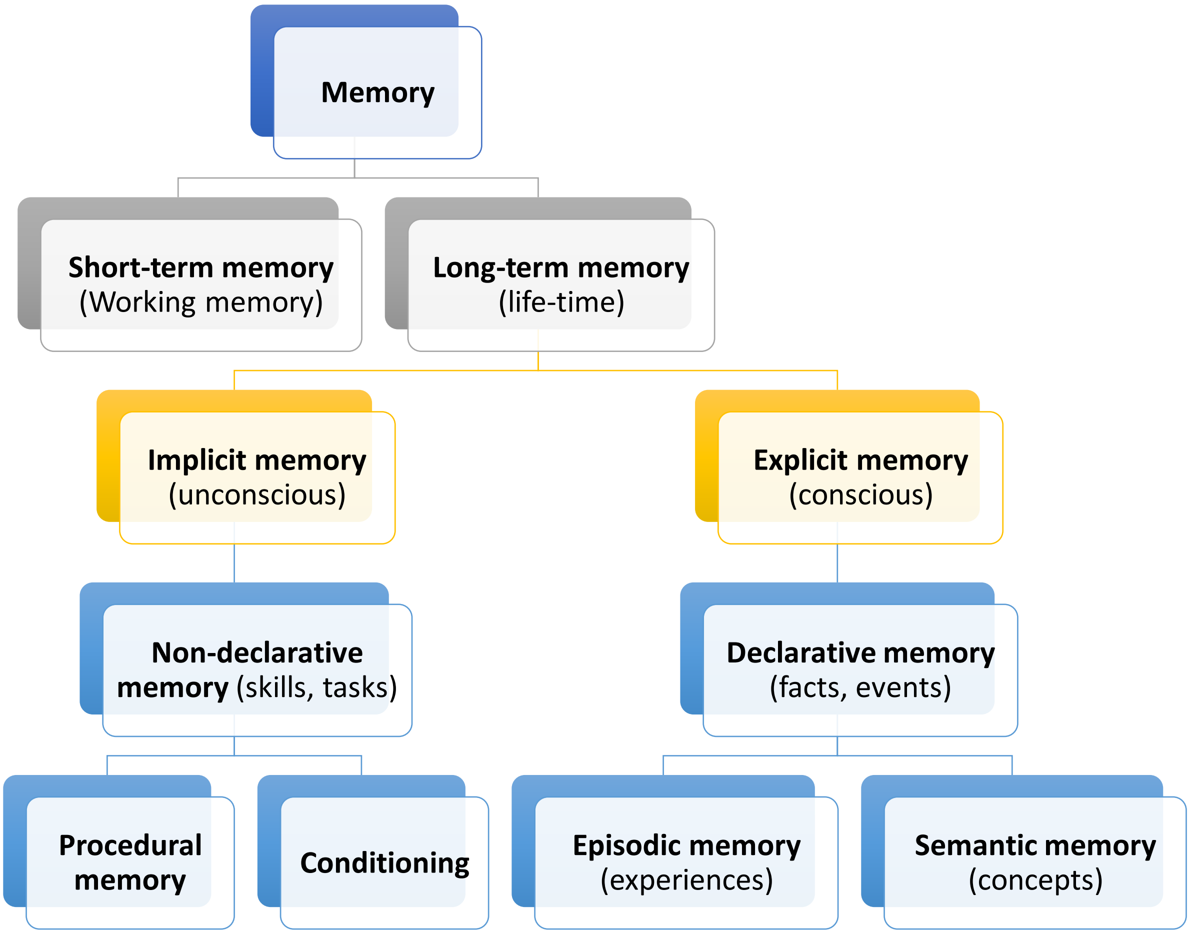

Figure 2. Types of human memory

Human memory can be divided into several categories (see Figure 2). The main distinction is between declarative and non-declarative memory. Non-declarative memory refers as unconscious memory or automatic memory, which do not require explicit and conscious effort to think, such as riding a bike or washing dishes. Most of musicians and professional athletes are found to have ability to perform procedural memories, which is responsible for knowing how to perform motor actions or skills. Conditioning is part of implicit memory and the classic example is Pavlovian conditioning, which associate the bell ring to the food when feeding a dog. After a few repeated trainings, dog eventually shows salivation when the bell ring without the food. On the other hand, declarative memory refers as explicit memories, which involves conscious and intentional remembering or recalled. It is also responsible for storing information, such as events, facts or concepts.

Declarative memory has been subdivided into two components, i.e. episodic memory and semantic memory. It is often agreed that, episodic memory involves the storage and retrieval of a person's unique recollection of a specific event whereas semantic memory refers as a structured record of general facts or common knowledge (Lesch & Pollatse, 1993; Rohrer, Wixted, Salmon, & Butters, 1995). Unlike episodic memory, personal experience doesn't come into play in semantic memory. The main difference between episodic and semantic memory is remembering versus knowing (Griffiths, Dickinson, & Clayton, 1999). Episodic memory refers as remembering a person's specific past experiences with respect to time and place. For example, if someone was asked to recall on what they had eaten on the day before, they would use episodic memory to recall the information. Meanwhile, semantic memory is concerned with what we know about facts or common knowledge. For example, questions like “When is the St Patrick's Day?” and “In which city would you find the Empire State Building?” would be answered using semantic memory without linking with time and space or connecting to personal experiences.

Tulving (1983) have proposed that episodic memory and semantic memory are two completely independent memory systems, which also distinguished the differences between episodic and semantic memory on operating system and the types of information they process. He proposed that if a person acquires some semantic information, he must have learned that particular information directly or indirectly without possessing any meaningful memorable episode of such learning. For example, semantic memory allows us to recognise a car as a vehicle used for transportation (without having to recall how we learned what a car is).

Tulving (1972) argued that episodic and semantic memory systems differ from one another in several characteristics. The first difference is regarding the nature of store information. Episodic memory receives, and stores information consists of time and space related episodes or events. Meanwhile, semantic memory receives, and stores information consists of meanings. Secondly, episodic memory stores the information in term of autobiographical references whereas semantic memory uses cognitive references. The third difference is the act of retrieval of information. Episodic memory retrieval is quite vulnerable to transformation or loss of information due to the retrieval process makes the retrieved information accessible to inspection. On the other hand, semantic memory retrieval leaves the contents unchanged and makes semantic memory system less vulnerable to transformation or loss of information.

Past researches have been studied semantic memory using experimental method, focused on the structure of semantic memory (for example, study by Deese (1965) investigated on semantic structure based on participants' free associations) or retrieval processes in semantic memory. Most of the studies investigated on semantic retrieval processes used accuracy as criterion of participants' performance. For example, study by Horowitz, White, and Atwood (1968) asked their participants to remember the shown lists of words and recall was cued by the either the initial, middle or final third of each word (e.g. for the word "recognize", the cue was either rec…., …. ogn, or …. ize). The results showed that initial third cue performed the best in retrieval followed by final third and middle third.

1.3 Episodic memory

Episodic memory is mostly described as the only unique memory system, which works closely with particular time, in allowing people to consciously re-experience their past experiences. According to Tulving (2002), this phenomenon is referred as mental time travel. In other words, it is labelled as a record of a person's experiences at a specific time and place. The most significant feature of episodic memories is that every 'item' not only uniquely represents information about an event or episode but also able to be traced back in space and time. For example, one may remember recent holiday trip to Iceland, mentally recalled the time, location, and any specific event occurred during the trip such as interesting sightseeing or people met or incidents. Therefore, in order to recall the specific information correctly, he or she must access information regarding specific time and place.

Endel Tulving (1984) proposed and brought the concept of episodic memory into the research laboratory. Throughout the years, different laboratory techniques have developed by psychologists, such as recall of pictures or words or stories, and each technique requires participants to recall at the specific time of occurrence of the event (Tulving, 2002). There is a total of nine different tasks, classified as episodic memory tasks, as clearly described below (Tulving, 2002).

1. Free recall. Participant learns a series of words, pictures or other image materials and the main task is to memorise them. After that, participant will be required to recall the specific materials in any order after a certain interval of delay. The other variation is multiple-trial free recall, which pictures or words can be presented repeatedly along with a test after each presentation trial. Free recall tests are famously implemented in human episodic memory studies (for example, Backman, Small, & Fratiglioni, 2001; Herlitz, Nilsson, & Backman, 1997; Howard & Kahana, 2002; Tulving, 1985; Wheeler, Stuss, & Tulving, 1995)

2. Serial recall. Participant is exposed to a series of pictures, numbers, or words and recalls all of them in the specific sequence. Other variations involve providing an item from the sequences and asking for the other item, which showed before or, after the given item. Single or multiple-trial procedures can be applied. Several studies (e.g. Gruneberg, 1973; Stalder, 2005) used serial recall tests on college students.

3. Cued recall. Participant is exposed to a series of pictures, words, or sentences and provided a cue (something that is not presented). After that, he or she will be asked to recall a related event from the series (e.g. Andreson, Fincham, & Douglass, 1977; Crutcher & Ericsson, 2000). For example, “The fish attacked the swimmer”, the word shark will be presented as a cue.

4. *Paired-associate recall*. Participant learns different pairs of related items (e.g. cat-dog) or unrelated items (e.g. pickpocket-tightrope). Participant will be provided an item (e.g. pickpocket) and the task is participant needs to recall the other paired item (e.g. tightrope). This task uniquely measures the formation of associations. In this recall task, both single and multiple-trial procedures can be applied. Paired associate memory tasks are commonly used for testing hippocampal functions (e.g. Kesner, Hunsaker, & Warthen, 2008)

5. Recognition. This task requires participant to decide whether he or she recognizes an item from the previous studied set. In the laboratory paradigm (e.g. Hintzman & Caulton, 1997; Joordens & Hockley, 2000; Yonelinas, 2002), participant will learn a list of 100 words. After that, he or she will be given 200 words, which consists of half studied and half not studied words. The task is to identify the previously studied words by responding yes or no. This is called free-choice or yes-no recognition test. The other type is called forced-choice recognition test, which participant must select the word that was studied. Another variation is continuous recognition test, which long list of items will be presented, and participant's task is to judge each item as yes (studied) or no (not studied).

6. Absolute frequency judgment tasks. Participant studies a set of items such as words or pictures or images for a couple of times (e.g. Fozard & Yntema, 1966; Morton, 1968). The task is to judge how many times he or she studied each item. Another variation is relative frequency judgments. Two items will be provided throughout the study, and participant must judge which item was presented more often.

7. Relative recency judgments. Participant learns items and then answers which one occurred earlier or later in the series (e.g. Konorski, 1961). This task is to capture participant's estimates of the distance between events in time.

8. Source judgments. Participant will be exposed an information from a variety of sources, such as spoken or written, male or female speaker. After that, participant will be required to identify the source of the information. Source judgments tasks are widely used among the human adults (for example, Davachi, Mitchell, & Wagner, 2003; Lundstorm, Ingvar, & Petersson, 2005; Shimamura & Squire, 1987; Simons et al., 2002).

9. Metamemory judgments. Participant will be asked to judge the features of their episodic memories. For example, participant will rate how confident he or she is on the event occurred, from the scale of 1 (certainly did not) to 7 (certainly did). Metamemory judgments has been explored either through experimental memory perspective (Hart, 1965; Nelson & Narens, 1990) or developmental psychology viewpoint (Flavell, 1979) on children.

All the episodic memory tasks described above significantly capture the main aspect of episodic memory, i.e. allowing participants to retrieve information from specific time in the past (Tulving, 2002). However, Loftus (2005) has demonstrated that episodic memories are not always accurate, being subject to false recollection. One explanation for certain types of false memories is due to the process of memory reconsolidation (Hardt, Einarsson, & Nader, 2010).

1.4 Memory reconsolidation

According to McGaugh (2000), consolidation theory proposes that memories are prone to any changes during a certain limited window after encoding. However, as the time passes, memories will become consolidated, resistant to change and stored as the long-term memory. The term consolidation is acknowledged by McGaugh (1966). Memory consolidation involves a prolonged period after learning when new information becomes fixed at a cellular level and interleaved among already existing memories to enrich our body of personal and factual knowledge. According to Bramham and Messaoudi (2005), it usually consists of two processes, i.e. synaptic consolidation (which happens within first few hours after learning) and system consolidation (which memories become independent over a week or years). Evidences for consolidation phenomenon has been demonstrated in several past researches, in which new memories are labile during a certain period of time. For example, Duncan (1949) discovered that performance can be impaired by electroconvulsive shock or protein synthesis inhibitors (Flexner, Flexner, & Stellar, 1965) or new learning (Gordon & Spear, 1973).

However, Muller and Pilzecker (1900) discovered interference effects instead of consolidation theory. In their study, participants were asked to memorise a list of paired syllables. On the test day, cue syllables were presented, and the number of recalled syllables was used to measure memory retention. Results demonstrated a reduction in the number of retrieved syllables from the first list was observed if a distractor (second list) was presented shortly after training. In addition, the longer the interval between two lists, the less the performance was affected.

One of the most exciting ideas that emerge from the animal models and to human memory model in the recent years is the idea of reconsolidation process. This reactivation-induced reconsolidation theory has opposed the consolidation theory (Nader, 2003; Sara, 2000). According to Nader (2003), reactivation allows memories to return to a labile state, where memories can be updated, usually adaptively and accurately. However, this normal process can be subverted to result in inaccurate or false memories or even erased. This process is defined as reconsolidation, which shared the similar process as initial consolidation (see Figure 3). Through reconsolidation process, memory may become labile and susceptible to impairments (Debiec, LeDoux, & Nader, 2002; Duvarci & Nader, 2004), re-stabilised and strengthened (Forcato, Rodriguez, Pedreira, & Maldonado, 2010; Hupbach, Gomez, Hardt, & Nadel, 2007; Rodriguez-Ortiz, De la Cruz, Gutierrez, & Bermidez-Rattoni, 2005; Schiller et al., 2010) depending on different conditions, whether through repetitions of learning experiences of different types of retrieval, as well as mediates memory updating (Alberini, 2005; Duvarci & Nader, 2004; Sara, 2000). Memory reconsolidation phenomenon has been demonstrated in several experimental paradigm, from animal models to humans (Anokhin, Tiunova, & Rose, 2002; Nader & Einarsson, 2010; Rose & Rankin, 2006; Walker, Brakefield, Hobson, & Stickgold, 2003), suggesting that reconsolidation is a fundamental topic in memory research.

Figure 3. Consolidation and reactivation-induced reconsolidation theory

1.4.1 Memory reconsolidation process in animal models

Cued recall of the original memory is the main component that initiate memory reconsolidation effect (Suzuki et al., 2004). In Pavlovian fear conditioning, a conditioned stimulus (CS) is paired with an unconditioned stimulus (UCS). When placed in the training context, the animal shows conditioned fear responses, e.g. freezing (Abel et al., 1997; Kida et al., 2002; Schafe, Nadel, Sullivan, Harris, & LeDoux, 1999). Memory reconsolidation effect explained that after reactivation, the consolidated fear memory returns to a labile state, which requires re-stabilisation, offers an opportunity to modify the fear memory with amnestic agent (Kindt, 2018).

In past, extensive researches on memory reconsolidation have been carried out using different kinds of laboratory animals, such as rats (e.g. Alberini, 2005; Dudai & Eisenberg, 2004; Nader & Einarsson, 2000) and extended to other animals (e.g., medakafish, Eisenberg, Kobilo, Berman, & Dudai, 2003; crabs, Pedreira, Perez-Cuesta, & Maldonado, 2004). Different pharmacological agents (e.g. protein synthesis inhibitors) were also used to affect the re-stabilisation stage (Carbo Tano, Molina, Maldonado, & Pedreira, 2009; Frenkel, Maldonado, & Delorenzi, 2005; Lee, Milton, & Everitt, 2006). Most reconsolidation studies on animal models have used fear conditioning paradigm and have successfully demonstrated that the injection of protein synthesis inhibitors or beta-blockers after fear reactivation could reduce the specific fear memory (e.g. Nader, Schafe, & LeDoux, 2000; Przybyslawski, Roullet, & Sara, 1999; Sara, 2000).

In 2000, Nader and colleagues conducted a fear conditioning study using rat and hypothesised that the reminder reactivated the original fear-conditioning memory and impaired the memory. Rats were first received several tone-shocks on Day 1. On the following day (Day 2), half of the rats were exposed to the tone again, which elicited freezing, indicating that rats recalled the conditioned fear memory. All the rats were then either injected with a protein-synthesis inhibitor or vehicle into their amygdala. For the fear-testing on Day 3, rats who had received the reminding tone before the inhibitor injection showed less freezing than vehicle injection rats and as well as than rats who were not reminded. This demonstrated that the protein-synthesis inhibitor blocked reconsolidation, which led to memory impairment and suggested that reactivation of the fear memory placed the memory to a labile state. Besides that, they also found out that short-term fear memory was still intact whereas the long-term fear memory was significantly reduced. This suggested that memory reconsolidation undergoes two stages, i.e. consolidated memories transfer to labile state upon reactivation and consolidated memories need time-dependent re-stabilisation to persevere.

Lee (2008) discovered that a consolidated contextual fear memory could be strengthened by a second learning trial when the consolidated memory was previously reactivated. Interestingly, impairing memory reactivation with a pharmacological treatment hindered the improvement effect of the second learning trial on the target memory but increased in memory strength induced by second training. (Lee, 2008). This strongly suggested memory reconsolidation might able to update and enhance existing memories. This strengthening memory reconsolidation idea was also supported by De Oliveira Alvares et al. (2013), which also investigated the potential roles of memory reconsolidation using contextual fear conditioning paradigm in rats. Rats were placed in the chamber for 3 minutes and received two foot-shocks, separated by 30 seconds interval. Rats were then kept in the conditioning environment after the last shock. After the conditioning, rats were re-exposed to the different contexts without foot-shocks for different durations, depending on the experiment conditions. On the testing day (day 5 or 28), rats were tested for 4 minutes in different contexts depending on experiment conditions. They discovered that memory reconsolidation enables the incorporation of new information through updating mechanism as well as maintains the contextual detailed content over time and memory strengthening upon reactivation.

1.4.2 Memory reconsolidation process in humans

Interestingly, memory reconsolidation provides an opportunity to alter unwanted memories, especially those traumatic memories. Brunet et al. (2008) discovered the administration of beta-blocker after reactivation of traumatic memories may reduce the emotional stress of the traumatic event. Despite the increasing laboratory evidences for memory reconsolidation, however, a huge limitation in human laboratory research is that neurobiological processes of memory destabilisation and re-stabilisation hard to detect or observe (Kindt, 2018). Therefore, detecting memory reconsolidation with emotional memory disorders are still unidentified.

Walker, Brakefield, Hobson, & Stickgold (2003) successfully demonstrated human reconsolidation effect. Participants were trained to do first finger-tapping task in a simple sequence (e.g., 4-1-3-2) on Day 1. Two days later, they briefly rehearsed the first sequence and learned a second sequence (e.g., 2-3-1-4). On the testing day (Day 3), results showed that accuracy performance for Sequence 1 was significantly impaired compared to those participants who did not rehearse Sequence 1 before learning Sequence 2. This suggests that memory for Sequence 1 on Day 2 has been impaired. These studies also demonstrated the evidence of human episodic memory reconsolidation (Schiller & Phelps, 2011; Schwabe, Nader, & Pruessner, 2014). Reconsolidation effects have been significantly found in humans, not only for implicit memory, such as conditioning (e.g. Galluccio, 2005) and procedural memory (e.g. Walker et al., 2003), but also for episodic memory, which involves recollection of events (Forcato et al., 2007; Hupbach et al, 2007). However, Hardwicke, Taqi, and Shanks (2016) replicated Walker et al. (2003) study but did not find any evidence of inaccurate or false memories predicted by reconsolidation theory.

Since animal studies (Dudai, 2006; Tronson & Taylor, 2007) have demonstrated fear memories can change through reconsolidation process during retrieval, Kindt, Soeter, and Vervliet (2008) discovered that B-adrenergic receptors are involved in the human reconsolidation process which resulted in weakening of fear memory and stopped the return of traumatic memory. It was clear that oral administration of B-adrenergic receptor antagonist propranolol before memory reactivation disrupted the reconsolidation of fear memory.

As pharmacological agents, such as protein synthesis inhibitors, that have been largely used in animals are not ethically safe for humans uses and violated the protocol for human experiment ethics codes, human reconsolidation has been conducted commonly using behavioural interference paradigm or new object learning paradigm (Hupbach, Gomez, & Nadel, 2009), which new information is presented after reactivating the memory and memory for the original information is tested after a period of delay to check the occurrence of the reconsolidation process (Hupbach et al., 2009). Hupbach, Gomez, Hardt, and Nadel (2007) asked their participants to learn a set of objects (List 1) that were pulled out from a blue basket. Some participants were given a reminder of List 1 by showing them the blue basket before learning the List 2. Results showed that reminder did successfully reactivate the memory of List 1, where new information from List 2 was easily incorporated, but not vice versa. This asymmetric intrusion was illustrated as evidence for human episodic memory reconsolidation phenomenon. However, Sederberg, Gershman, Polyn, and Norman (2011) found out that this asymmetric intrusion can be explained by item-context binding and temporal context. Sederberg et la. (2011) argued that temporal context can be used as retrieval cue as it can be bound to its memory trace.

Forcato et al. (2007) discovered updating via memory reconsolidation phenomenon using a paired-associate learning (i.e. learning an association between a cue syllable and response syllable). In their study, participants were asked to learn two different verbal materials in two training sessions with a 24 hours interval. After that, they were asked to retrieve corresponding to the first and second learning. Forcato et al. (2007) discovered two distinctive memory roles, i.e. memory updating, suggesting destabilisation of original memory which allows the integration of new information into original memory; and memory strengthening, suggesting labilization-reconsolidation process which strengthens the original memory.

On the other hand, Schwabe and Wolf (2009) suggested the learning of new information impedes the reconsolidation of neutral autobiographical memories. Participants were randomly assigned into four groups, i.e. reactivation with interference, reactivation only, interference only, and control group. Participants in reactivation with interference group completed an autobiographical memory test followed by learned an unfamiliar story. Participants in the reactivation only group were asked to complete the autobiographic memory test only. In contrast, participants in interference only group were asked to learn the unfamiliar story only. Participants in control group omitted the procedure on Day 1. A week later, participants in reactivation with interference and reactivation only group were asked to recall the autobiographic events they have described the week before. The interference only and control group were asked to complete the autobiographic memory test. This study found out that participants who memorised the unfamiliar story immediately after recalled past autobiographic experiences were impaired in their memory for neural experiences. This suggested that emotional events were more likely to be consolidated and less sensitive to reconsolidation process (Suzuki et al. 2004).

Chan and LaPaglia (2013) investigated the memory reconsolidation phenomenon using misinformation model. Participants were recruited to watch a movie about fictional terrorist attack. The main manipulation was whether participants were recalled the specific details from the movie before they were presented with misinformation that replaced the original information. If the retrieval successfully triggered the reconsolidation process, the new information that was presented during the relearning stage should update the original memory. Results showed that original memory was impaired in the reactivation condition, which suggested the evidence for reconsolidation effect in human episodic memory. However, the experiments in Chan and LaPaglia (2013) paper can be quite problematic as learning, mainly because both reactivation and test were administered on the same day. Ecker, Hogan, and Lewandowsky (2017) also found the similar reconsolidation effect using misinformation model, which also supported by Wilkes and Leatherbarrow (1998).

1.5 The Hupbach et al. (2007) list-learning paradigm

Given that numerous laboratory studies (e.g. Forcato et al., 2007; Hupbach et al., 2007; Walker et al., 2003) showing that the reactivation of an episodic memory (e.g. a learned list of items or images) and render that memory vulnerable to erroneous change (i.e. recalling an item that was not presented at that time), current studies choose to replicate the famous object-learning paradigm conducted by Hupbach et al. (2007). Firstly, Hupbach et al. (2007) paradigm is easy to implement and replicate. Secondly, this list-learning paradigm is most widely used in examining episodic memory. Thirdly, Hupbach et al. (2007) paradigm has raised controversy in reconsolidation literatures (for example, Klingmuller, Caplan, & Sommer, 2017).

Their research study consisted of a total of two encoding sessions and a retrieval session, involving participants to study two separate lists of objects. Our study replicated Hupbach et al. (2007) study with a few modifications.

In their study, participants were recruited and informed to memorise different lists of objects on three different sessions, i.e. on Monday, Wednesday and Friday of the same week. On Monday (Day 1), participants were asked to name and memorise the first list of objects (List 1), which were pulled out one item at a time from a distinctive blue basket. The procedure was repeated until the participants reached the learning criteria, i.e. remembered at least 17 out of 20 objects or until a maximum of four learning trials was reached. In our study, instead of pulling out one item at a time from the blue basket, participants will be asked to learn the first list of 20 images using sequential presentation slides method and will be tested immediately once the presentation slides end.

On Wednesday (Day 2), there were slight differences in procedure among the three groups. The key manipulation was some of the participants were given reminder of prior learning experience of List 1. For the participants in the reminder group, the same experimenter from Monday showed them the empty blue basket and asked whether they remembered the presence of blue basket. Participants were asked to describe what exactly happened on Monday without explicitly recall any specific objects from List 1. On the other hand, for participants in no-reminder group, a new experimenter administrated the procedures in a different testing room. The new experimenter did not present the blue basket and did not ask participants to describe what happened on Monday. The third group, i.e. interference control participants, omitted the procedure on Wednesday. Participants in both reminder and no-reminder groups were then asked to memorise the second list of objects (List 2). Instead of pulling the objects one by one from the blue basket, all the objects were spread out on the table in front of the participants and they were given 30 seconds to study and memorise them. After that, experimenter removed the objects and asked participants to recall as many objects as possible, in the same learning manner as on Day 1. In our study, instead of naming each objects which were placed in front of them, our participants will be preceded to learn the second list of 20 images using physical paper hand-out method.

On Friday (Day 3), the experimenter from Day 1 asked participants to recall as many objects as possible on Day 1. When participants could not recall any more objects, experimenter would engage the participants in a casual conversation on unrelated topic for about 30 seconds. This recall procedure was required to repeat for four times in order to test the reliability of recall.

Results found out that participants in reminder group and no-reminder group did not differ in the number of objects recalled from List 1. This strongly suggested that reminder did not strengthen or weaken the memory of original list. Furthermore, this also illustrated that learning a second list did not have significant impact on memory of the List 1. However, reminder did successfully reactivate the memory of List 1, where new information was easily incorporated. This could be justified through the finding, where participants in reminder group incorrectly recalled a high number of objects from List 2 compared to participants in no-reminder group, which showed fewer intrusions.

Hupbach et al. (2007) also varied the experiments by implementing whether participants were immediately asked to recall List 1 after learning List 2 on Day 2 (Wednesday) or they had another day off before their free recall test (delayed-test condition). In the immediate-test condition, participants in both conditions (reminder and no-reminder) were asked to recall List 1 immediately after they learned the List 2 on Day 2 (Wednesday). In the delayed test-condition, participants in both reminder and no-reminder condition were asked to return on Friday and were either asked to recall List 1 or List 2 objects.

The main finding was asymmetric intrusion effect where participants in reminder group with delayed-test condition incorrectly recalled a high number of objects from List 2 when they were supposing to recall the objects from List 1, but they did not incorrectly recall high number of objects from List 1 when they were asked to recall List 2. Participants in no-reminder condition with delayed-test did not intrude a high number of objects on either test. Hupbach et al. (2007) explained this asymmetric intrusion effect, by stating that presenting the List 1 reminder prior to the learning of List 2 would make the List 1 memory in a vulnerable state, in which List 2 would be used to update the memory of List 1. Thus, when participants were asked to recall List 1 objects, they would recall both List 1 as well as List 2 objects that were part of the update of List 1 memory.

Furthermore, participants in both reminder and no-reminder group with immediate-test condition did not intrude a high number of objects from List 2 when they were asked to recall List 1, showing that reminder did not have immediate effect on memory for List 1, but the effect evolved over time as suggested by reconsolidation theory. This can be found in Nader et al. (2000) study, as they discovered that the reminder effect was not obvious if memory is tested immediately after the reminder.

Based on the past findings, there are critical conditions that allow the original memory to be reactivated in such a way that allows memory reconsolidation to take place. While these conditions have been studied extensively in rodent experiments, the only condition demonstrated for human episodic memory is the necessity for re-exposure to the original learning environment (i.e. testing room; Hupbach et al., 2008).

Given the research gaps outlined above, the objective of current paper is to further investigate memory reconsolidation from different perspectives, such as auditory context. Since the famous object-learning paradigm conducted by Hupbach et al. (2007) is easy to replicate and most widely used in examining episodic memory, all three studies choose to replicate the Hupbach et al. (2007) object-learning paradigm, hoping that the research can be drawn together and some conclusions reached. Initially,

The first study (see Chapter 2) focused on the auditory factors in episodic memory reconsolidation, which aimed to investigate specifically the impact of music upon episodic memory reconsolidation. Hupbach et al. (2007) study was replicated to find out how important are re-exposure to music versus spatial context in reactivating the episodic memory to trigger memory reconsolidation. The second study (see Chapter 3) aimed to provide a conceptual replication of studies of Hupbach et al. (2007, 2008), in which focused on whether exposure solely to the initial learning context is sufficient to trigger reconsolidation effect on episodic memory. Memory reactivation can lead to two phenomena, either memory updating or reconsolidation with possibility of having inaccurate memories or memory strengthening, Therefore, my third study (see Chapter 4) focuses on testing directly the capacity of memory reactivation to facilitate memory strengthening.

Chapter 2

Study 1 Music and episodic memory processing

2.1 Abstract

Past researches demonstrated that episodic memories are not always accurate, subject to false recollection (Loftus, 2005). One significant explanation for false memories is due to the process of memory reconsolidation. The reactivation of a memory places memory to a labile state and allows that memory to be updated, usually adaptively and accurately. However, this normal process can be subverted to result in inaccurate or false memories (Hupbach et al., 2007). There has been little research focus on specific sensory modalities, such as olfactory and auditory. Therefore, current study focused on music as a learning context in memory reconsolidation. The specific aim was to investigate the impact of music upon episodic memory reconsolidation. A total of 50 participants were recruited via the Psychology Research Participation Scheme and experienced 3 sessions of testing, with 48 hours between each session. These delays were necessary in order to ensure that newly acquired memories receive some degree of consolidation in between sessions. On Day 1, participants were instructed to learn a list of 20 images using presentation slides method. They were tested immediately and given additional opportunities to learn the images until they have reached a criterion of learning, i.e. 85% correct or a maximum of four learning trials. This learning session was conducted in the presence of classical music. On Day 2, participants were invited to a different

testing room with the same researcher as on Day 1 and received reminder or not. They were randomly assigned into five different groups and instructed to learn a second set of 20 images, in the same manner as on Day 1, but using a physical paper hand-out method. In particular, this was aimed to focus on whether exposure solely to the music presented on Day 1 is sufficient to reactivate the episodic memory to induce episodic memory reconsolidation. On Day 3, all the participants were asked to recall the images that they have learned on Day 1. They were tested repeatedly up to 4 times with a brief distraction break in between each recollection in order to test for the reliability recall. A 5 x 4 mixed Analysis of Variance (ANOVA) was used to analyse the number of images recalled on Day 3 with the music groups as the between subjects whereas recall trials as the within subjects. Current results did not support the hypothesis as there were no significant differences in the amount of intrusions from List 2 among all five experimental music groups. This suggested that re-exposure to the same piece of music did not successfully reactivate the episodic memory to trigger reconsolidation. Experimental groups did not differ in the number of images correctly recalled from List 1 on Day 3, suggesting that music did not strengthen or weaken the memory of the original list, indicating that learning a second list had no lasting impact on original memory. Since current study failed to replicate findings from Hupbach et al. study (2007) and found out that re-exposure to the same piece of music did not successfully reactivate the episodic memory to trigger reconsolidation, future researches should eliminate the music element and focus on initial learning context to induce episodic memory reconsolidation.

2.2 Introduction

Most studies on memory consolidation imply that memories are unstable and prone to any changes immediately after learning, but memories can become resistant to change on a later stage when they are stabilised (McGaugh, 2000). However, this consolidation view has been challenged by reconsolidation theory, suggesting that reminder cue reactivates the consolidated memories and places them in a labile state, where memories can be destabilised and updated (Nader, 2003). Specifically, after original memory is reactivated, new information, which is associated or contradicts the reactivated memory, is presented. After a delay, the original memory is tested. If the new information modifies the original memory (either impairing or updating), a reconsolidation phenomenon has occurred.

This reconsolidation phenomenon has been extensively studied in various animal protocols (Nader et al., 2000) and mostly using behavioural interference paradigm in human reconsolidation (e.g. Forcato et al., 2007; Hupbach et al., 2007; James et al., 2015; Schiller et al., 2010; Schwabe & Wolf, 2009; Wichert, Wolf, & Schwabe, 2011). In the past decade, memory reconsolidation experiments were primarily conducted on animals. For instance, Nader and colleagues (2000) revealed that rats which had received the reminder before the inhibitor injection showed less freezing reaction compared to those vehicle-injected rats and control rats without reminders. Aside from animal testing, several laboratory studies on human memory reconsolidation (e.g. Forcato et al., 2007; Hupbach et al., 2007; Walker et al., 2003) demonstrated that human reconsolidation is still emerging. Most studies showed evidence on reactivation of episodic memory (e.g. a learned list of items or images) proving that memory is indeed vulnerable to erroneous change (i.e. recalling an item that was not presented at that time). Researchers have also successfully revealed reconsolidation effects on procedural memory and conditioning (Walker et al., 2003), which are considered as implicit memory that do not require conscious reactivation.

Since reconsolidation process have been successfully reported in several human memory studies, present study aims to focus primarily on episodic memory, a form of memory that allows for the conscious recollection of events. Episodic memory is described by many as the only unique memory that permits people to consciously re-experience their past experiences (Tulving, 2002), to investigate the memory reconsolidation effect.

In 2007, Hupbach and colleagues successfully demonstrated reconsolidation effects in human episodic memory by introducing concepts of post-reminder effects in episodic memory. Participants in their study learned the first set of objects (Set 1) in session 1. After 48 hours later, they were either provided a reminder of session 1 or not and learned a second set of objects (Set 2). On the third session, they were asked to recall the first set of objects (Set 1) from session 1. Results found out that participants who received reminder showed a high number of intrusions from second set of objects (Set 2), whereas participants who did not receive any reminder showed almost no intrusion. This strongly suggests that reactivation of previously learned material before presenting new information can lead to the incorporation of new information into the original memory. This finding proposes that memory reconsolidation is a constructive mechanism that allows memory to be updated with new information and this phenomenon has also been discussed in the animal literature (e.g. Lee, 2009). However, Hupbach et al. (2007) study did not specifically discuss the factor that led to memory reactivation, as participants in reminder group were brought back to the same experimenter room (same spatial context) with the same experimenter and were asked a reminder before learning the second set of objects (Set 2).

Theoretically speaking, encoding-specificity principle (Tulving & Thompson, 1973), which stated that the learning context while encoding information readily affects the recall of the information, emphasised that spatial context could serve as a cue for reactivating the memory of the first learning experience. Balsam (1985) found influence of context in both excitatory and inhibitory learning phenomenon. In 1975, Godden and Baddeley demonstrated that divers who learned and recalled under the water or learned and recalled on the dry land, successfully remembered 46% more than divers who learned in one environment and recalled in another environment. This suggested that a phenomenon where materials learned in one environment is better recalled than in a different environment. According to Eich (1980) and Smith (1988), context-dependency effects showed that the spatial context serves as part of the memory trace and can be used to enhance memory retrieval. Grant et al. (1998) found out that students tend to score higher in their exam when the environment of the examination hall shared the same auditory background noises as their study classroom. This evidence highlights that context-dependency effect applies to auditory environment in addition to unrelated materials. This context-dependency effects for recognition also have been successfully found in several studies (e.g. Canas & Nelson, 1986; Smith, 1985; Smith & Vela, 1992). However, there are a few studies that did not demonstrate this effect (e.g. Bell et al., 1984; Godden & Baddeley, 1980; Smith, Vela, & Williamson, 1988). Hupbach, Hardt, Gomez, & Nadel (2008) found the unique role of spatial context in reactivating memory. In three experiments to test whether memory reconsolidation is context dependant or not, they explored the different reminder (Experiment 1), combination of reminders (Experiment 2) and spatial context reminder (Experimenter 3). They found that spatial context does not act as memory cue but served as a platform during reactivating episodic memory in a context, which could produce intrusions (Nadel et al., 1985).

Based on past findings, there are critical conditions that allow the original memory to be reactivated in such a way that allows memory reconsolidation to take place. While these conditions have been studied extensively in rodent experiments, the only condition demonstrated for human episodic memory is the necessity for re-exposure to the original learning environment (i.e. testing room; Hupbach et al., 2008). However, there has been little further study, especially into the specific sensory modalities of such a context (i.e. visual, auditory and olfactory components). Therefore, in this chapter (study 1), the main aim would be investigating further in episodic memory reconsolidation by adding the element of music, acting as an auditory context and cued reminder. Music appears to have strong influential role in many people’s daily life. From morning to late night, no matter young or old generation, a lot of people will choose to listen to different music genre from classical to rock music. Therefore, music can uniquely construct our memories, especially our episodic or autobiographic memories.

Most of the music memory literature focused on the parameters of music, i.e. tempo and timbre and how this information encodes into our long-term memory (Jancke, 2008). For example, Halpern and Mullensiefen (2007) examined the influences of tempo and timbre on implicit and explicit memories for tunes. Participants were asked to give explicit and implicit memory ratings for a set of 80 tunes, which included 40 tunes that had previously been played and heard. Results demonstrated that change in both timbre and tempo impaired explicit memory whereas change in tempo made implicit tune recognition worse. There are other studies emphasizing on memory for musical pitch (Jancke, 2008). Besides that, there are increasing number of studies on music training and cognitive skills which work closely with working memory, such as non-verbal reasoning (e.g. Forgeard, Winner, Norton, & Schlaug, 2008), IQ (e.g. Schellenberg, 2004), reading skills (e.g. Moreno, Margues, Santos, Santos, Castro, & Besson, 2009). Music theorists previously suggested that episodic memory is commonly treated as less musically relevant mechanism, but recent studies proposed the other way, in which emphasizing that episodic memory could be one of the important elements in music (Sloboda & O'Neill, 2001). In short, music is an ideal auditory stimulus as it is readily associated with episodic memory. This raises the attention in memory research and allows more refined questions to be posed concerning the capacity of music to trigger episodic memory retrieval and reconsolidation. Fagen et al. (1997) investigated auditory context and memory retrieval among three-monthold young infants. Young infants were trained to move an overhead crib mobile when music (either very different music or similar music) were played. They found out that change in auditory context impaired the retention and the results were consistent with Solheim, Hensler, and Spear (1980)'s study on young animals' memories which susceptible to the influence of different context.

Music can be a powerful tool for committing new information to memory. Most existing researches mainly focused in comparing explicit memory presented in a musical versus non-musical condition using free recall or recognition memory (Tamminen, Darby, Rastle, & Williamson, 2015). In 1994, Wallace demonstrated that word is better recalled when it is heard as a song rather than as in speech. Participants were asked to memorise the lyrics to a ballad with the words presented either in speech or song. Participants were then asked to recall the words both during the training session, which consisted of repeated presentations, and in a delayed test. Results showed that participants in the song condition scored high recall accuracy during training and continued to be higher in the delayed test as well. Similar findings were also found in the studies by Calvert and Tart (1993), McElhinney and Annett (1996), as well as Kilgour, Jakobson, and Cuddy (2000). This strongly suggested that music can assist in learning, as well as in retrieving (Wallace, 1994). In addition, Kang and Williamson (2014) found out that background music may have a positive effect on memory, which obscuring the difference between in speech (spoken) and song conditions.

2.2.1 Rationale of current study

The overall aim of this study was to investigate specifically the impact of music upon episodic memory reconsolidation. Although there has been quite extensive study of music and episodic memory, this would not provide an answer to whether music can serve as for activating reconsolidation and allowing memory updating in the same way as physical spatial context. Hupbach et al. (2007) study was replicated to find out how important are re-exposure to music versus spatial context in reactivating the episodic memory to trigger memory reconsolidation. In this study, all the participants were asked to memorise first 20 novel items (List 1) with the Classical music playing at the background on the first day (except for the no music condition on both days group). To measure re-exposure to music in reactivating episodic memory, five groups with different music genres (i.e. same Classical music, different Classical music, old school Jazz music, no music on Day 2 and no music on both days group) were introduced on second day in a different testing room (different spatial context). Participants in different groups then memorised second list of 20 novel items (List 2) accordingly. To measure explicit recall, free call technique was adopted on the actual test day (Day 3). Current study predicted that participants in same Classical music group, acted as reminder group, would misattribute the highest number of intrusions (images from List 2) on the free recall.

2.3 Materials and Method

2.3.1 Design and participants

All procedures of this study were approved by the Science, Technology, Engineering and Mathematics (STEM) Ethics Review Committee in University of Birmingham. A total of 50 undergraduate students from University of Birmingham were recruited through Psychology Research Participation Scheme (RPS), an online platform for researchers to recruit participants from the scheme. All the 50 participants gave their informed consent to participate in this study and received either course credit or cash credit for their participation. Due to the nature of this study, which involved listening to music, participants were required to have no hearing impairment. All of them were randomly assigned to five different music groups, i.e.

(i) Same Classical music group
(ii) Different Classical music group
(iii) Very different music group (old school Jazz music)
(iv) Music-on-day 1-only group
(v) No music on both days group

Current study was replicated based on the list-learning paradigm used in Hupbach, Gomez, and Nadel (2009), aiming to test whether exposure solely to the music presented on Day 1 is sufficient to reactivate the episodic memory to induce memory reconsolidation. All the 50 participants experienced 3 different testing sessions, with 48 hours between each session. These delays were necessary in order to ensure that newly acquired memories were fully consolidated by the time of memory reactivation in between sessions, as suggested in Hupbach et al. study (2009).

2.3.2 Materials

Memory task: Each list 1and list 2 consisted of 20 unrelated images (see Table 1 for the full list). Visual images were randomly selected from the exemplar pairs paradigm developed by Brady, Konkle, Alvarez, and Oliva (2008) (see Figure 4 for examples).

Table 1

Lists of Visual Images Presented on Day 1 and Day 2

List 1	List 2
Chips	Rabbit
Basket	Air balloon
Wheelchair	Sunglasses
Tractor	Money
Aeroplane	Ship
Staple remover	Ladder
Grapes	Muffin
Spray bottle	Pliers
Thread	Starfish
Soother	Bicycle
Christmas hat	Fan
Razor	Key
Balloon	Train
Grand piano	Tortoise
Globe	Trophy
Chocolate bar	Ice cream
Cow	Bass guitar
Hanger	Antique camera
Calculator	Measuring cylinder
Goggles	Microscope

Figure 4. Examples of visual images in list 1 and 2 on Day 1 and Day 2

Music: In order to investigate the influences of music on memory reconsolidation, two pieces of Classical music and a piece of old school Jazz music were selected. The first piece of Classical music, which presented on Day 1, was John Williams' *Cavatina*, a 1970 classical guitar piece, whereas the second piece of Classical music, which was presented on Day 2, was Tchaikovsky's *Andantino Semplice,* one of the three movements in Piano Concerto No. 1. The third piece of music was a completely different music genre, i.e. old school Jazz music, Miles Davis's *Move*, acted as comparison to Classical music, presented on Day 2. Participants were memorising the images presented either through sequential presentation slides on the computer or physical paper hand-out method to them with the music at the background, which played through speaker with moderate volume.

2.3.3 Procedure

On Day 1, at the beginning of the experiment, participants were informed that they would experience 3 sessions of testing, with 48 hours between each session, required to memorise a series of visual images. The sessions took place on Monday, Wednesday, and Friday of the same week. Participants were instructed to learn first list of 20 images in the presence of the first piece of Classical music, John Williams' *Cavatina*, except for the no music group. Each visual image was appeared on the screen for 4 seconds with immediate progression to the next visual image. They were then tested immediately by performing free recall. This procedure was repeated until the participants either successfully remembered 17 images out of 20 images (85% correct) or a maximum of four learning trials. Throughout the whole free recall session, experimenter manually recorded all the participants' responses.

On Day 2, participants were brought to a different testing cubicle with the same researcher as on Day 1 and performed different testing sessions according to the groups. The procedure on Day 2 differed for same Classical music and the other four groups (i.e. different Classical music, old school Jazz music, music-on-day 1 only, no music on both days groups). For participants in the same Classical music group, the same researcher as on Day 1 played the first 10 seconds of John Williams' *Cavatina* and asked, "Do you remember this song and what we did with it?" Participants were encouraged to describe the procedure without explicitly recall the specific images from List 1. For participants in the other four groups, the same researcher did not ask what had happened during Day 1 nor presenting the first 10 seconds of John Williams' *Cavatina*. Participants in all groups were instructed to learn a second list of 20 visual images with different music at the background, except for the same Classical music group, but using a physical paper hand-out method with one visual image per page. For example, participants in very different music group (old school Jazz music) were asked to learn the second list of 20 images with the Miles Davis's *Move* at the background. Day 2 procedure differed from Day 1 so that the task would not serve as a reminder. Participants were then tested immediately by performing free recall technique, in the same learning criterion as on Day 1.

On Day 3 testing day, all the participants were returned to the same testing cubicle with the same experimenter as on Day 1 and asked to recall the visual images that they learned on Day 1. No music was presented at all on this day and free recall techniques was used. Experimenter manually recorded all the participants' responses with simple binary coding, i.e. correct recall of Day 1 visual images and erroneous intrusions of Day 2 visual images. They were also tested repeatedly four times with brief distractions in between each recollection in order to test for the reliability of recall. This whole free recall technique took approximately 15 minutes. At the end of the study, participants were fully debriefed on the rational of the study, with the explanation on context is an important factor in reactivating memory and background music has not yet been investigated as a contextual stimulus.

The presentation methods are illustrated on Figure 5 and the different experimental procedures between five groups are tabulated on Table 2.

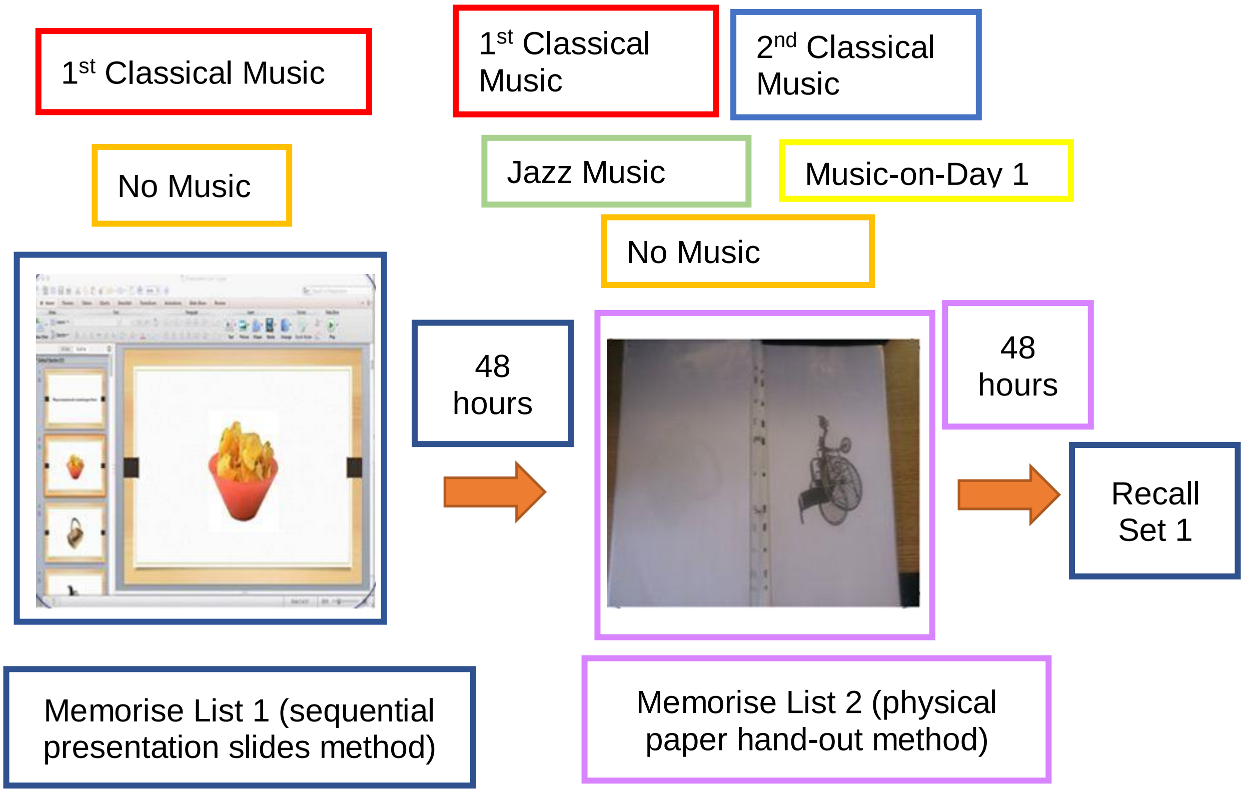

Figure 5. Illustration of the experimental procedures for the study 1

Table 2.
Experimental Procedures for Study 1

<table>
<tr><th></th><th>Same Classical music
John Williams’ *Cavatina*</th><th>Different Classical music
Tchaikovsky’s *Andantino Semplice*</th><th>Very different music (Jazz music)
Miles Davis’ s *Move*</th><th>Music-on-day 1-only</th><th>No music on both days</th></tr>
<tr><td rowspan="3">Day 1</td><td colspan="4">**First learning session** was conducted in the presence of the **first Classical music,** John Williams’ *Cavatina.*</td><td>**First learning session** was conducted with **no music** background at all.</td></tr>
<tr><td colspan="5">All groups of participants were to learn the first list of **20 images using sequential presentation slides method on the computer.**</td></tr>
<tr><td colspan="5">Learning criteria: Participants were tested immediately once the image slides ended and given opportunities to learn the visual images until they remembered at least 17 out of 20 items (85% correct) or a maximum of four learning trials.</td></tr>
</table>

Day 2	Same experimenter from Day 1 was administered the second learning session, but in a **different testing room**.				
	Second learning session was conducted in the presence **of same classical music as on Day 1.** At the beginning, first 10 seconds of *Cavatina* was presented and asked, “Do you remember this song and what we did with it?”	**Second learning session** was conducted in the presence of **second piece of classical music.**	**Second learning session** was conducted in the presence of **Jazz music.**	**Second learning session** was conducted with **no music** background.	**Second learning session** was conducted with **no music** background.
	All the participants were instructed to learn the second list of **20 visual images using physical paper hand-out method.**				
Day 3	All the participants were brought back to the same room as Day 1 and performed the same free recall.				

2.4 Results

On the testing day (Day 3), participants were asked to recall the visual images that learned on Day 1. Therefore, any falsely recalled images from Day 2 would be treated as intrusions. The number of images correctly and falsely recalled on Day 3 was analysed using 5 x 4 mixed Analysis of Variance (ANOVA), with different music groups as the between subjects variable whereas recall trials (1 – 4) or intrusion trials (1 – 4) as the within subject variable. Assumption of sphericity was tested and corrected using Greenhouse-Geisser where appropriate. In this study, Bonferroni correction method was used to adjust post-hoc multiple comparisons for both intrusion and recall trials.

Figure 6 illustrates the mean numbers of images correctly recalled and falsely recalled on Day 3 (out of 20) across five different groups.

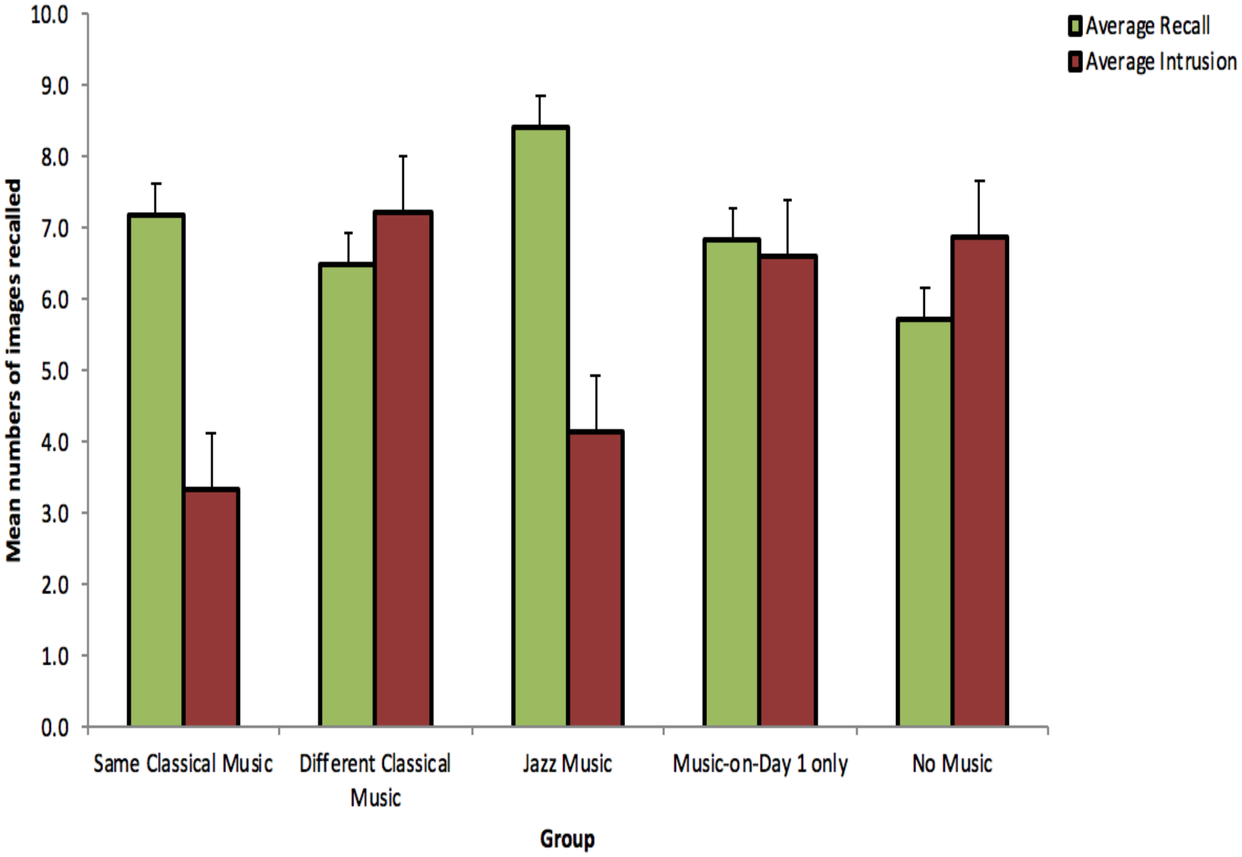

Figure 6. Mean numbers of images (+ SE) correctly and falsely recalled out of 20 on Day 3 across five different groups

2.4.1 Intrusions from Day 2

The ANOVA revealed no significant interaction effect between trials and group was reported, *F* (6.8, 76.0) = 1.456, *p* = 0.198, as well as no significant main effect of group, *F* (4, 45) = 2.159, *p* = 0.089, suggesting no significant differences between all five groups in the intrusions of visual images (see Figure 6).

The ANOVA revealed a significant main effect of trials, *F* (1.7, 76.0) = 11.004, ***p* < 0.001**, suggesting trials were significantly different to each other respectively, specifically going upward (see Figure 7).

A post hoc pairwise comparison (see Table 3) also found out that there were significant differences between trials. Intrusion 1 significantly differed than intrusion2 (***p* = 0.001**), intrusion 3 (***p* = 0.001**) and intrusion 4 (***p* = 0.002**). However, there were no significant differences between intrusion 2 and intrusion 3 (*p* = 1.000), intrusion 2 and intrusion 4 (*p* = 1.000), intrusion 3 and intrusion 4 (*p* = 1.000). Table 4 illustrated the mean, standard error of mean and standard deviation for each trial.

Table 3
Post hoc Pairwise Comparison for Each Intrusion Trial

		Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Intrusion 1	Intrusion 2	- 0.820**	0.191	0.001	- 1.347	- 0.293
	Intrusion 3	- 1.060**	0.246	0.001	- 1.740	- 0.380
	Intrusion 4	- 1.160**	0.294	0.002	- 1.972	- 0.348
Intrusion 2	Intrusion 3	- 0.240	0.209	1.000	- 0.817	0.337
	Intrusion 4	- 0.340	0.256	1.000	- 1.048	0.368
Intrusion 3	Intrusion 4	- 0.100	0.095	1.000	- 0.361	0.161

**$p < 0.01$

Table 4
Descriptive Statistics for Each Intrusion Trial

	Intrusion 1	Intrusion 2	Intrusion 3	Intrusion 4
Mean	4.880	5.700	5.940	6.040
Std. Error of Mean	0.523	0.545	0.603	0.636
Std. Deviation	3.696	3.851	4.264	4.499

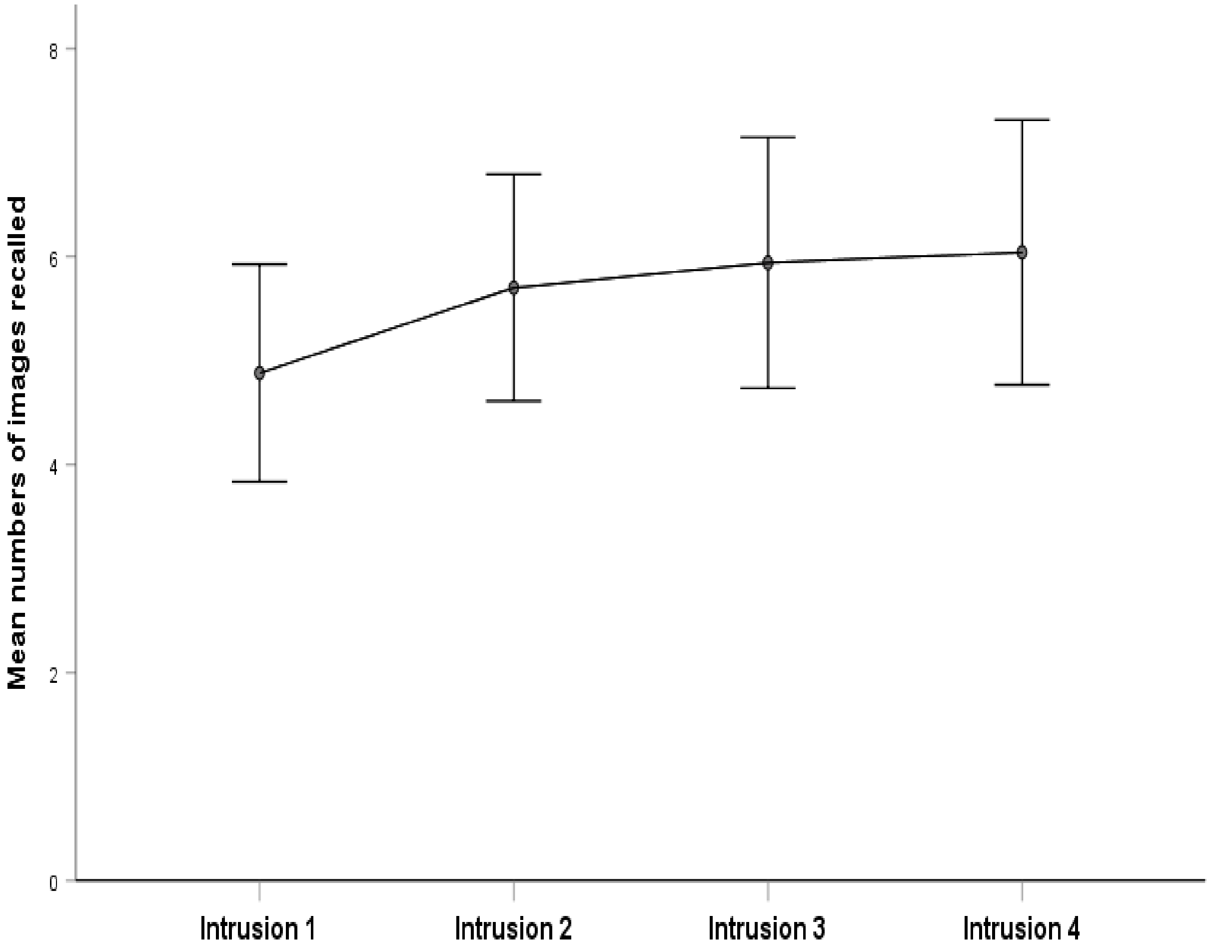

Figure 7. Mean numbers of images (± SE) falsely recalled across all four intrusion trials

2.4.2 Recall List from Day 1

The ANOVA reported no significant interaction effect between trials and group, *F* (5.4, 61.1) = 1.101, *p* = 0.371 (see Figure 8), as well as no significant main effect of group, *F* (4, 45) = 0.767, *p* = 0.552, suggesting no significant differences between all five different music groups in the recall of visual images (see Figure 6).

The ANOVA revealed no significant main effect of trial, *F* (1.4, 61.1) = 3.353, *p* = 0.059, suggesting trials did not significantly different across all four trials (see Figure 8).

A post hoc pairwise comparison (see Table 5) did not find any significant differences between trials. Recall 1 significantly differed than recall 2 (***p* = 0.003**). However, there were no significant differences between recall 1 and recall 3 (*p* = 0.281), recall 1 and recall 4 (*p* = 0.115), recall 2 and recall 3 (*p* = 1.000), recall 2 and recall 4 (*p* = 1.000), recall 3 and recall 4 (*p* = 0.625). Table 6 illustrated the mean, standard error of mean and standard deviation for each trial.

Table 5

Post hoc Pairwise Comparison for Each Recall Trial

		Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Recall 1	Recall 2	- 0.720**	0.192	0.003	- 1.249	- 0.191
	Recall 3	- 0.780	0.382	0.281	- 1.833	0.273
	Recall 4	- 0.960	0.395	0.115	- 2.051	0.131
Recall 2	Recall 3	- 0.060	0.368	1.000	- 1.075	0.955
	Recall 4	- 0.240	0.392	1.000	- 1.321	0.841
Recall 3	Recall 4	- 0.180	0.109	0.625	- 0.480	0.120

**$p < 0.01$

Table 6

Descriptive Statistics for Each Recall Trial

	Recall 1	Recall 2	Recall 3	Recall 4
Mean	6.320	7.040	7.100	7.280
Std. Error of Mean	0.533	0.527	0.527	0.573
Std. Deviation	3.771	3.725	3.727	4.051

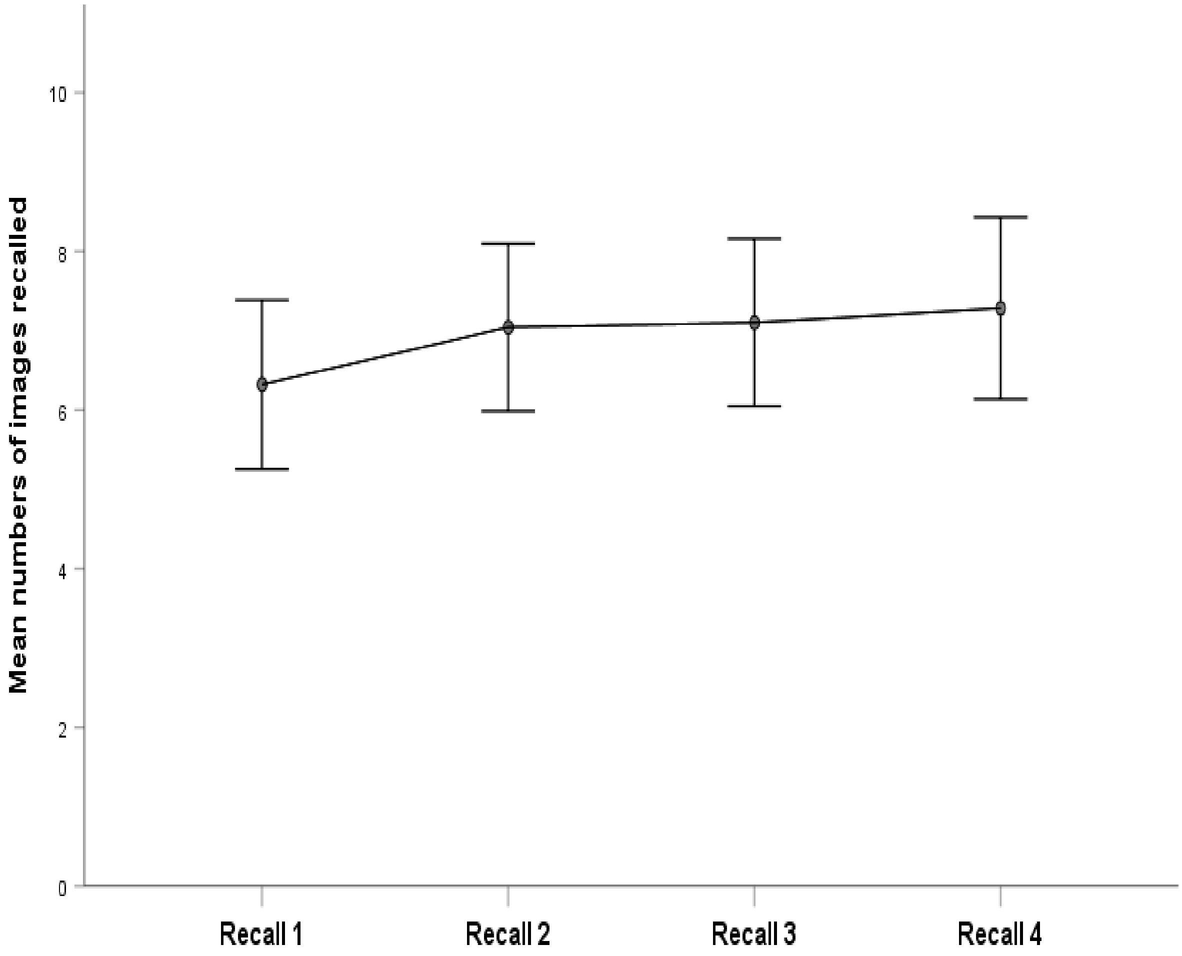

Figure 8. Mean numbers of images (± SE) correctly recalled across all four recall trials

2.5 Discussion

There has been little research study on specific sensory modalities, such as olfactory and auditory. Hence, the primary focus of current study 1 was to investigate the impact of music as a learning context upon episodic memory reconsolidation. Participants were asked to learn the second list of 20 novel items (List 2) in a different testing room (different spatial context) on Day 2 so that music would serve as the only reminder to investigate memory reconsolidation. On the testing day (Day 3), all the participants were asked to recall the visual images that learned on Day 1. Any falsely recalled images from Day 2 would be treated as intrusions. The 5 x 4 mixed ANOVA reported no significant interaction effect between intrusions trials and group, as well as no significant main effect of group, suggesting no significant differences between all five groups in the intrusions of visual images. And, similar pattern of results also reported in recall trial, i.e. no significant interaction effect between recall trials and group, and no significant main effect of group, suggesting no significant differences between all five groups in the recall of visual images as well.

Current results showed no significant group differences in both intrusions and recall of visual images, but there was variation across the groups. This is surprising as; the no music control group is expected to have few intrusions and the other groups were predicted to be different. The same Classical music group, predicted to have highest number of intrusions, had the lowest numerically compared to the other four music groups (i.e. different Classical music, old school Jazz music, no music on Day 2 and no music on both days group). This contradicted with the findings by Hupbach et al. (2007), in which they found out that reminder reactivated memory of the original list, where participants in the reminder group incorrectly intermixed more objects from List 2 in their free recall. However, the experimental groups did not differ in the number of images correctly recalled from List 1 on Day 3, suggesting that music did not strengthen or weaken the memory of the original list, which was consistent with the findings by Hupbach et al. (2007), indicating that learning a second list had no lasting impact on original memory.

The most significant support for reconsolidation could be misinformation and hindsight bias effects, as proposed by Hardt, Einarsson, & Nader (2010). In Loftus (2005) study, participants were provided with some misleading information when answering questions about a viewed original event. The results of memory test showed that participants were incorrectly delivered false information instead of when asked to recall the original event. These intrusions mainly occurred because the post-event questions were acted as reminder, causing the original event to be retrieved and become labile. Therefore, the reactivated memory was modified based on the misleading information (Hardt et al., 2010). Forcato et al. (2010) also highlighted the potential function of memory reconsolidation as a constructive mechanism in allowing memories to be vulnerable to changes and updated with new information. This effect was also significantly found in several studies, such as animal literatures (e.g. Lee, 2009). However, the reconsolidation effect as suggested by Forcato et al. (2010) in their paired associates learning paradigm did not occur in current study 1. In current study, the same piece of music, *Cavatina* by Williams, which was delivered to participants in Day 1 and Day 2, was originally served as a reminder. The music was acted as a cue to retrieve the memory of the List 1 from Day 1 and placed them in a labile state, so that the input of List 2 would modify the reactivated memory. However, current results presented the otherwise. Re-exposure to the same piece of Classical music did not successfully reactivate the episodic memory to trigger reconsolidation, while participants from different Classical music group showed higher intrusions. More importantly, participants in the absence of music group showed high intrusions, suggesting that the parameters in current study were not amenable enough to observe the reconsolidation effect.

According to source-monitoring explanation (Johnson, Hashtroudi, & Lindsay, 1993), the more similarities in between two different context, the more likely source confusions are to happen. In current study, procedures for each group on Day 1 and Day 2 were different, except the two similarities, i.e. the same researcher was administrated the study on both days and the same piece of Classical music was presented on both days for same Classical music group. Therefore, source confusion should occur in same Classical music group, which should misattribute the highest number of intrusions. However, current results did not successfully demonstrate both reminder effect and source-monitoring account as same Classical music group appeared to have the least intrusions.

Hupbach, Hardt, Gomez, and Nadel (2008) suggested that spatial context is not a cue but serves as a platform during reactivating episodic memory in a context, which could produce intrusions. They proposed that revisiting the spatial context where the first list of images was learned, memory for the first list is reactivated and could be easily modified and updated with new incorporated information. In contrast, learning a second list of images in a different spatial context activates a new, different platform, and thus did not modify the memory for the first list. Since Hupbach et al. (2008) suggested the idea of context as platform, music in current study may well not serves as a cue but serves as a platform. Thus, this might explain participants in same Classical music group appeared to have the least intrusions compared to the other four music groups. This suggested that re-exposure to the same piece of music did not successfully reactivate the episodic memory to trigger reconsolidation. However, as both learnings in current study took place in two different testing cubicles (different spatial context), participants in no music on both days group should perform better in recall performance and had less intrusions. However, current results showed the opposite effect, i.e. high intrusion was found in no music on both days group. Klingmuller et al. (2017) originally aimed to replicate Hupbach et al. (2007) study. However, their first and third study failed to replicate the Hupbach et al. (2007) results, where participants in their study had better memory performances.

Taken together, current study highlighted a main point, i.e. reconsolidation process may not be as reliable as suggested in previous reconsolidation studies, supported by both Klingmuller et la. (2017) and Van Schie, Van Veen, Van Den Hout, and Engelhard (2017). Instead of reconsolidation with inaccurate memories, memory strengthening was potentially found here. The first finding revealed that participants in current study had considerably better memory performance compared to participants in

Hupbach et al. study (2007) although same conditions were applied, i.e. undergraduate students were recruited and participated for course credit. Using modified procedure that music was used as a reminder cue, study 1 still failed to replicate Hupbach et al. study (2007) and found out that re-exposure to the same piece of music did not successfully reactivate the episodic memory to trigger reconsolidation. This failed replication should be due to small sample sizes in current study 1, which we only recruited 10 participants for each group, compared to sample sizes in Hupbach et al. study (2007), which consisted of 12 participants for each group. Therefore, in the next study, more participants will be recruited to increase the power size.

As Nader et al. (2005) proposed, reconsolidation process consists of three essential steps. Firstly, reactivating the existing memory and placing them in a labile state followed by modification of the prior existing memory, and finally reconsolidating the modified memory. Original aim of current study was unable to be fulfilled, likely because reconsolidation itself was not being engaged for some reason. Therefore, further researches will be modified with two outstanding questions, firstly, original research question, which will not be pursued further, because of, the factors that led to memory reconsolidation was unable to examine precisely. Secondly, a need to replicate the Hupbach et al. study (2007, 2008), especially in light of Klingmuller et al. (2007), which is the aim for the next chapter. The next chapter (Study 2) involved examining solely on context-dependent effect, proposing that if re-exposure to the same context puts the original memory into a labile state, then the learning of new information should alter the original memory.

Chapter 3

Study 2 Reconsolidation of episodic memory processing

3.1 Abstract

Past researches have demonstrated that episodic memories are not always accurate, being subject to false recollection (Loftus, 2005). One emerging explanation for false memories is due to the process of memory reconsolidation. The reactivation of a memory places memory to a labile state and allows that memory to be updated, usually adaptively and accurately. However, this normal process can be subverted to result in inaccurate or false memories (Hupbach et al., 2007). The specific aim of the current study was to provide a conceptual replication of studies of Hupbach et al. (2007, 2008). In particular, current study was focused on whether exposure solely to the initial learning context is sufficient to reactivate episodic memory to induce episodic memory reconsolidation. A total of 108 university students were randomly assigned into three different groups, i.e. same-experimenter-same-room group (the Experimental Group; expected to engage reconsolidation), different-experimenter-different-room group (the Control Group) and a further no interference control. For the first two groups, participants experienced 3 testing sessions, with 48 hours between each session. These delays were necessary in order to ensure that newly acquired memories were fully consolidated by the

time of memory reactivation. The interference control participants omitted Day 2. On Day 1, participants were instructed to learn a list of 20 images using a sequential presentation slides method. They were tested immediately and given additional opportunities to learn the images until they had reached a criterion of learning, i.e. 85% correct or a maximum of four learning trials. On Day 2, participants were asked either to the same testing room as Day 1 or a different testing room and instructed to learn a second set of 20 images, in the same manner as on Day 1, but using a physical paper hand-out method. A second researcher administered the Day 2 session in the different testing room. On Day 3, all the participants were returned to the Day 1 room, with the original experimenter and asked to recall the images that they learned on Day 1. They were tested repeatedly up to 4 times with a brief distraction break in between each recollection in order to test for the reliability of recall. Recall was made up of correct recall of Day 1 images and erroneous intrusions of Day 2 items. A mixed Analysis of Variance (ANOVA) was used to analyse the number of images recalled on Day 3 with the groups as the between subjects and recall trials as the within subjects. The results unexpectedly showed no difference in intrusions between the Experimental and Control groups (with both showing a modest number of intrusions). In contrast, while the Control Group had poorer recall of Day 1 items compared to the no interference control, performance in the Experimental Group was preserved. Therefore, there appears to be dissociation between updating of list memory and resistance to the memory-weakening effects of interference. While it remains unclear whether the latter phenomenon is functionally related to reconsolidation, it is consistent with a body of evidence suggesting that reactivation-induced reconsolidation can maintain or even strengthen memories.

3.2 Introduction

As Study 1 did not successfully demonstrate the reconsolidation effect as predicted, several points are open to speculation. Firstly, since music context did not successfully demonstrate the reconsolidation effect, current study 2 would replicate the basic effect on initial learning context, by removing the music element, to induce episodic memory reconsolidation. If re-exposure to the same context puts the original memory into a labile state, then the learning of new information should alter the original memory. Secondly, sample size in Study 1 was relatively small, which have recruited only 10 participants for each group, and failed to replicate Hupbach et al. study (2007). Therefore, in current study 2, more participants will be recruited to increase the power size.

Classical theory proposed that learning of new information, which is transformed into long-term memory through consolidation process, requires protein synthesis (McGaugh, 2000). Therefore, once memory consolidated over time, memory became permanent and insensitive to any disruption (Squire & Alvarez, 1995) [see Figure 9 for traditional view of memory encoding by Nadel et al. (2012)]. According to Nadel, Hupbach, Gomez, and Newman-Smith (2012), when we experience an event, some characteristics of that event will be encoded through consolidation process. After a while, it will become permanent and store in long-term memory, which cannot be disrupted.

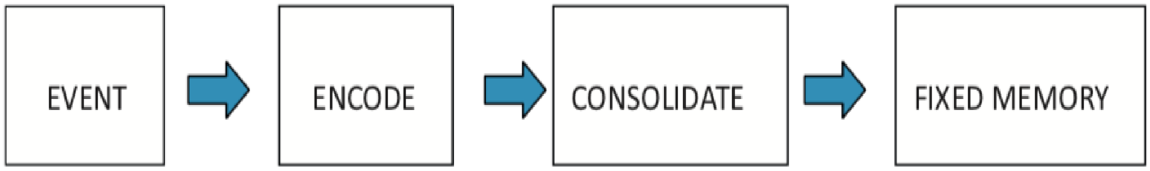

Figure 9. Traditional view of memory encoding by Nadel et al. (2002)

However, this view of consolidation theory has been challenged. Figure 10 demonstrated the possible effects of reactivation induced memory trace lability (Nader et al., 2012). Once consolidation memory reactivated, memory becomes labile and open to several changes, including disrupting memory or updating memory (Nader et al., 2000; Walker et al., 2003) or re-stabilizing memory (Hupbach et al., 2007). Several researches suggested that old memories that are insensitive to protein synthesis inhibitors can become vulnerable if they are reactivated (Anokhin, Tiunova, & Rose, 2002; Judge & Quartermain, 1982; Kida et al., 2002; Lewis, 1979; Mactutus Riccio, & Ferek, 1979; Misanin, Miller, & Lewis, 1968; Nader et al., 2000; Richardson, Riccio, & Mowrey, 1982; Sara, 2000; Taubenfeld, Milekic, Monti, & Alberini, 2001). Therefore, there is a chance that memories can be modified in many ways after they are consolidated, which proposes that old memories are not indefinitely stable (Misanin et al., 1968; Nader et al., 2000).

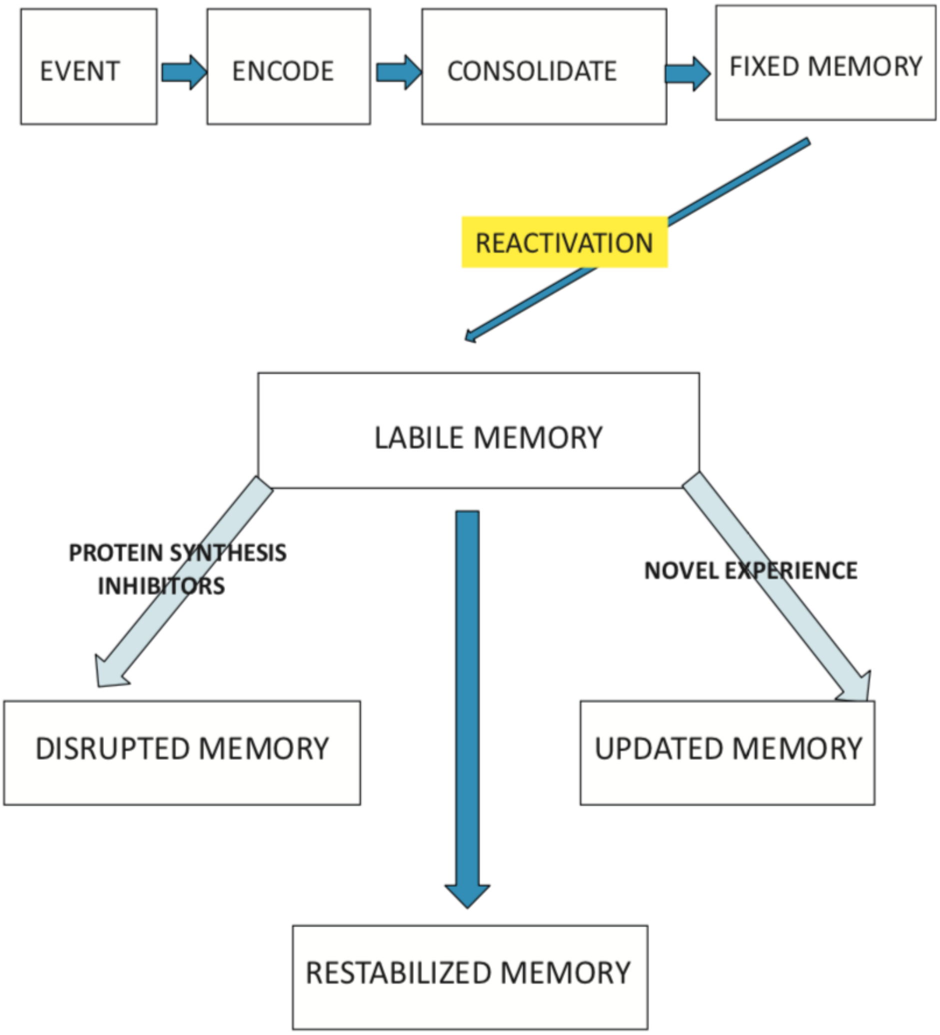

Figure 10. Possible effects of reactivation induced memory trace lability by Nadel et al. (2002)

The famous and most widely studied way is reconsolidation, which is the focus of current chapter. Memory reconsolidation is a fairly new process that occurs when previously consolidated memories that are stored in the long-term memory being recalled and actively consolidated (Rodriguez, Horne, & Padilla, 1999), destabilized (Nader, Schafe, & Le Doux, 2000) and modified (Spear, Lewis, McGaugh, & Ralph, 1973). This reconsolidation phenomenon was first noted in a rodent research when a fear conditioned memory was reduced by inducing electroconvulsive shock during the reconsolidation period after a fear memory reminder (Misanin et al., 1968). Past studies also suggested that memory can be reactivated in such a way that allows memory reconsolidation to take place, such as the stimuli itself or the context in which the stimuli was presented in (Spear et al., 1973).

In past, this reconsolidation phenomenon has increasingly studied using behavioural paradigm. For example, the fear conditioning study conducted by Nader et al. (2000), suggesting that consolidated fear memories return to a labile state during the reactivation period. In their study, the rodents were trained to pair a tone (conditioned stimulus, CS) with an aversive foot-shock (unconditioned stimulus, US), in a manner dependent upon the basolateral amygdala. This study discovered that re-exposure to the tone consequently elicited the freezing response only. Results also found out that the protein-synthesis inhibitor blocked the reconsolidation process, which led to memory impairment. This memory impairment findings also successfully replicated in several studies (e.g. Alberini, 2007; Dudai & Eisenberg, 2004). Taubenfeld et al. (2001) also found out those rodents with training that if they stepped down off a platform onto a grid floor they would receive an aversive foot-shock, displayed a long latency to step down off the platform. Apart from fear conditioning and inhibitory avoidance using associative learning tasks, reconsolidation phenomenon was also tested on taste-recognition memory task, which accessed via an attenuation of neophobia paradigm (Rodriguez-Ortiz et al., 2005). Animals exposed to novel taste generate neophobic response of reduced consumption, followed by increasing intake after repeated presentations of the same tastant.

Other than the animal research, list-learning procedures have been used to assess reconsolidation in human episodic memory, such as Hupbach et al. (2007)'s list-learning paradigm, which consisted of two encoding sessions and a retrieval session. Participants were recruited to memorise different lists of objects on different sessions on different days. As portrayed in Figure 11 by Nadel et al. (2012), in several human episodic reconsolidation studies (such as Hupbach et al., 2007, 2008, 2009), participants were asked to learn a list of twenty daily objects on Day 1. Two days later, they were asked to return and either reminded of previous learning experience or not and learn the second list of twenty objects. Two days later again, they were asked to return and recall the objects from either first or second list. Hupbach et al. (2007) study constantly showed that participants often intermixed List 2 objects into the recall of List 1 on the final test day. However, participants do not include List 1 objects into the recall of List 2, which suggesting this is not a simple source confusion effect (Nader et al., 2002). Hupbach et al. (2011) recommended that the most effective reminder to elicit memory reconsolidation effect is the initial unfamiliar spatial context. This experimental procedure based on learning interfering information was further used in several studies to examine episodic memory reconsolidation (e.g. Dongaonkar, Hupbach, Gomez, & Nadel, 2013; Gershman, Schapiro, Hupbach, & Norman, 2013; Hupbach, 2015; Hupbach et al., 2008, 2009, 2011; Jones et al., 2012, 2015; Potts & Shanks, 2012; Wichert et al., 2011, 2013).

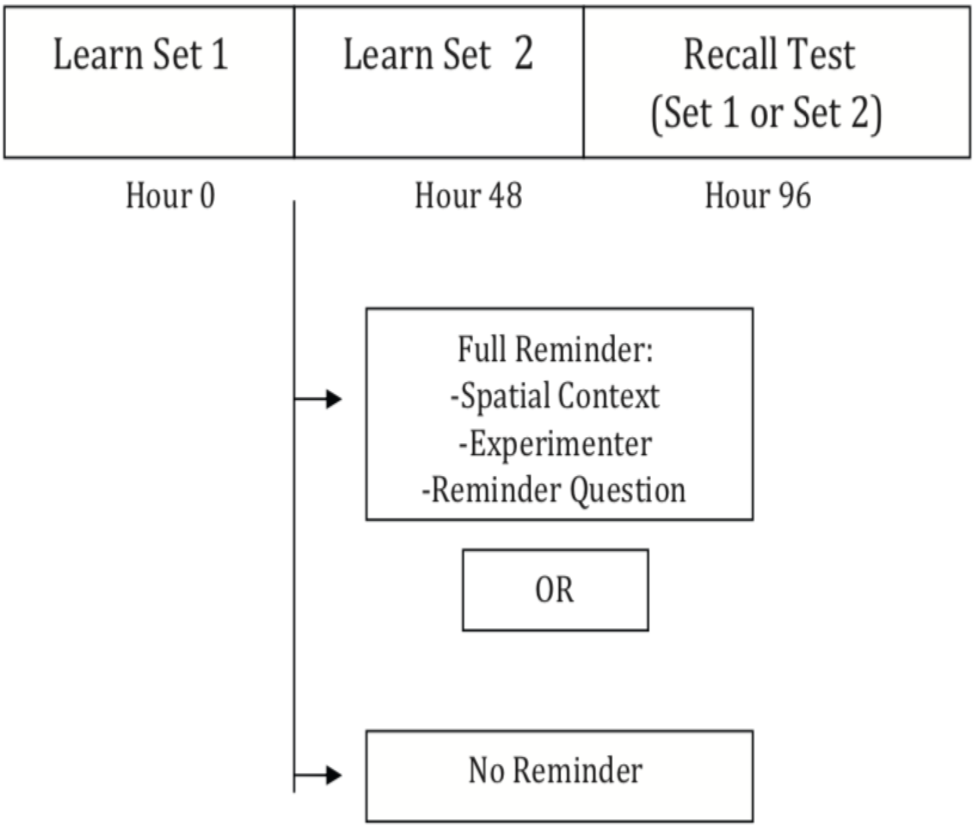

Figure 11. Paradigm for the episodic memory reconsolidation study by Nadel et al. (2012)

Klingmuller et al. (2017) originally aimed to replicate Hupbach et al. (2007) study. However, their first and third study failed to replicate the Hupbach et al. (2007) results, where participants in their study had better memory performances. In particular, participants in their study were participated for compensation, which this might affect participants' motivation. Nicholls, Loveless, Thomans, Loetscher, and Churches (2015) recently reported that motivational difference mostly dependent on either participant participated for course credits or compensation. On the other hand, their second study found out that participants whom re-exposed to highly unusual context appeared to have more intrusions of List 2, but the replication was small in amount. Besides that, Jones, Pest, Vargas, Glisky, and Fellous (2015) also failed to discover memory reconsolidation effect. They found out that young rats and humans in reminder group falsely recalled significantly more objects from Set 2 compared to no reminder group, suggesting that reminder group triggered the reactivation of Set 1 objects on Day 2 and allowed the intrusion of Set 2 items into Set 1. They also found a different pattern in aged participants, which aged participants in no reminder group have significantly more intrusions compared to reminder group. They concluded that contextual reminders are not adequate to trigger memory reconsolidation in aged rats or humans. While these conditions have been studied extensively in rodent experiments, the only condition demonstrated for human episodic memory is the necessity for re-exposure to the original learning environment (i.e. testing room; Hupbach et al., 2008).

3.2.1 Rationale of current study

The overall aim of the current study was to provide a conceptual replication of studies of Hupbach et al. (2007, 2008). In particular, the current study was focused on whether exposure solely to the initial learning context is sufficient to trigger reconsolidation effect on episodic memory. In this study, a total of 108 participants were recruited and randomly assigned into three different groups, i.e. same-experimenter-same-room (the Experimental Group; expected to engage reconsolidation), different-experimenter-different-room (the Control Group), and a no interference control group. On Day 1, all the participants were asked to memories first 20 novel images (List 1) using a sequential presentation slides method. On Day 2, participants were asked either to the same testing cubicle as Day 1 or a different testing cubicle and instructed to learn a second set of 20 visual images, using a physical paper hand-out method. To measure explicit recall, free recall technique was implemented on the actual testing day (Day 3).

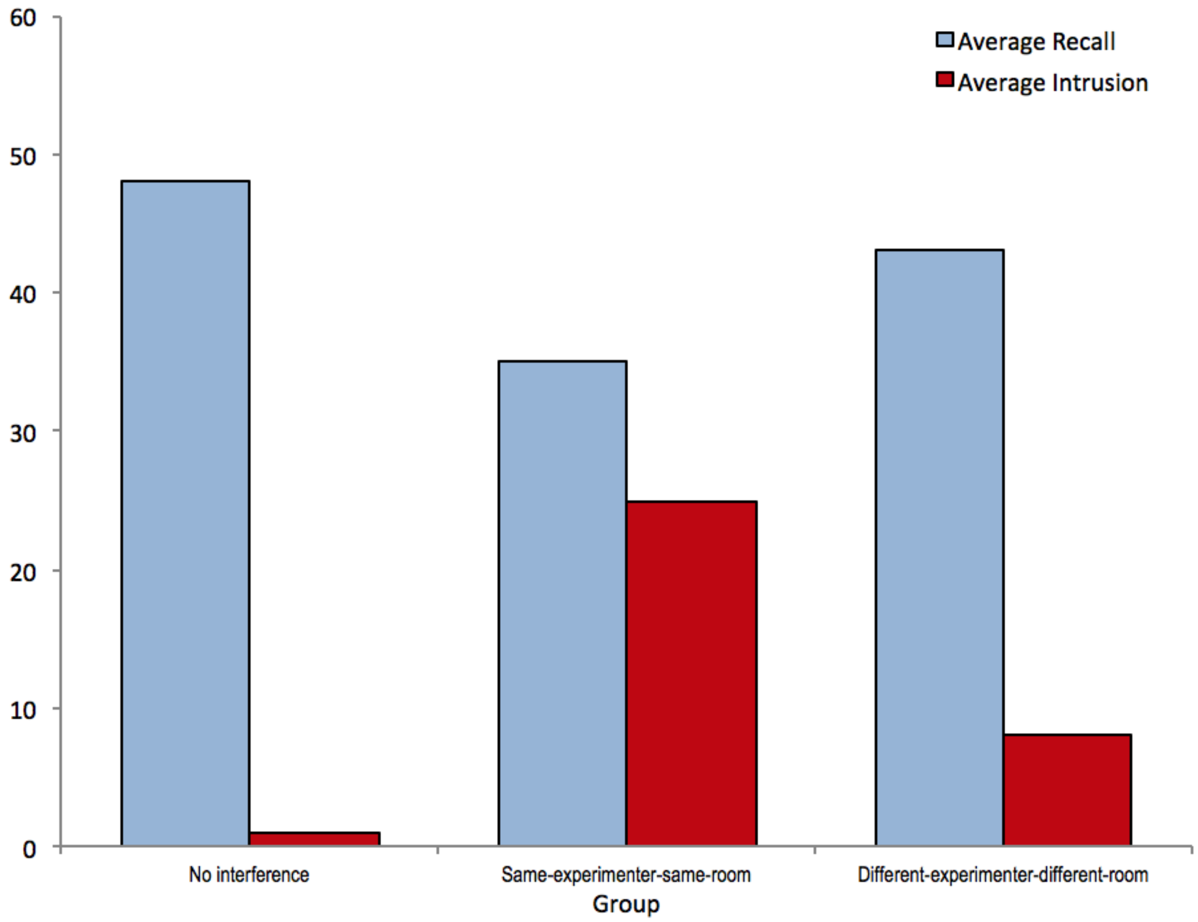

Figure 12. Prediction for study 2

According to Hupbach et al. (2007), reminders placed the memory of list on Day 1 into a labile state, and immediate learning of list on Day 2 appeared to alter memory for Day 1. Hence, in current study, if re-exposure to the same context puts the original memory into a labile state, then the learning of new information should alter the original memory. Current study predicted that participants in same-experimenter-same-room group, acts as reminder group, and intrusion should appear the highest among the groups (see Figure 12).

3.3 Materials and Method

3.3.1 Design and participants

All procedures of this study were approved by the Science, Technology, Engineering and Mathematics (STEM) Ethics Review Committee in University of Birmingham. A total of 108 university students from University of Birmingham were recruited through Psychology Research Participation Scheme (RPS), an online platform for researchers to recruit participants from the scheme. All the 108 participants gave their informed consent to participate in this study and received either course credit or cash credit for their participation. All of them were randomly assigned to three different groups, i.e.

(a) Same-experimenter-same-room group (the Experimental Group; expected to engage reconsolidation)
(b) Different-experimenter-different-room group (the Control Group)
(c) A further no interference control group

Participants in both Experimental and Control group experienced 3 different testing sessions, with 48 hours between each session. These delays were necessary in order to ensure that newly acquired memories were fully consolidated by the time of memory reactivation in between sessions (Hupbach et al., 2009). On the other hand, the further no interference control participants omitted Day 2 testing session.

3.3.2 Materials

Learning task: Both list 1 and list 2 consisted of 40 unrelated visual images (see Table 7 for the full list). Visual images were randomly selected from the exemplar pairs paradigm developed by Brady, Konkle, Alvarez, and Oliva (2008) (see Figure 13 for examples).

Table 7

Lists of Visual Images Presented on Day 1 and Day 2

List 1	List 2
Chips	Rabbit
Basket	Air balloon
Wheelchair	Sunglasses
Tractor	Money
Aeroplane	Ship
Staple remover	Ladder
Grapes	Muffin
Spray bottle	Pliers
Thread	Starfish
Soother	Bicycle
Christmas hat	Fan
Razor	Key
Balloon	Train
Grand piano	Tortoise
Globe	Trophy
Chocolate bar	Ice cream
Cow	Bass guitar
Hanger	Antique camera
Calculator	Measuring cylinder
Goggles	Microscope

Figure 13. Examples of visual images in list 1 and 2 on Day 1 and Day 2

3.3.3 Procedure

On Monday (Day 1), at the beginning of the experiment, participants were informed that they would experience 3 sessions of testing, with 48 hours between each session, and required to memorise a series of visual images. Therefore, the sessions took place on Monday, Wednesday and Friday of the same week.

Participants were instructed to learn the first list of 20 visual images. Each visual image was appeared on the screen for 4 seconds with immediate progression to the next visual image. After the learning session, they were asked to complete two distraction tasks, i.e. counting tasks [e.g. participants were asked to count backwards in predefined steps (e.g. steps of 7) from number (e.g. 523)], which lasted approximately 3 minutes, to provide a delay between learning and recall session. Immediately after the distraction tasks, participants were then tested by performing free recall. This procedure was repeated until the participants either successfully remembered 17 images out of 20 images (85% correct) or a maximum of four learning trials. Throughout the whole free recall session, experimenter manually recorded all the participants' responses.

On Wednesday (Day 2), participants were either brought back to the same testing room with the same researcher as on Day 1 or a different testing room in the different building with a different researcher and instructed to learn the second list of 20 visual images, but using a physical paper hand-out method within 30 seconds. Current study aimed to replicate Hupbach effect, although current study did not replicate Hupbach effect completely as the experimental group did not receive any reminder question. Experimenter manually timed and ended the 30 seconds' learning session. After 30 seconds, participants were asked to complete two distraction tasks for 3 minutes. Immediately after the distraction tasks, free recall technique was implemented. The further no interference control participants omitted Day 2 testing sessions.

On Friday (Day 3), all the participants were returned to the same room with the same experimenter as on Day 1 and asked to recall the visual images that they learned on Day 1. Free recall technique was used, and experimenter manually recorded all the participants' responses with simple binary coding, i.e. correct recall of Day 1 visual images and erroneous intrusions of Day 2 visual images. They were also tested repeatedly four times with brief distractions in between each recollection in order to test for the reliability of recall. This whole free recall technique took approximately 15 minutes. At the end of the study, participants were fully debriefed on the rational of the study, with the explanation on how experimenter modified their recollection.

The presentation methods are illustrated on Figure 14 and the different experimental procedures between three groups are tabulated on Table 8.

Table 8
Experimental Procedures for Study 2

	Same-experimenter-same-room (the Experimental Group)	Different-experimenter-different-room (the Control Group)	No interference control
Day 1	All groups of participants learned the first list of 20 visual images using a sequential presentation slides method on the computer.		
	Learning criteria: Participants were given opportunities to learn the visual images until they remembered at least 17 out of 20 images (85% correct) or a maximum of four learning trials.		
Day 2	Same experimenter from Day 1 was administered the second learning session in the same room as on Day 1.	Different experimenter was administered the second learning session in the different testing room.	Omitted Day 2 testing session.
	Participants were instructed to learn second list of 20 visual images using physical paper hand-out method within 30 seconds.		
Day 3	All the participants were brought back to the same room as Day 1 and performed the same free recall.		

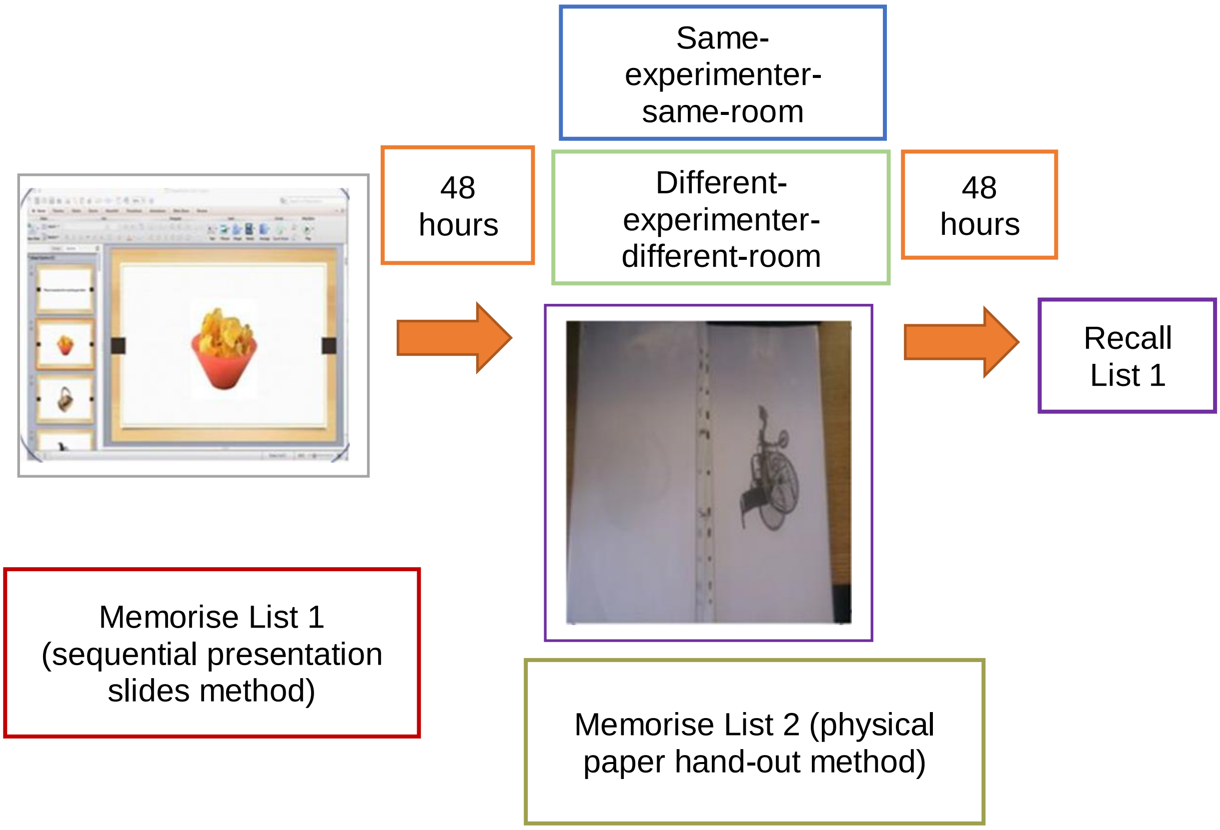

Figure 14. Illustration of the experimental procedures for study 2

3.4 Results

On the testing day (Day 3), participants were asked to recall the visual images that learned on Day 1. Therefore, any falsely recalled images from Day 2 would be treated as intrusions. The number of images correctly and falsely recalled on Day 3 was analysed using 3 x 4 mixed Analysis of Variance (ANOVA), with different music groups as the between subjects variable whereas recall trials (1 – 4) or intrusion trials (1 – 4) as the within subject variable. Assumption of sphericity was tested and corrected using Greenhouse-Geisser where appropriate. In current study, Bonferroni correction method was used to adjust post-hoc multiple comparisons for both intrusion and recall trials.

Figure 15 illustrates the mean numbers of images correctly and falsely recalled on Day 3 across three different groups (no interference control, same-experimenter-same-room and different-experimenter-different-room group).

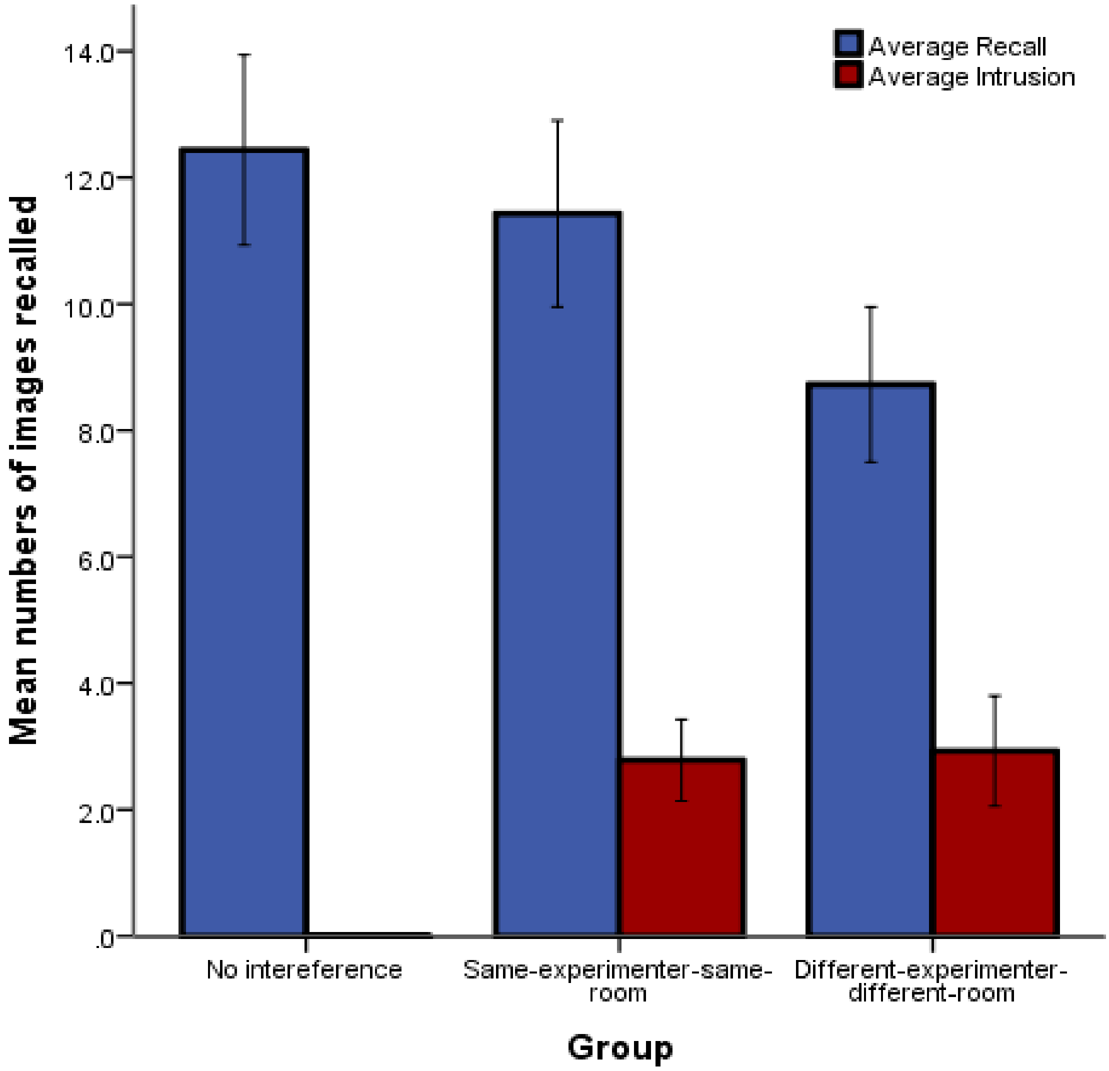

Figure 15. Mean numbers of images (+ SE) correctly and falsely recalled on Day 3 across three different groups

3.4.1 Intrusions from Day 2

The ANOVA revealed a significant interaction effect between trials and group was reported, *F* (2.7, 143.9) = 2.885, ***p* = 0.042**, as well as a significant main effect of group, *F* (2, 105) = 33.609, ***p* < 0.001**, suggesting significant differences between all three groups in the intrusions of visual images (see Figure 15). Analysis of simple main effects revealed significant effects of group at each trial, i.e. intrusion 1, *F* (2, 107) = 32.561, ***p* < 0.001**; intrusion 2, *F* (2, 107) = 23.085, ***p* < 0.001**; intrusion 3, *F* (2, 107) = 18.658, ***p* < 0.001**; intrusion 4, *F* (2, 107) = 16.963, ***p* < 0.001.**

A post hoc test (see Table 9) on the main effect of group revealed that both same-experimenter-same-room (Experimental Group) [*t* (70) = - 8.021, ***p* < 0.001**] and different-experimenter-different-room (Control Group) [*t* (70) = 8.376, ***p* < 0.001**] were significantly higher in intrusion ratings on Day 3 than no interference group. However, intrusion ratings did not significantly differ between same-experimenter-same-room (Experimental Group) and different-experimenter-different-room (Control Group), *t* (70) = - 0.640, *p* = 0.525. This pattern of results was observed at each test trial (see Table 10).

Table 9

Post hoc Multiple Comparisons for Each Group

	Group	Mean Difference	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Different-experimenter-different-room	No interference	2.486***	0.000	1.580	3.392
	Same-experimenter-same-room	- 0.292	1.000	- 1.198	0.614
No interference	Same-experimenter-same-room	- 2.778***	0.000	- 3.684	- 1.872

***$p < 0.001$

Table 10

Post hoc Multiple Comparisons for Each Intrusion Trial in Different Group

		Group	Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Intrusion 1	Different-experimenter-different-room	No interference	3.306***	0.000	2.064	4.547
		Same-experimenter-same-room	- 0.472	1.000	- 1.713	0.769
	No interference	Same-experimenter-same-room	- 3.778***	0.000	- 5.019	- 2.534
Intrusion 2	Different-experimenter-different-room	No interference	2.361***	0.000	1.349	3.374
		Same-experimenter-same-room	- 0.167	1.000	- 1.179	0.846
	No interference	Same-experimenter-same-room	- 2.528***	0.000	- 3.540	- 1.515

Intrusion 3	Different-experimenter-different-room	No interference	2.083***	0.000	1.040	3.127
		Same-experimenter-same-room	- 0.333	1.000	- 1.377	0.7100
	No interference	Same-experimenter-same-room	- 2.417***	0.000	- 3.460	- 1.373
Intrusion 4	Different-experimenter-different-room	No interference	2.194***	0.000	1.086	3.303
		Same-experimenter-same-room	- 0.194	1.000	- 1.303	0.914
	No interference	Same-experimenter-same-room	- 2.389***	0.000	- 3.497	- 1.281

***$p < 0.001$

The ANOVA also revealed a significant main effect of trials, *F* (1.4, 143.9) = 11.102, ***p* < 0.001**, suggesting trials were significantly different to each other respectively, specifically going downward (see Figure 16).

A post hoc pairwise comparison (see Table 11) also found out that there were significant differences between trials. Intrusion 1 significantly differed than intrusion 2 (***p* = 0.012**), intrusion 3 (***p* = 0.001**), and intrusion 4 (***p* = 0.004**). However, there were no significant differences between intrusion 2 and intrusion 3 (*p* = 0.536), intrusion 2 and intrusion 4 (*p* = 1.000), intrusion 3 and intrusion 4 (*p* = 1.000). Table 12 illustrated the mean, standard error of mean and standard deviation for each trial.

Table 11
Post hoc Pairwise Comparison for Each Intrusion Trial

		Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Intrusion 1	Intrusion 2	0.731*	0.232	0.012	0.108	1.354
	Intrusion 3	0.861**	0.224	0.001	0.258	1.464
	Intrusion 4	0.833**	0.235	0.004	0.201	1.465
Intrusion 2	Intrusion 3	0.130	0.076	0.536	- 0.074	0.333
	Intrusion 4	0.102	0.098	1.000	- 0.162	0.366
Intrusion 3	Intrusion 4	- 0.028	0.074	1.000	- 0.227	0.172

*$p < 0.05$
**$p < 0.01$

Table 12
Descriptive Statistics for Each Intrusion Trial

	Intrusion 1	Intrusion 2	Intrusion 3	Intrusion 4
Mean	2.361	1.630	1.500	1.528
Std. Error of Mean	0.263	0.202	0.202	0.212
Std. Deviation	2.729	2.098	2.098	2.202

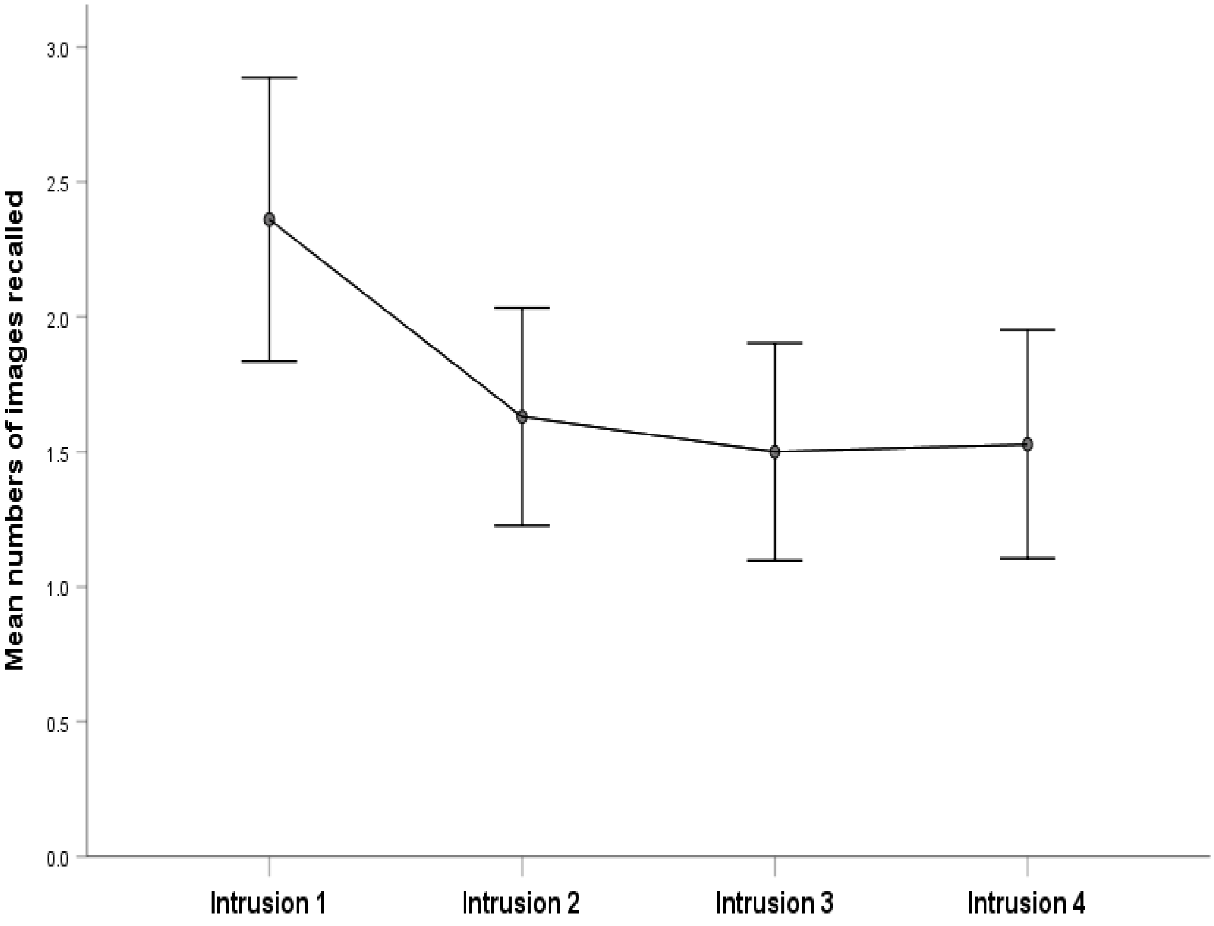

Figure 16. Mean numbers of images (± SE) falsely recalled across all four intrusion trials

3.4.2 Recall List from Day 1

The ANOVA reported a significant main effect of group, *F* (2, 105) = 6.892, ***p* = 0.002**, suggesting significant differences between all three groups in the recall of visual images (see Figure 17). However, no significant interaction effect between trials and group was found, *F* (3.9, 207.5) = 1.382, *p* = 0.242 (see Figure 15).

A post hoc test (see Table 13) on the main effect of group revealed that participants in no interference control group [*t* (70) = - 3.501, ***p* = 0.001**] and same-experimenter-same-room group (Experimental Group) [*t* (70) = - 2.775, ***p* = 0.007**] experienced higher correct recall ratings on Day 3 than participants in different-experimenter-different-room group (Control Group). However, there was no significant difference in the amount of recall between no interference and same-experimenter-same-room group (Experimental Group), *t* (70) = 0.531, *p* **=** 0.597. This pattern of results was observed at each test trial (see Table 14).

Table 13

Post hoc Multiple Comparisons for Each Group

	Group	Mean Difference	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Different-experimenter-different-room	No interference	- 2.674**	0.003	- 4.565	- 0.782
	Same-experimenter-same-room	- 2.278*	0.012	- 4.169	- 0.387
No interference	Same-experimenter-same-room	0.396	1.000	- 1.495	2.287

**$p < 0.01$

*$p < 0.05$

Table 14

Post hoc Multiple Comparisons for Each Recall Trial in Different Group

		Group	Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Recall 1	Different-experimenter-different-room	No interference	- 2.917**	0.002	- 4.907	- 0.926
		Same-experimenter-same-room	- 2.583**	0.006	- 4.574	- 0.593
	No interference	Same-experimenter-same-room	0.333	1.000	- 1.657	2.324
Recall 2	Different-experimenter-different-room	No interference	- 2.667**	0.003	- 4.580	- 0.753
		Same-experimenter-same-room	- 2.333*	0.011	- 4.247	- 0.420
	No interference	Same-experimenter-same-room	0.333	1.000	- 1.580	2.247

Recall 3	Different-experimenter-different-room	No interference	- 2.722**	0.002	- 4.637	- 0.808
		Same-experimenter-same-room	- 2.306*	0.012	- 4.220	- 0.391
	No interference	Same-experimenter-same-room	0.417	1.000	- 1.498	2.331
Recall 4	Different-experimenter-different-room	No interference	- 2.389**	0.008	- 4.287	- 0.491
		Same-experimenter-same-room	- 1.889	0.052	- 3.787	0.009
	No interference	Same-experimenter-same-room	0.500	1.000	- 1.398	2.398

**$p < 0.01$
*$p < 0.05$

The ANOVA revealed a significant main effect of trials, *F* (1.9, 207.5) = 34.514, ***p* < 0.001**, suggesting trials were significantly increased across all four trials (see Figure 17).

A post hoc pairwise comparison (see Table 15) also found out that there were significant differences between trials. Recall 1 significantly differed from recall 2 (***p* < 0.001**), recall 3 (***p* < 0.001**), and recall 4 (***p* < 0.001**). However, there were no significant differences between recall 2 and recall 3 (*p* = 1.000), recall 2 and recall 4 (*p* = 0.129), recall 3 and recall 4 (*p* = 0.079). Table 16 illustrated the mean, standard error of mean and standard deviation for each trial.

Table 15

Post hoc Pairwise Comparison for Each Recall Trial

		Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Recall 1	Recall 2	- 0.750***	0.101	0.000	- 1.021	- 0.479
	Recall 3	- 0.815***	0.132	0.000	- 1.169	- 0.461
	Recall 4	- 0.981***	0.132	0.000	- 1.335	- 0.627
Recall 2	Recall 3	- 0.065	0.083	1.000	- 0.288	0.159
	Recall 4	- 0.231	0.099	0.129	- 0.498	0.035
Recall 3	Recall 4	- 0.167	0.066	0.079	- 0.344	0.011

***p < 0.001

Table 16

Descriptive Statistics for Each Recall Trial

	Recall 1	Recall 2	Recall 3	Recall 4
Mean	10.556	11.306	11.370	11.537
Std. Error of Mean	0.354	0.339	0.339	0.331
Std. Deviation	3.680	3.514	3.519	3.438

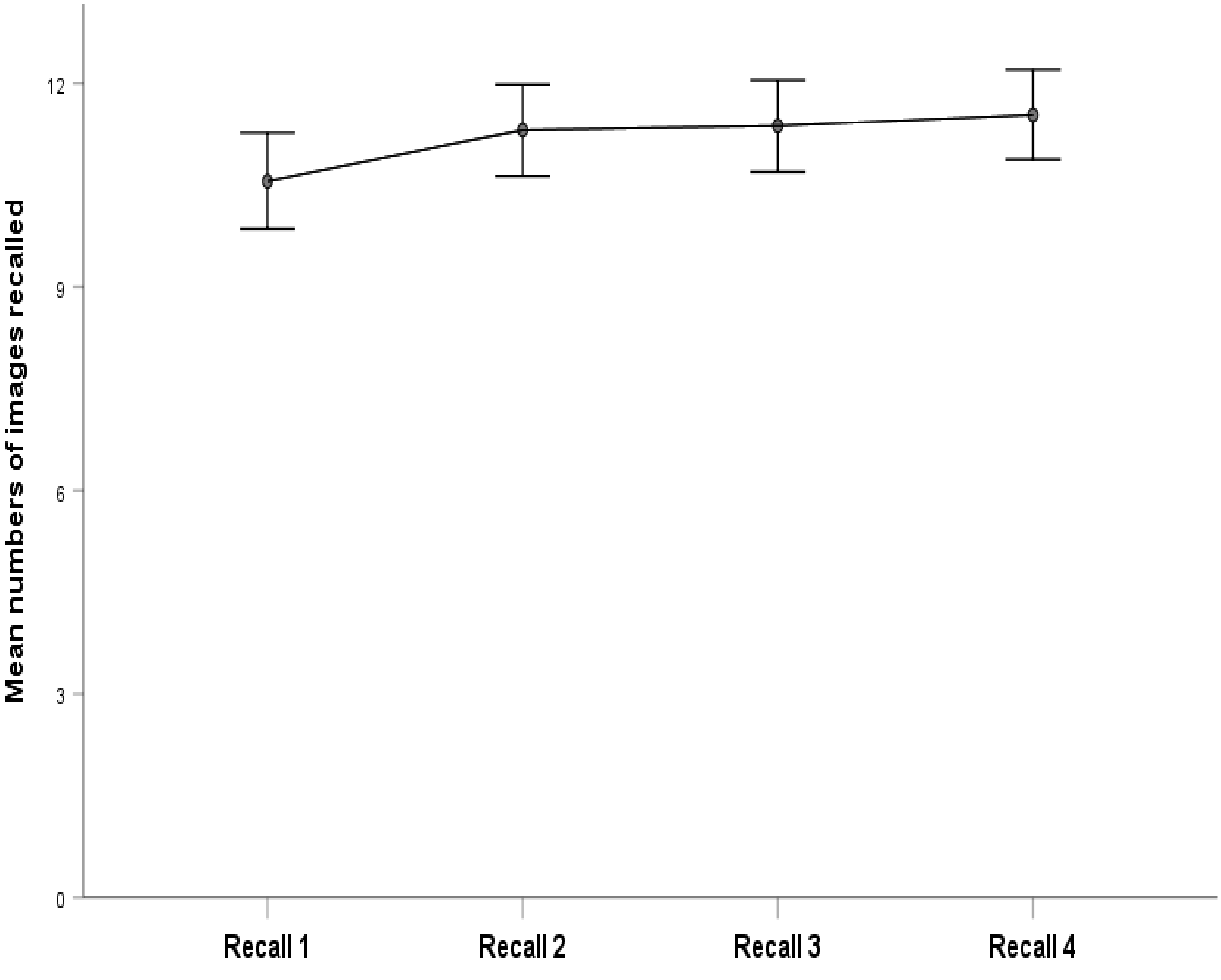

Figure 17. Mean numbers of images (± SE) correctly recalled across all four recall trials

3.5 Discussion

The primary aim of the current study 2 was to provide a conceptual replication of studies of Hupbach et al. (2007, 2008). In particular, the current study was focused on whether exposure solely to the initial learning context is sufficient to trigger reconsolidation effect on episodic memory. In current study, a total of 108 participants were recruited and randomly assigned into three different groups, i.e. same-experimenter-same-room, different-experimenter-different-room, and a no interference control group. On Day 1, all the participants were asked to memories first 20 novel images (List 1) using a sequential presentation slides method. On Day 2, participants were asked either to the same testing room as Day 1 or a different testing room and instructed to learn a second set of 20 visual images, using a physical paper hand-out method. On the testing day (Day 3), all the participants were asked to recall the visual images that learned on Day 1. Any falsely recalled images from Day 2 would be treated as intrusions. The 3 x 4 mixed ANOVA unexpectedly showed no difference in intrusions between the Experimental and Control groups (with both showing a modest number of intrusions). In contrast, while the Control Group had poorer recall of Day 1 items compared to the no interference control, performance in the Experimental Group was preserved. Therefore, there appears to be dissociation between updating of list memory and resistance to the memory-weakening effects of interference. While it remains unclear whether the latter phenomenon is functionally related to reconsolidation, it is consistent with a body of evidence suggesting that reactivation-induced reconsolidation can maintain or even strengthen memories.

According to Artinian, De Jaegar, Fellini, De Saint Blanquat, and Roullet (2007) and Sara (2010), re-exposure to the experimental context was sufficient to trigger reactivation and reconsolidation. the argument relies upon an assumption that the triggering of reconsolidation necessarily allows updating and hence intrusions. Therefore, if similar context triggers reconsolidation by putting the memory of Day 1 into a labile state, we should observe higher intrusions in same-experimenter-same-room condition. Hence, current study 2 hypothesised that participants in same-experimenter-same-room group, which acts as reminder group, and intrusions should appear the highest among the groups. However, current study did not support this hypothesis. Current results found out that there were no significant differences in intrusions between same-experimenter-same-room and different-experimenter-different-room group. This contradicted with the findings of Hupbach et al. (2007) study, in which they found out participants in reminder group incorrectly intermixed more objects from List 2 in their free recall.

Current experiment explains the special role of spatial context for memory reconsolidation. One of the defining features of episodic memories is that they have spatial signature, reflecting the fact that it is important for us to remember where an event happened. When an old context is revisited, the original details will be reactivated, and new element (if there are any), can be merged. In contrast, when a new context is encountered, an entirely new detail is created, reflecting the fact that a new episode is to be remembered. Hupbach et al. (2008) suggested that the role of spatial context is not only just a cue but serves as a platform in reactivating episodic memory to produce intrusions. Nadel et al. (1985) proposed that when the context of the first learning was revisited, the memory for the first learning would be reactivated, and could then modify and update by incorporating new information from second list. In contrast, the learning of a second list of objects in a new spatial context created a different platform, which would create a brand-new episodic memory, and thus different spatial context did not modify the memory of first list.

The spatial contexts used in current study were two different rooms. However, from the perspective of the reconsolidation theory, there is a possibility that participants in current study failed to distinguish these two different rooms explicitly and coded them as ordinary university experimental rooms. The two different rooms might not be unique enough to be a significant context or to be associated with each list (Unsworth, Spillers, & Brewer, 2012). This might be the main reason why a contextual reminder failed to trigger memory reconsolidation in current study. According to Hupbach et al. (2008), different experiences could have happened in one familiar spatial context, therefore, familiar spatial context might not be effective in discriminating a particular episode from one another. Current study, which was consistent to Kingmuller et al. (2017) study, both failed to replicate the Hupbach et al. (2007) study. Participants in our study and Klingmuller et al. (2017) study appeared to have better memory performance compared to Hupbach et al. (2007) study, with one difference is motivational difference, in which participants in our study was participated for course credit whereas participants in Klingmuller et al.

(2007) study was participated for compensation. Current study was supported by Jones et al. (2105), i.e. contextual reminders were not sufficient to trigger memory reconsolidation. Besides that, current study was also consistent with Glisky, Rubin, and Davidson (2001) study, which showed that context might have been encoded at common level without any further distinctive details as well as Hall, Symonds, and Rodriguez (2009), which have also found familiar spatial context failed to initiate memory reactivation in their taste aversion experiment.

Hupbach, Gomez and Nadel (2011) found out that the role of spatial context in memory reactivation and updating only when the spatial environment was unfamiliar. In other words, spatial context does not serve as cue in triggering incorporation of new information into old memories, especially in highly familiar spatial context. They recruited children and tested them in their familiar environment, i.e. their homes. In their study, children learned the second list of objects in the same spatial context as on Day 1, and they were either tested by the same experimenter on all three days and were given a reminder question before the learning of second list or were tested by a different experimenter and received no reminder question. Results showed that familiar spatial environment did not serve as a reminder, and therefore, other reminders were more effective in a highly familiar spatial context. Their study suggested that an unfamiliar spatial context can reactivate the target memory whereas a familiar spatial context might reactivate any of many memories. The main reason is unfamiliar spatial environment seems to “overshadow” other cues, e.g. experimenter and the procedures, which is the other way around for familiar spatial environment.

As discussed later, there is evidence in the results that exposure to the same context alone did reactivate the learned memory, as there were significant differences in recall performance between different-experimenter-different-room and same-experimenter-same-room group. Current study 2 hypothesised that participants in same-experimenter-same-room group should have the least recall among the group. However, current results showed the opposite, i.e. recall performance in the different-experimenter-different-room group appeared to be the worst, as the original context is not reinstated at the retrieval, making access to the original items more difficult. Hupbach et al. (2011) suggested that the most effective reminder to trigger memory reconsolidation is the initial unfamiliar spatial context, however, current study showed the opposite effect, i.e. same context strengthened the memory of the original list. Rather than reactivate a state of vulnerability to trigger reconsolidation, retrieval led to higher performance in same-experimenter-same-room than other groups. This finding is consistent with several existing studies which found that retrieval practice against interference effect (Pott & Shanks, 2012) and suggested retrieval strengthens rather than impairs the recall (Roediger & Butler, 2011).

Therefore, there appears to be dissociation between updating of list memory and resistance to the memory-weakening effects of interference. While it remains unclear whether the latter phenomenon is functionally related to reconsolidation, it is consistent with a body of evidence suggesting that reactivation-induced reconsolidation can maintain or even strengthen memories. Current study strongly suggested that same context strengthened the memory of the original list. Therefore, future research will be focusing on strengthening memory, which will be presented on Study 3. Future studies will focus on the retrieval-relearning phenomenon, aiming to see whether memory retrieval and further learning strengthen the memory for episodic memory.

Chapter 4

Study 3: Episodic memory strengthening

4.1 Abstract

Memory reactivation can lead to two phenomena: memory updating/reconsolidation with possibility of having inaccurate memories and memory strengthening. We tested directly the capacity of memory reactivation to facilitate memory strengthening. Participants learned visual object-scene paired associated and two days later were subjected to a retrieval test and/or further learning in the same room and with the same experimenter. When subsequently tested on the paired associate recall, participants that received retrieval followed by relearning, relearning followed by retrieval, or two relearning episodes all had greatly improved performance. Groups that received one or two retrieval episodes performed as poorly as a control group, with all three groups showing evidence of memory decay. Finally, participants that received a single relearning episode performed at an intermediate level, with mild improvement. An idea of implementing 6 hours interval in between Day 2 sessions was suggested, aimed to determine whether or not the learning effect is mediated by reconsolidation processes, showing that participants in retrieval-6 hours-relearning and relearning-6 hours-retrieval groups had improved their performance, in the same manner as retrieval-relearning and relearning-retrieval group. The common effects of retrieval-relearning, relearning-retrieval, relearning-relearning, retrieval-6 hours-relearning, relearning-6 hours-retrieval

to strengthen episodic memory may reflect different underlying processes, one or more of which might be related to memory reconsolidation.

4.2 Introduction

The traditional memory theory suggests that each time we remember some past experiences, the original past memory will be retrieved. This view has been challenged in the late 1960s, stating that retrieved existing memories are vulnerable to changes (Milekic & Alberini, 2002; Nader, Schafe, & LeDoux, 2000; Suzuki et al., 2004). Past studies discovered that the reminder cue made the consolidated memory became labile again (Misanin et al., 1968; Schneider & Sherman, 1968). This phenomenon is referred as memory reconsolidation, an act of reactivating existing memories in response to a memory trace. Reconsolidation is either just the re-stabilisation of a destabilised memory, or the whole destabilisation and re-stabilisation cycle. This is how and why we can recover memories from long ago. Through reconsolidation process, memory may become labile and susceptible to impairments (Debiec, et al., 2002; Duvarci & Nader, 2004), re-stabilised and strengthened (Forcato et al., 2010; Hupbach et al., 2007; Rodriguez-Ortiz et al., 2005; Schiller et al., 2010) depending on different conditions, whether through repetitions of learning experiences or different types of retrieval. However, recent evidences revealed that reconsolidation allows changes in memory content, which proposes that reconsolidation mediates memory updating (Alberini, 2005; Duvarci & Nader, 2004; Sara, 2000). Gold and McGaugh (1975) also proposed that reactivation provides an opportunity for new learning to occur although Spear (1976) argued that memory reactivation increases the retrievability of old memories. It also suggested that memory reactivation promotes changes in memory strengthening (Spear & Mueller, 1984) or old-to-new memory binding (Johnson & Chalfonte, 1994). Sandrini, Cohen, and Censor (2015) characterised memory reconsolidation as a unique process that allows changes in memory strength or updating memory via integration of new information during reactivation period (see Figure 18 for the illustration of updating or modifying through reconsolidation process).

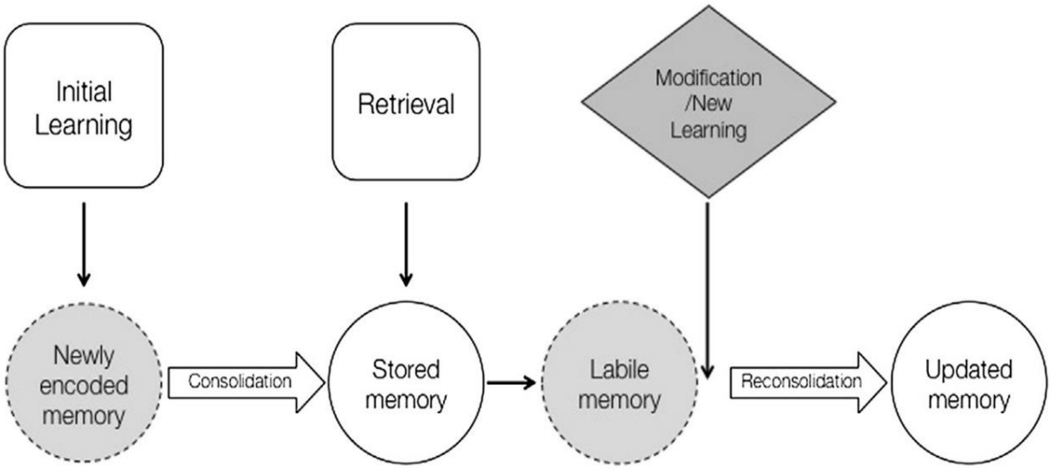

Figure 18. Illustration of memory formation and updating via reconsolidation process. After a period of initial learning, a new memory is encoded. This new memory is unstable until a period of consolidation. When a stored memory is retrieved, it will return to a labile state, which allows any modification or updating process when new information is introduced after retrieval. This reflected reconsolidation process mediates memory updating.

Reconsolidation studies suggested that reactivation of consolidated memories put the memory in a labile state and require reconsolidation process to stabilise or maintain the memory (Hardt et al., 2010; Tronson & Taylor, 2007) or updating (Lee, 2010; Morris et al., 2006). Memory reconsolidation phenomenon has been demonstrated in a few existing studies, using different species, although it was not observed in several conditions (for example, Alberini, 2005; Dawson & McGaugh, 1969; Tronson & Taylor, 2007). When demonstrating memory updating, the crucial point is the availability of new information during reactivation that susceptible to encourage reconsolidation phenomenon (Morris et al., 2006; Pedreira et al., 2004; Rodriguez-Ortiz et al., 2005). Memory reconsolidation studies with animals often used associative learning paradigm (e.g. fear conditioning) to show memory changes (Nader et. al., 2000). According to Nader (2003), memory reconsolidation process consists of two different stages, i.e. reactivation-dependent destabilisation process and protein synthesis-dependent destabilisation phase. Based on the stages, Lee (2008) found a second learning trial strengthened a consolidated contextual fear memory, but only following destabilisation and thus supported the idea of memory updating in reconsolidation process. This strengthening memory reconsolidation idea was supported by other researchers as well (De Oliveira Alvares et al., 2012; Inda, Muravieva, & Alberini, 2011; Wiltgen & Silva, 2007). The fear learning paradigm also used to study amygdala-dependent memory reconsolidation in humans (Schwabe, Nader, & Prussner, 2014). Results showed that reconsolidation processes do occur in human episodic memory (Forcato et al., 2007; Hupbach et al., 2007; Wichert et al., 2011).

One of the functions of memory reconsolidation is to modify or update existing memories. Few existing studies have demonstrated reconsolidation updating / strengthening phenomenon. For example, Lee (2010) used context pre-exposure facilitation effect paradigm (CPFE) to train the rats, in which rats were initially exposed to a novel context (which represented consolidation mechanism) and received a foot shock in following session (which represented reconsolidation mechanism). This idea of memory reconsolidation updating / strengthening was also portrayed in Inda et al. (2011) study, which evidenced hat either multiple short reactivations or second training session (Lee, 2008), help to strengthen memory retention.

De Oliveira Alvares et al. (2013) explored the potential functional roles of memory reconsolidation using contextual fear conditioning paradigm in rats. In their study, rats were placed in the chamber for 3 minutes and received two footshocks, separated by 30 seconds interval. Rats were then kept in the conditioning environment after the last shock. After the conditioning, rats were re-exposed to the different contexts without footshocks for different durations, depending on the experiment conditions. On the testing day (day 5 or 28), rats were tested for 4 minutes in different contexts depending on experiment conditions. They discovered that memory reconsolidation enables the incorporation of new information through updating mechanism as well as maintains the contextual detailed content over time and memory strengthening upon reactivation.

Despite of memory updating or reconsolidation with possibility of having inaccurate memories, additional learning might strengthen existing memories.

Instead of using contextual fear conditioning, behavioural interference is used to examine the updating / strengthening effect. However, there is little experimental evidences showing support on this view (Dudai, 2006; Lewis, 1979; Nader, 2003;).Forcato et al. (2007) discovered updating via memory reconsolidation phenomenon using a paired-associate learning (i.e. learning an association between a cue syllable and response syllable). In their study, participants were asked to learn two different verbal materials in two training sessions with a 24 hours interval. After that, they were asked to retrieve corresponding to the first and second learning. Forcato et al. (2007) discovered two distinctive memory roles, i.e. memory updating, suggesting destabilisation of original memory which allows the integration of new information into original memory; and memory strengthening, suggesting labilization-reconsolidation process which strengthens the original memory. Wichert et al. (2011) used a similar paradigm and asked their participants to learn a list of pictures on the first session. A week later, half of the participants were asked to explicitly recall as many pictures as they could from the first session before they started to learn a second list of pictures. On the testing day (1 week after second session), participants were asked to complete a recognition test in which they were required to identify whether the presented picture had been presented on the first or second session. They found out the strength of new learning after reactivation was critical in memory updating.

4.2.1 Rationale of current study

Memory reactivation can lead to two phenomena, either memory updating or reconsolidation with possibility of having inaccurate memories or memory strengthening. In current study, we aimed to test directly the capacity of memory reactivation to facilitate memory strengthening. All the participants were asked to learn 40 visual object-scene paired associations. Immediately after the learning session, participants were instructed to recall the associated objects out loud when the scene images were presented. Two days later, they were brought back to the same testing room as on Day 1, with the same experimenter, and performed different testing sessions according to group randomisation. An idea of implementing 6 hours interval in between Day 2 sessions was suggested as well, aimed to determine whether or not the learning effect is mediated by reconsolidation processes. Current study predicted that retrieval followed by relearning would strengthen human declarative memory.

4.3 Materials and Method

4.3.1 Design and participants

All procedures of this study were approved by the Science, Technology, Engineering and Mathematics (STEM) Ethics Review Committee in University of Birmingham. A total of 171 undergraduate students from University of Birmingham were recruited through Psychology Research Participation Scheme (RPS), an online platform for researchers to recruit participants from the scheme. All the 171 participants gave their informed consent to participate in this study and received course credit for their participation. All of them were randomly assigned to nine different groups within three cohorts (see Figure 19).

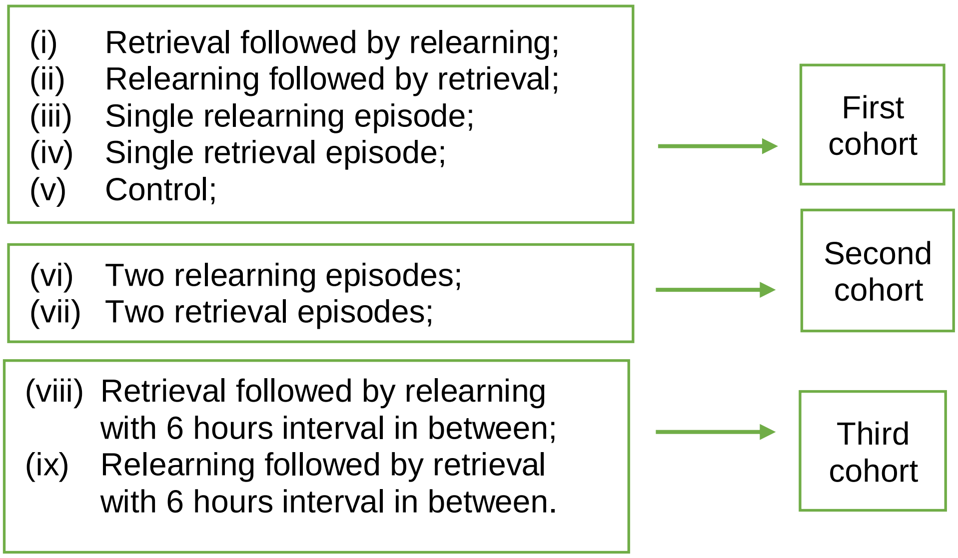

Figure 19. Different groups with different cohorts

4.3.2 Materials

Learning task: Association list consisted of 80 items (see Table 17 for the full list), including:

(a) 40 objects, which randomly selected from the unique object paradigm by Brady, Konkle, Alvarez, and Oliva (2008) for their visual long-term memory study;

(b) 40 scene images, which randomly selected from the scene categories paradigm by Konkle, Brady, Alvarez, and Oliva (2010) on their study investigated the role of scene categories in visual long-term memory.

Both individual objects and scene images were randomly paired for each participant for paired-associate learning task (See Figure 20 for examples). And, PsychoPy software (Peirce, 2007; 2009) was used on a desktop computer to run the current experiment in a testing cubicle.

Table 17

Lists of Objects and Scene Images Presented on Day 1 and 2

Objects	Scene images
Ashtray	Arch
Asparagus	Bathroom
Axe	Beach
Banana	Bedroom
Board game	Bridge
Bottle opener	Car
Bowling pin	Castle
Butterfly	Classroom
Celery	Closet
Cigarette	Concert hall
Claw hairclips	Construction site
Clock	Corridor
Coin	Country road
Cuff	Field
Donald duck	Hospital
Egg	Industrial area
Hat	Island
Ice cream	Laboratory
Keyboard	Laundry room
Large Mac screen	Library
Parrot	Living room
Pear	Market
Pencil	Mountain
Pink hoodie	Museum
Popcorn	Nursery
Pot	Parking
Radio	Pyramid

Rope
School bus
Scooter
Sunflower
Swan
Teabag
Telephone booth
Tie
Traffic light
Vending machine
Violin
Water filter
Zebra

Race stadium
Sauna
Skate park
Soccer field
Stadium
Staircase
Stream
Street
Temple
Treehouse
Tunnel
Volleyball court
Waterfall

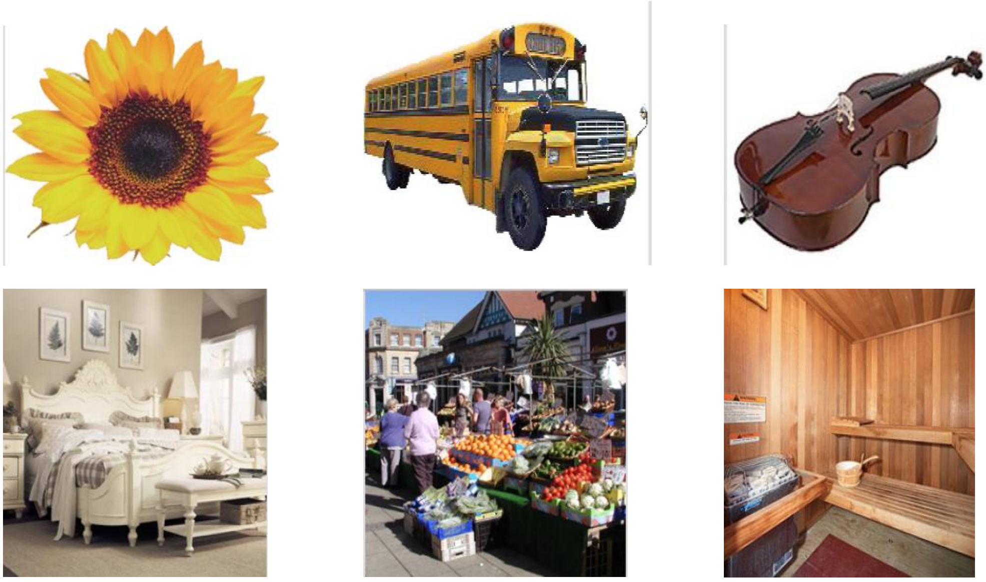

Figure 20. Examples of objects and scenes images presented on Day 1 and 2

4.3.3 Procedure

On Day 1, participants were informed that they would experience 3 or 4 sessions of testing, with 48 hours between each session or additional 6 hours delayed interval between relearning and retrieval (for group h and i), depending on group randomisation (see Table 18), i.e.

(a) Retrieval followed by relearning (retrieval-relearning);
(b) Relearning followed by retrieval (retrieval-relearning);
(c) Single relearning episode;
(d) Single retrieval episode;
(e) Control;
(f) Two relearning episodes (relearning-relearning);
(g) Two retrieval episodes (retrieval-retrieval);
(h) Retrieval followed by relearning with 6 hours interval in between (retrieval-6 hours-relearning);
(i) Relearning followed by retrieval with 6 hours interval in between (relearning-6 hours-retrieval).

Therefore, the current study took place on Monday, Wednesday and Friday of the same week in order to ensure that newly acquired memories receive some degree of consolidation in between sessions, as suggested in Hupbach et al. study (2009).

In current study, the participants were instructed to learn each paired association of objects and scene images. Each association, with object positioned above the scene image, was presented on a single trial on the screen for 4 seconds with immediate progression to the next association.

Immediately after the learning session, participants were instructed to recall the associated objects out loud when the scene images were presented on the screen for 6 seconds with immediate progression to the next scene images. Throughout the whole recall session, experimenter manually recorded all the participants' responses with simple binary coding, i.e. correct versus incorrect response. No feedback was provided on the spot.

On Day 2, participants were brought back to the same testing cubicle as on Day 1, with the same experimenter, and performed different testing sessions according to the group randomisation. For retrieval-relearning group, participants were first presented the scene image on the computer screen for four seconds and were requested to perform silent recall (i.e. remember but not verbalise the associated object image). After that, participants were asked to complete a 10-minutes mathematical distraction task. They were then given a second learning session, which was identical to the initial learning, but with a randomised order of paired-associate presentation. And, no responses from participants were recorded on Day 2. Participants were randomly allocated to the experimental cohorts (see Figure 19) as stated below:

(i) Reversal of the order of retrieval and relearning (i.e. relearning-retrieval); single presentation of either retrieval or relearning session, followed by distractor task; control group with participants merely completed the Big 5 personality test (John & Srivastava, 1999) and distractor task.

(ii) Double presentation of either retrieval or relearning sessions (retrieval-retrieval and relearning-relearning), with mathematical distraction task between two presentations.

(iii) Delayed 6 hours interval between retrieval and relearning session (retrieval-6 hours-relearning and relearning-6 hours-retrieval), aimed to put the second experience outside the reconsolidation window. The 10-minutes mathematical distraction task was completed after the first experience.

On Day 3 testing day, all the participants were returned to the same testing cubicle as on Day 1 and were tested in an identical manner to the immediate test, i.e. asked to recall the associated objects out loud that they learned on Day 1 when the scene images popped up on the screen for 6 seconds with immediate progression to the next scene images. All their responses were also recorded with simple binary coding, i.e. correct and incorrect response. At the end of the study, participants were fully debriefed on the rational of the study, i.e. testing directly the capacity of memory reactivation to facilitate memory strengthening.

The presentation methods are illustrated on Figure 21 and the different experimental procedures between all nine groups are tabulated on Table 18.

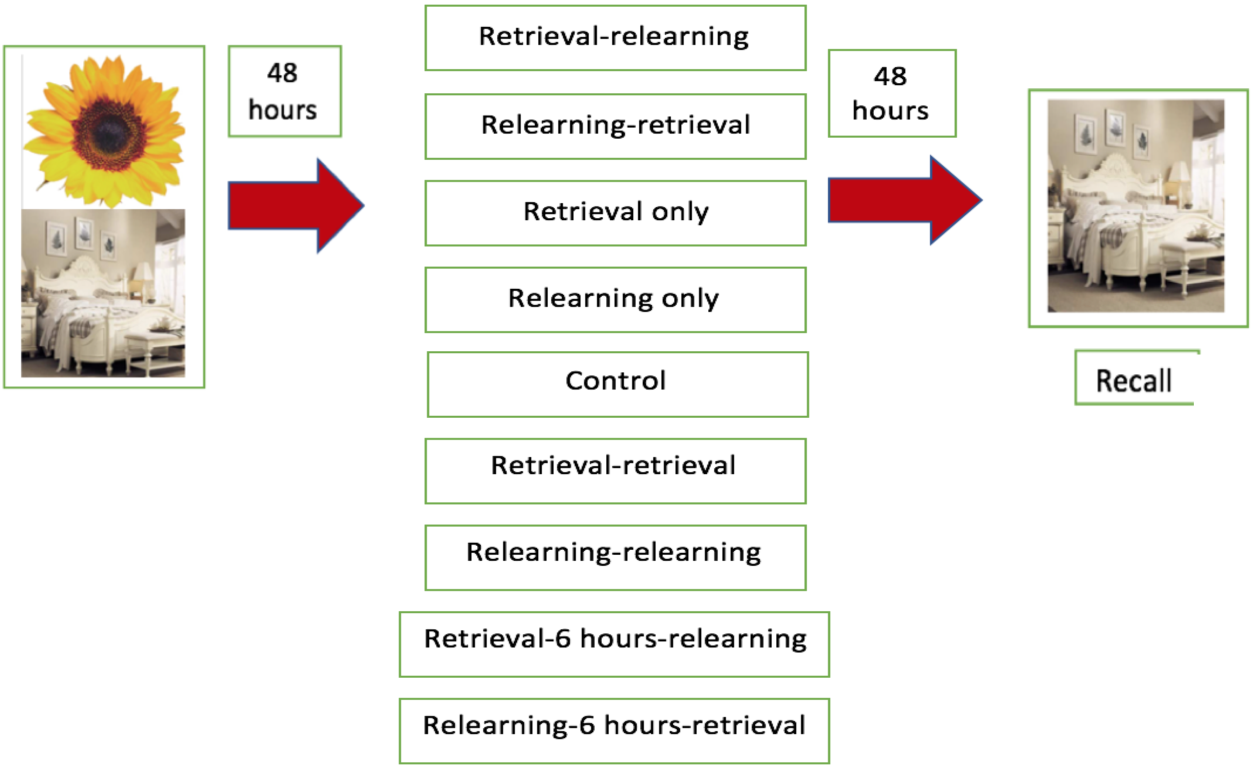

Figure 21. Illustration of the experimental procedures for the study 3

Table 18

Experimental Procedures for Study 3

<table>
<tr><th></th><th>Retrieval-relearning</th><th>Relearning-retrieval</th><th>Retrieval only</th><th>Relearning only</th><th>Control</th><th>Retrieval-retrieval</th><th>Relearning-relearning</th><th>Retrieval -6 hours-relearning</th><th>Relearning -6 hours-retrieval</th></tr>
<tr><td>Day 1</td><td colspan="9">All groups of participants learned 40 paired-associates and recalled the paired object when cued with the scene.</td></tr>
<tr><td rowspan="3">Day 2</td><td colspan="9">Participants were brought back to the same room as on Day 1 and performed different testing sessions accordingly to the groups.</td></tr>
<tr><td colspan="4">Participants were first asked to perform retrieval or relearning session accordingly.</td><td>Participants were asked to complete a set of personality tasks.</td><td colspan="4">Participants were first asked to perform retrieval or relearning session accordingly.</td></tr>
<tr><td colspan="9">A set of mathematical distraction tasks was given to provide 10 minutes delay.</td></tr>
</table>

	Participants were then asked to perform relearning or retrieval session accordingly.	Day 2 procedures end here.	Participants were then asked to perform relearning or retrieval session accordingly.	Participants were asked to return back to the same room after 6 hours. Participants were then asked to perform relearning or retrieval session accordingly.
	• Participants who experienced one or two retrieval sessions were asked to perform silent recall, i.e. not saying the associated objects out loud. • Participants who experienced one or two relearning sessions did not experience any recall test on Day 2, but instructed to learn single or two trials of random order of the same association. • Participants who experienced combination of retrieval and relearning sessions were asked to perform silent recall before or after the relearning session of random order of the same association accordingly.			
Day 3	All the participants were brought back to the same room as Day 1 and performed the same immediate recall on Day 1.			

4.4 Results

The number of images correctly recalled on Day 1 and Day 3 was analysed using repeated measures mixed Analysis of Variance (ANOVA), with different groups as the between subjects variable and recall performances on Day 1 and Day 3 as the within subjects variable. Different groupings (see Figure 22 for schematic diagram) with different comparisons were analysed based them being run in different cohorts, i.e.

(a) Retrieval followed by relearning and relearning followed by retrieval group compared with single relearning, single retrieval and control group;

(b) Retrieval followed by relearning and relearning followed by retrieval group compared with two relearning episodes and two retrieval episodes group;

(c) Single retrieval and control group compared with two retrieval episodes group;

(d) Retrieval followed by relearning and relearning followed by retrieval group compared with retrieval followed by relearning with 6 hours interval in between and relearning followed by retrieval with 6 hours interval in between group

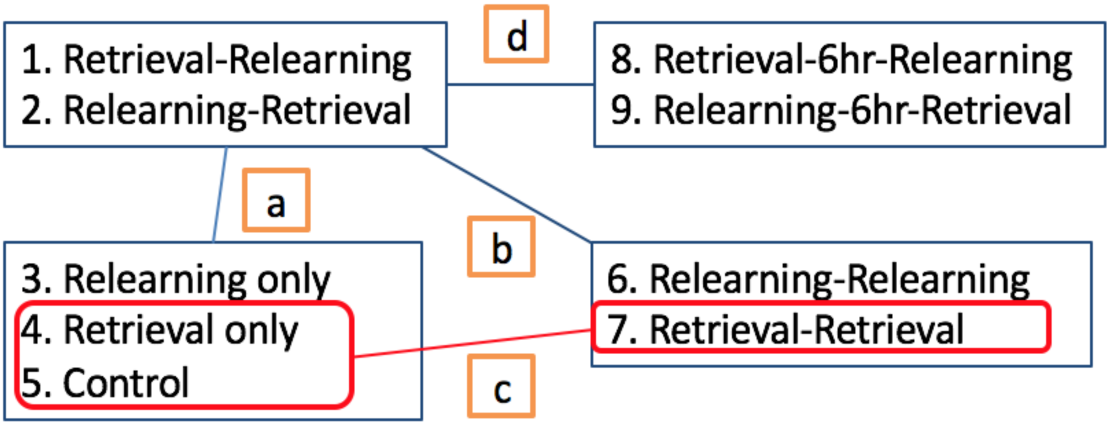

Figure 22. Schematic diagram on different groupings with different comparisons

4.4.1 Retrieval followed by relearning and relearning followed by retrieval group compared with single relearning episode, single retrieval episode and control group

4.4.1.1 Interaction between different days' recall performance and group

The ANOVA revealed a significant main effect of recall performance, *F* (1, 90) = 11.420, ***p* < 0.010**, suggesting recall performances on Day 1 and 3 were significantly different to each other. A significant interaction effect between recall performance and group was reported as well, *F* (4, 90) = 51.667, ***p* < 0.001**, suggesting that significant differences between all five groups in the improvement on recall performance from Day 1 to Day 3 (see Figure 23). However, no significant main effect of group was found, *F* (4, 90) = 1.935, *p* = 0.111 (see Table 20). Table 19 illustrated the mean, standard error of mean and confidence interval for interaction between different days' recall performance and group.

Table 19

Descriptive Statistics for Different Group on Different Days' Recall Performance

	Recall Performance	Mean	Std. Deviation	Std. Error
Retrieval-relearning	Day 1	16.316	9.111	2.090
	Day 3	24.526	10.156	2.330
Relearning-retrieval	Day 1	16.842	6.825	1.566
	Day 3	27.105	8.319	1.909
Single retrieval	Day 1	19.789	9.169	2.103
	Day 3	14.105	8.672	1.990
Single relearning	Day 1	15.842	9.002	2.065
	Day 3	19.895	10.530	2.416
Control	Day 1	19.526	8.085	1.855
	Day 3	11.368	5.356	1.229

Table 20

Post hoc Pairwise Comparison for Each Group on Recall Performances

		Mean Difference	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Retrieval-relearning	Relearning-retrieval	- 1.553	0.564	- 6.885	3.780
	Single retrieval	3.474	0.199	- 1.859	8.806
	Single relearning	2.553	0.344	- 2.780	7.885
	Control	4.973	0.067	- 0.359	10.306
Relearning-retrieval	Single retrieval	5.026	0.064	- 0.306	10.359
	Single relearning	4.105	0.130	- 1.227	9.438
	Control	6.526*	0.017	1.194	11.858
Single retrieval	Single relearning	- 0.921	0.732	- 6.254	4.412
	Control	1.500	0.578	- 3.833	6.833
Single relearning	Control	2.421	0.369	- 2.912	7.754

*$p < 0.05$

4.4.1.2 Recall performance on Day 3

ANOVA concluded that there was an effect of group on Day 3 recall performance, but not on Day 1 performance. There was a statistically significant difference on Day 3 recall performance between all five groups as determined by ANOVA, F (4, 94) = 10.947, $\boldsymbol{p < 0.001}$ (see Figure 23). A post hoc test revealed that participants in retrieval-relearning and relearning-retrieval performed better recall than participants in single retrieval ($\boldsymbol{p < 0.001}$) and control group ($\boldsymbol{p < 0.001}$). Plus, participants in single relearning also performed better recall than participants in single retrieval ($\boldsymbol{p = 0.046}$) and participants in control group ($\boldsymbol{p = 0.004}$) but performed significantly worse than participants in relearning followed by retrieval ($\boldsymbol{p = 0.013}$). Interestingly, there is no significance difference on recall performance between single relearning and retrieval followed by relearning. And, there is no significance difference on recall performance between single retrieval and control group as well.

4.4.1.3 Recall performance on Day 1

The ANOVA revealed no significant main effect of recall performance on Day 1, F (4, 94) = 0.910, $p = 0.462$, suggesting no significantly difference on Day 1 recall performance among all five groups. Participants were performing quite consistent across all five groups (see Figure 23).

From these results, we can conclude that there were differential memory improvements across all five groups. Retrieval-relearning and relearning-retrieval groups showed the greatest memory performance among all groups from Day 1 to Day 3 (see Figure 23), especially significant greater memory performance compared to single retrieval episode and control group. This suggested that 2 spaced episodes of retrieval and relearning strengthen memory, but the order of presentation does not appear to matter (see Table 21 and 22). However, both groups did not show much greatness in absolute memory performance with comparison to single relearning episode group, suggesting that they were similarly good at strengthening the episodic memory. Furthermore, single relearning episode significantly improved memory from Day 1 to 3 but not for single retrieval episode.

Table 21

Post hoc Pairwise Comparison for Each Group on Day 1 Recall Performance

			Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Day 1 Recall Performance	Retrieval-relearning	Relearning-retrieval	- 0.526	0.849	- 5.996	4.943
		Single retrieval	- 3.474	0.210	- 8.943	1.996
		Single relearning	0.474	0.864	- 4.996	5.943
		Control	- 3.211	0.247	- 8.680	2.259
	Relearning-retrieval	Single retrieval	- 2.947	0.287	- 8.417	2.522
		Single relearning	1.000	0.717	- 4.470	6.470
		Control	- 2.684	0.332	- 8.154	2.786
	Single retrieval	Single relearning	3.947	0.155	- 1.522	9.417
		Control	0.263	0.924	- 5.207	5.733
	Single relearning	Control	- 3.684	0.184	- 9.154	1.786

Table 22

Post hoc Pairwise Comparison for Each Group on Day 3 Recall Performance

			Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Day 3 Recall Performance	Retrieval-relearning	Relearning-retrieval	- 2.579	0.369	- 8.251	3.093
		Single retrieval	10.421***	0.000	4.749	16.093
		Single relearning	4.632	0.108	- 1.040	10.303
		Control	13.158***	0.000	7.486	18.830
	Relearning-retrieval	Single retrieval	13.000***	0.000	7.328	18.672
		Single relearning	7.211*	0.013	1.539	12.882
		Control	15.737***	0.000	10.065	21.409
	Single retrieval	Single relearning	- 5.789*	0.046	- 11.461	- 0.118
		Control	2.737	0.340	- 2.935	8.409
	Single relearning	Control	8.526**	0.004	2.855	14.198

***$p < 0.001$
**$p < 0.01$
*$p < 0.05$

Figure 23 illustrates the mean numbers of images correctly recalled on Day 1 and Day 3 across five different groups (retrieval followed by relearning, relearning followed by retrieval, single retrieval episode, single relearning episode and control group).

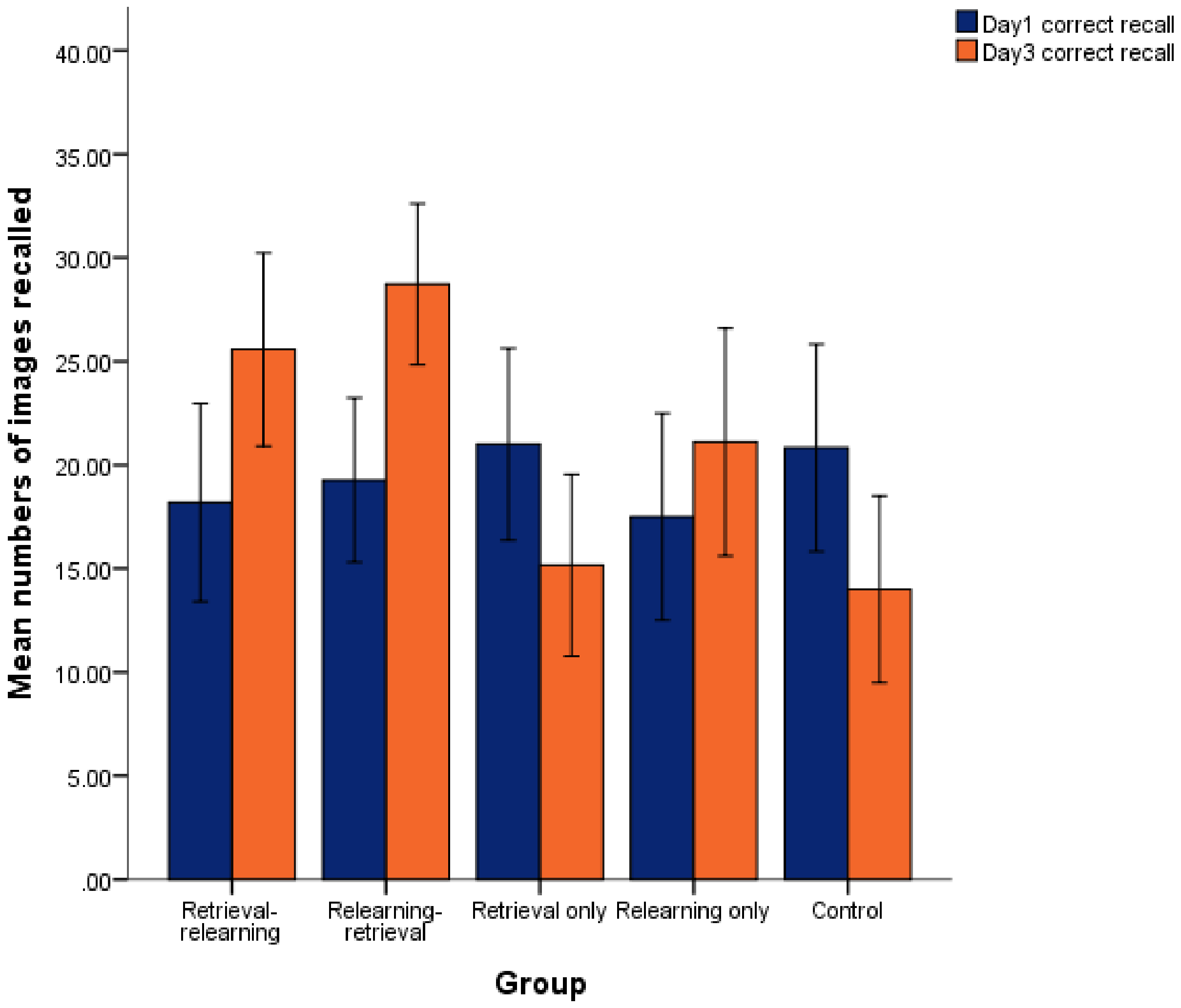

Figure 23. Mean numbers of images (+ SE) correctly recalled on Day 1 and Day 3 across five different groups

4.4.2 Retrieval followed by relearning and relearning followed by retrieval group compared with two relearning episodes and two retrieval episodes group

Since previous analyses found out the greatest memory improvement in both retrieval followed by relearning and relearning followed by retrieval groups, therefore current analyse would choose to compare the two great memory improvement groups (retrieval followed by relearning and relearning followed by retrieval groups) with two relearning episodes and two retrieval episodes groups.

4.4.2.1 Interaction between different days' recall performance and group

The ANOVA revealed a significant main effect of recall performance, *F* (1, 72) = 75.502, ***p* < 0.001**, suggesting recall performances on Day 1 and 3 were significantly different to each other. Recall performances for retrieval followed by relearning, relearning followed by retrieval, and two relearning episodes group were significantly improved from Day 1 to Day 3, whereas recall performance for two retrieval episodes group were significantly impaired from Day 1 to Day 3. A significant interaction effect between recall performance and group was reported as well, *F* (3, 72) = 50.412, ***p* < 0.001**, suggesting that significant differences between all four groups in the improvement on recall performance from Day 1 to Day 3 (see Figure 24). However, no significant main effect of group was found, *F* (3, 72) = 0.965, *p* = 0.414 (see Table 24). Table 23 illustrated the mean, standard error of mean and confidence interval for interaction between different days' recall performance and group.

Table 23

Descriptive Statistics for Different Group on Different Days' Recall Performance

	Recall Performance	Mean	Std. Deviation	Std. Error
Retrieval-relearning	Day 1	16.316	9.111	2.090
	Day 3	24.526	10.156	2.330
Relearning-retrieval	Day 1	16.842	6.825	1.566
	Day 3	27.105	8.319	1.909
Retrieval-retrieval	Day 1	21.263	7.978	1.830
	Day 3	13.842	10.340	2.372
Relearning-relearning	Day 1	15.263	8.517	1.953
	Day 3	24.842	6.085	1.396

Table 24

Post hoc Pairwise Comparison for Each Group on Recall Performances

		Mean Difference	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Retrieval-relearning	Relearning-retrieval	- 1.553	0.558	- 6.810	3.704
	Retrieval-retrieval	2.868	0.280	- 2.389	8.125
	Relearning-relearning	0.368	0.889	- 4.889	5.625
Relearning-retrieval	Retrieval-retrieval	4.421	0.098	- 0.836	9.678
	Relearning-relearning	1.921	0.469	- 3.336	7.178
Retrieval-retrieval	Relearning-relearning	- 2.500	0.346	- 7.757	2.757

4.4.2.2 Recall performance on Day 3

There was a statistically significant difference on Day 3 recall performance between all four groups as determined by ANOVA, *F* (3, 75) = 8.468, ***p* < 0.001** (see Figure 24). A post hoc test revealed that participants who experienced two retrieval episodes performed significantly worse than participants who experienced retrieval followed by relearning (***p* < 0.001**), relearning followed by retrieval (***p* < 0.001**) and two relearning episodes (***p* < 0.001**). However, there were no significance differences on recall performance between the two great memory improvement groups (retrieval followed by relearning and relearning followed by retrieval groups) and two retrieval episodes groups.

4.4.2.3 Recall performance on Day 1

The ANOVA revealed no significant main effect of recall performance on Day 1, *F* (3, 75) = 1.999, *p* = 0.122, suggesting participants were performing quite consistent across all four groups (see Figure 24).

We can again conclude that both retrieval followed by relearning and relearning followed by retrieval groups showed the greatest memory improvement among all groups from Day 1 to Day 3 (see Figure 24), especially significant greater memory improvement compared to two retrieval episodes group. However, both groups did not show much greatness in memory improvement with comparison to two relearning episodes group, suggesting that three groups were similarly good at strengthening the episodic memory. From the results, we can also justify that all four groups, i.e. retrieval followed by relearning, relearning followed by retrieval, single relearning episode and two relearning episodes were similarly good at strengthening the episodic memory (see Table 25).

Table 25

Post hoc Pairwise Comparison for Each Group on Day 1 and Day 3 Recall Performance

			Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Day 1 Recall Performance	Retrieval-relearning	Relearning-retrieval	- 0.526	0.843	- 5.798	4.746
		Retrieval-retrieval	- 4.947	0.065	- 10.219	0.325
		Relearning-relearning	1.053	0.692	- 4.219	6.325
	Relearning-retrieval	Retrieval-retrieval	- 4.421	0.099	- 9.693	0.851
		Relearning-relearning	1.579	0.552	- 3.693	6.851
	Retrieval-retrieval	Relearning-relearning	6.000*	0.026	0.728	11.272

Day 3 Recall Performance	Retrieval-relearning	Relearning-retrieval	- 2.579	0.374	- 8.330	3.172
		Retrieval-retrieval	10.684***	0.000	4.933	16.436
		Relearning-relearning	- 0.316	0.913	- 6.067	5.436
	Relearning-retrieval	Retrieval-retrieval	13.263***	0.000	7.512	19.015
		Relearning-relearning	2.263	0.435	- 3.488	8.015
	Retrieval-retrieval	Relearning-relearning	- 11.000***	0.000	- 16.751	- 5.249

***$p < 0.001$
*$p < 0.05$

Figure 24 illustrates the mean numbers of images correctly recalled on Day 1 and Day 3 across four different groups (retrieval followed by relearning, relearning followed by retrieval, two retrieval episodes, and two relearning episodes group).

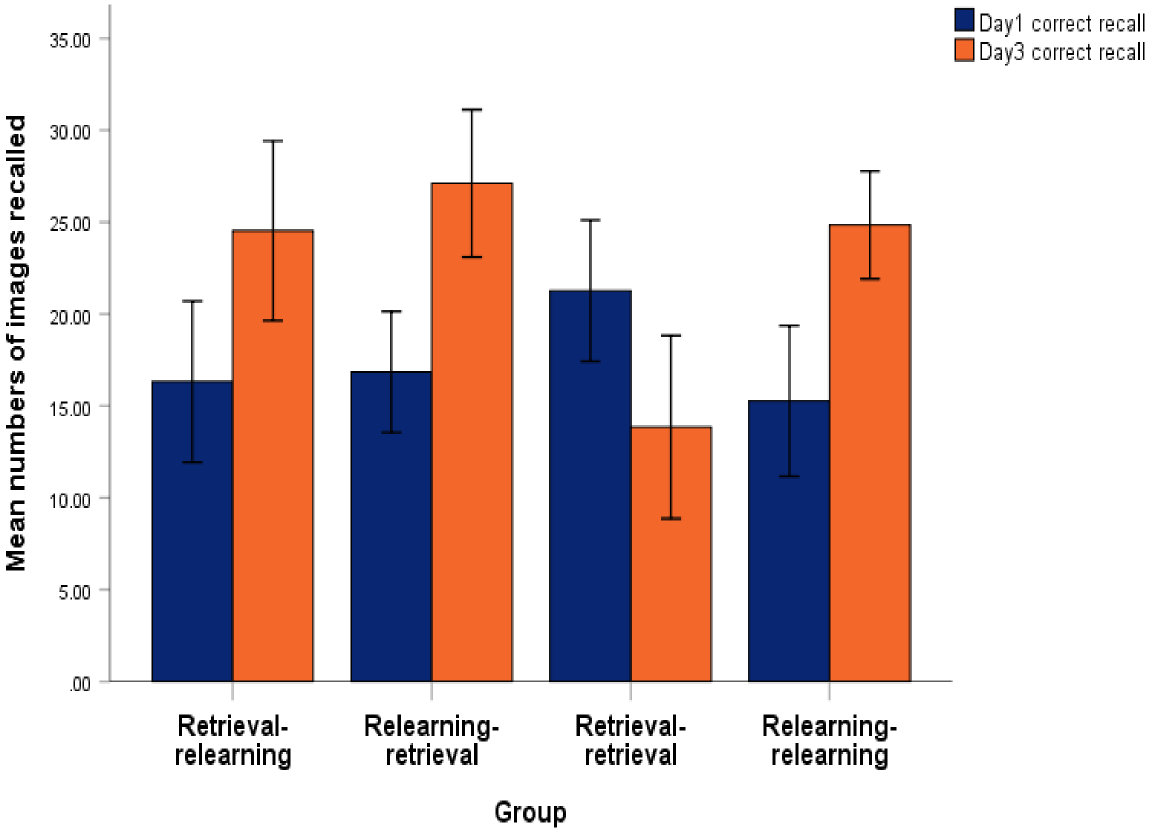

Figure 24. Mean numbers of images (+ SE) correctly recalled on Day 1 and Day 3 across four different groups

4.4.3 Single retrieval episode and control group compared with two retrieval episodes group

Previous ANOVA analyses constantly demonstrated deterioration in recall performances from Day 1 to Day 3 on three groups, i.e. single retrieval episode, two retrieval episodes and control groups. Therefore, current analysis would like to find out the differences among these three groups in recall performances.

4.4.3.1 Interaction between different days' recall performance and group

The ANOVA revealed a significant main effect of recall performance, *F* (1, 54) = 102.587, ***p* < 0.001**, suggesting recall performances on Day 1 and 3 were significantly different to each other. Recall performances for all three groups (single retrieval episode, control and two retrieval episodes group) were significantly impaired from Day 1 to Day 3. However, no significant interaction effect between recall performance and group was reported as well, *F* (2, 54) = 1.098, *p* = 0.341, suggesting that no significant differences between all three groups in the improvement on recall performance from Day 1 to Day 3 (see Figure 25). Furthermore, no significant main effect of group was found, *F* (2, 54) = 0.351, *p* = 0.706 (see Table 27). Table 26 illustrated the mean, standard error of mean and confidence interval for interaction between different days' recall performance and group.

Table 26

Descriptive Statistics for Different Group on Different Days' Recall Performance

	Recall Performance	Mean	Std. Deviation	Std. Error
Single retrieval	Day 1	19.790	9.169	2.103
	Day 3	14.105	8.672	1.990
Control	Day 1	19.526	8.085	1.855
	Day 3	11.368	5.356	1.229
Retrieval-retrieval	Day 1	21.263	7.978	1.830
	Day 3	13.842	10.340	2.372

Table 27

Post hoc Pairwise Comparison for Each Group on Recall Performances

		Mean Difference	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Single retrieval	Control	1.500	0.565	- 3.690	6.690
	Retrieval-retrieval	- 0.605	0.816	- 5.796	4.585
Control	Retrieval-retrieval	- 2.105	0.420	- 7.296	3.085

4.4.3.2 Recall performance on Day 1 and Day 3

There were no statistically significant differences on both Day 1, F (2, 56) = 0.234, p = 0.792, and Day 3 recall performances, F (2, 56) = 0.616, p = 0.544, between all three deteriorating groups as determined by ANOVA.

From these results, we can conclude that participants that received one retrieval episode, t (36) = 1.170, p = 0.250 and two retrieval episodes, t (36) = -0.926, p = 0.361, performed as poorly as control group on Day 3, showing evidence of memory decay (see Table 28).

Table 28

Post hoc Pairwise Comparison for Each Group on Day 1 and Day 3 Recall Performance

			Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Day 1 Recall Performance	Single retrieval	Control	0.263	0.924	- 5.219	5.745
		Retrieval-retrieval	- 1.474	0.592	- 6.956	4.008
	Control	Retrieval-retrieval	- 1.737	0.528	- 7.219	3.745
Day 3 Recall Performance	Single retrieval	Control	2.737	0.319	- 2.716	8.190
		Retrieval-retrieval	0.263	0.923	- 5.190	5.716
	Control	Retrieval-retrieval	- 2.474	0.367	- 7.927	2.979

Figure 25 illustrates the mean numbers of images correctly recalled on Day 1 and Day 3 across three different groups (single retrieval episode, control and two retrieval episodes group).

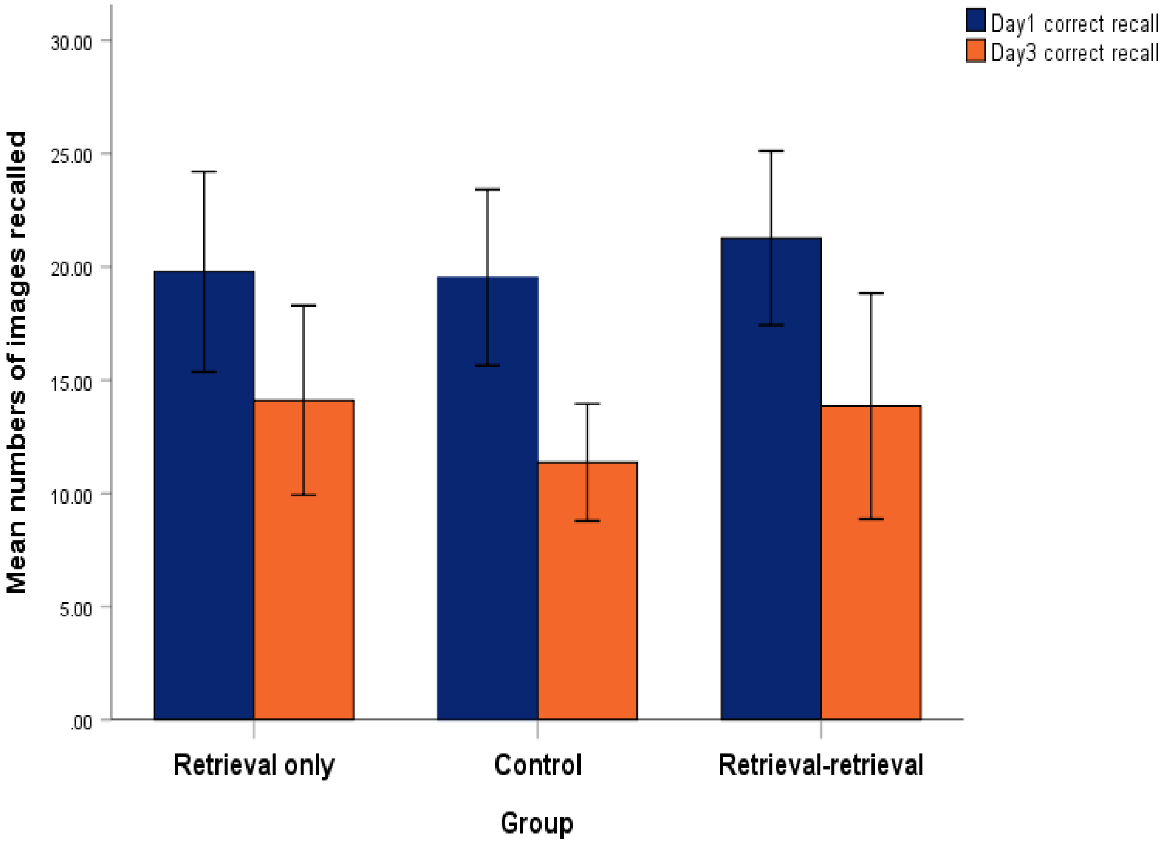

Figure 25. Mean numbers of images (+ SE) correctly recalled on Day 1 and Day 3 across three different groups

4.4.4 Retrieval followed by relearning and relearning followed by retrieval group compared with retrieval followed by relearning with 6 hours interval in between and relearning followed by retrieval with 6 hours interval in between group

Since there were no significant improvement performances among four groups (retrieval followed by relearning, relearning followed by retrieval, single relearning episode and two relearning episodes groups), an idea of implementing 6 hours interval in between sessions was suggested, aimed to put the second session experience outside the reconsolidation window. Therefore, current analyses would compare the two greatest memory performance groups (retrieval followed by relearning and relearning followed by retrieval) with retrieval followed by relearning with 6 hours interval in between and relearning followed by retrieval with 6 hours interval in between groups.

4.4.4.1 Interaction between different days' recall performance and group

The ANOVA revealed a significant main effect of recall performance, *F* (1, 72) = 222.780, *p* **< 0.001**, suggesting recall performances on Day 1 and 3 were significantly different to each other. Recall performances for all four groups were significantly improved from Day 1 to Day 3. A significant interaction effect between recall performance and group was reported as well, *F* (3, 72) = 10.341, *p* **< 0.001**, suggesting that significant differences between all four groups in the improvement on recall performance from Day 1 to Day 3 (see Figure 26). Furthermore, no significant main effect of group was found, *F* (3, 72) = 0.995, *p* = 0.400 (see Table 30). Table 29 illustrated the mean, standard error of mean and confidence interval for interaction between different days' recall performance and group.

Table 29
Descriptive Statistics for Different Group on Different Days' Recall Performance

	Recall Performance	Mean	Std. Deviation	Std. Error
Retrieval-relearning	Day 1	16.316	9.111	2.090
	Day 3	24.526	10.156	2.330
Relearning-retrieval	Day 1	16.842	6.825	1.566
	Day 3	27.105	8.319	1.909
Retrieval-6 hours-relearning	Day 1	17.368	9.269	2.126
	Day 3	20.263	9.649	2.214
Relearning-6 hours-retrieval	Day 1	19.158	8.448	1.938
	Day 3	27.421	7.515	1.724

Table 30
Post hoc Pairwise Comparison for Each Group on Recall Performances

		Mean Difference	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Retrieval-relearning	Relearning-retrieval	- 1.553	0.573	- 7.022	3.917
	Retrieval-6 hours-relearning	1.605	0.560	- 3.865	7.075
	Relearning-6 hours-retrieval	- 2.868	0.299	- 8.338	2.601
Relearning-retrieval	Retrieval-6 hours-relearning	3.158	0.254	- 2.312	8.628
	Relearning-6 hours-retrieval	- 1.316	0.633	- 6.786	4.154
Retrieval-6 hours-relearning	Relearning-6 hours-retrieval	- 4.474	0.107	- 9.943	0.996

4.4.4.2 Recall performance on Day 1 and Day 3

ANOVA found no statistically significant differences on both Day 1, *F* (3, 75) = 0.404, *p* = 0.750, and Day 3 recall performances, *F* (3, 75) = 2.584, *p* = 0.060, between the two greatest memory performance groups (retrieval followed by relearning and relearning followed by retrieval) with retrieval followed by relearning with 6 hours interval in between and relearning followed by retrieval with 6 hours interval in between groups (see Table 31 and 32).

Table 31

Post hoc Pairwise Comparison for Each Group on Day 1 Recall Performance

			Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Day 1 Recall Performance	Retrieval-relearning	Relearning-retrieval	- 0.526	1.000	- 7.981	6.928
		Retrieval-6 hours-relearning	- 1.053	1.000	- 8.507	6.402
		Relearning-6 hours-retrieval	- 2.842	1.000	- 10.297	4.612
	Relearning-retrieval	Retrieval-6 hours-relearning	- 0.526	1.000	- 7.981	6.928
		Relearning-6 hours-retrieval	- 2.316	1.000	- 9.770	5.139
	Retrieval-6 hours-relearning	Relearning-6 hours-retrieval	- 1.790	1.000	- 9.244	5.665

Table 32

Post hoc Pairwise Comparison for Each Group on Day 3 Recall Performance

			Mean Difference	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Day 3 Recall Performance	Retrieval-relearning	Relearning-retrieval	- 2.579	1.000	- 10.476	5.318
		Retrieval-6 hours-relearning	4.263	0.884	- 3.634	12.160
		Relearning-6 hours-retrieval	- 2.895	1.000	- 10.792	5.002
	Relearning-retrieval	Retrieval-6 hours-relearning	6.842	0.129	- 1.055	14.739
		Relearning-6 hours-retrieval	- 0.316	1.000	- 8.213	7.581
	Retrieval-6 hours-relearning	Relearning-6 hours-retrieval	- 7.158	0.098	- 15.055	0.739

Figure 26 illustrates the mean numbers of images correctly recalled on Day 1 and Day 3 across four different groups (retrieval followed by relearning, relearning followed by retrieval, retrieval followed by relearning with 6 hours interval in between and relearning followed by retrieval with 6 hours interval in between group).

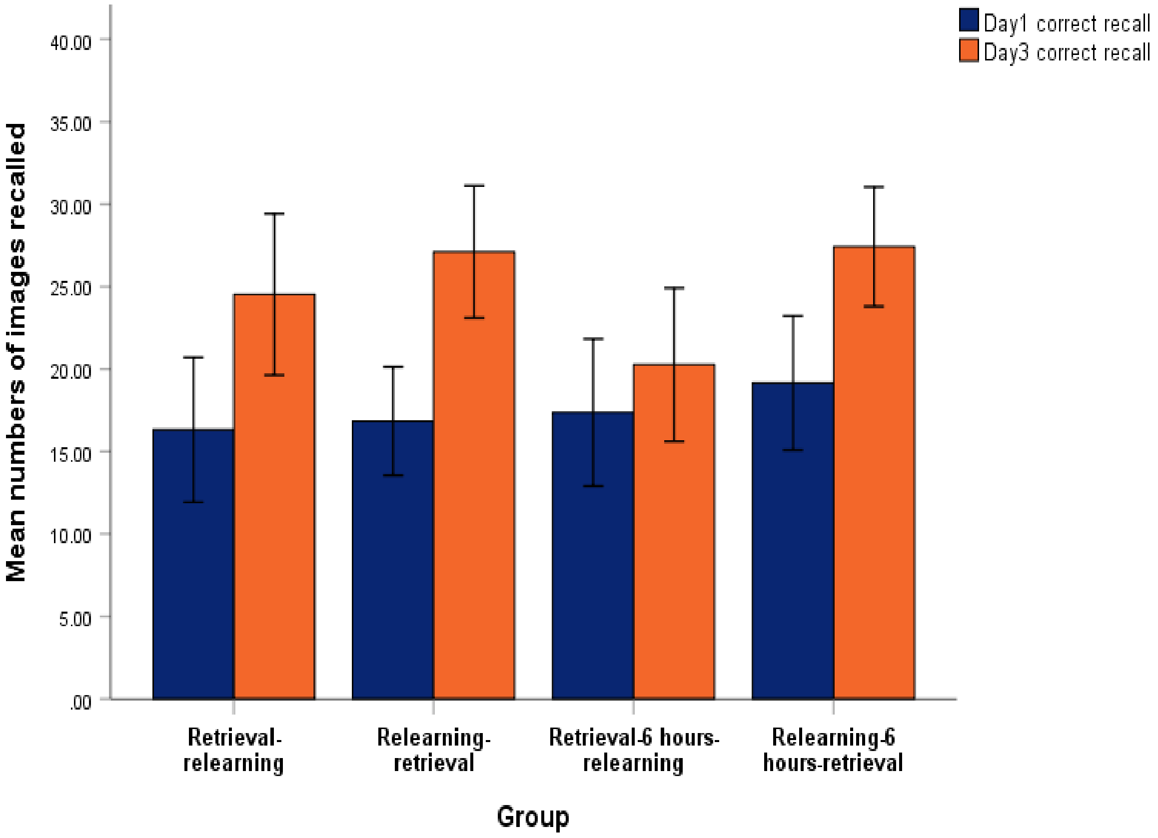

Figure 26. Mean numbers of images (+ SE) correctly recalled on Day 1 and Day 3 across four different groups

4.5 Discussion

One of the functions of memory reconsolidation is to modify or update existing memories (Dudai, 2006; Lewis, 1979; Nader, 2003). In current study, we investigated directly the capacity of memory reactivation to facilitate memory strengthening and our studies supported the idea of updating existing memories. All the participants were asked to learn 40 visual object-scene paired associations. Immediately after the learning session, participants were instructed to recall the associated objects out loud when the scene images were presented. Two days later, they were brought back to the same testing room as on Day 1, with the same experimenter, and performed different testing sessions according to group randomisation. An idea of implementing 6 hours interval in between Day 2 sessions was suggested as well, aimed to determine whether the learning effect is mediated by reconsolidation processes or not.

Current results revealed that the pattern of results was complex and suggested that there were differential memory improvements across all five groups. Results showed that participants in both groups, i.e. retrieval followed by relearning and relearning followed by retrieval groups, performed better recall than participants in single retrieval episode and control group. Despite the order of presentation, this suggested that 2 spaced episodes of retrieval and relearning showed the greatest memory strengthening among all the groups from Day 1 to Day 3. This result was supported by Sara (2000), which implied different steps of consolidation will modify how the information stored, especially in the memory strength. These repeated labilization-reconsolidation processes suggested the strength of new learning after reactivation is a critical factor in memory updating. Plus, participants in single relearning episode group also performed better recall than participants in single retrieval and control group. However, both retrieval followed by relearning and relearning followed by retrieval groups did not show much great performance compared to single relearning episode, suggesting that they were similarly good at strengthening the episodic memory. From these results, we suggested that relearning is better than retrieval, which is an important element in strengthening episodic memory and there is no effect of retrieval at all.

Since the 2 spaced episodes of retrieval and relearning showed the greatest memory strengthening in previous analyse, this raises the question of whether the nature of the episodes is important. Therefore, following analyse would compare the two great memory improvement groups (retrieval followed by relearning and relearning followed by retrieval groups) with two relearning episodes and two retrieval episodes groups. Results again showed that participants in retrieval followed by relearning and relearning followed by retrieval groups performed better recall than participants in two retrieval episodes group but did not show much greatness in memory improvement with comparison to two relearning episodes group, suggesting that three groups were similarly good at strengthening episodic memory. Once again, this strongly suggested that relearning episode is important in strengthening the episodic memory despite the number of relearning episodes. Current results suggested relearning episode reactivated the memory, allowing subsequent retrieval or relearning to update the memory strength.

Results constantly showed deterioration in recall performances on single retrieval episode, two retrieval episodes and control group. ANOVA found out that participants that received one retrieval episode and two retrieval episodes performed as poorly as control group on Day 3, showing evidence of memory decay. This strongly suggested that retrieval episode did not have beneficial effects in strengthening episodic memory at all.

Since there were no significant improvement performances among four groups (retrieval followed by relearning, relearning followed by retrieval, single relearning episode and two relearning episodes groups), an idea of implementing 6 hours interval in between sessions was suggested to put the second session experience outside the reconsolidation window. By comparing the two greatest memory performance groups (retrieval followed by relearning and relearning followed by retrieval) with retrieval followed by relearning with 6 hours interval and relearning followed by retrieval with 6 hours interval groups, results found there were no significant differences in recall performances among all four groups. This suggested that they were all similarly good at strengthening episodic memory. There was no greater strengthening observed compared to relearning alone.

The present results presented that relearning within the reconsolidation period opened by retrieval improved memory in human memory. Retrieval followed by relearning strengthened human memory. A few studies were in line with our current study, such as Forcato et al. (2007), which discovered two memory roles, i.e. memory updating, suggesting destabilisation of original memory which allows the integration of new information into original memory;

and memory strengthening, suggesting labilization-reconsolidation process which strengthens the original memory. Karpicke and Roediger (2008) trained their participants to learn foreign language vocabulary as word pairs and their aim was to evaluate the effect of repeated learning or repeated reactivation without feedback on a recall test a week after initial learning. Their results demonstrated that repeated study after learning had no effect on delayed recall, but repeated reactivation enhanced the memory. This study was in line with our current study, which the effects of retrieval followed by relearning and relearning followed by retrieval supported the idea of updating and strengthening the existing memories. Retrieval straight after learning process has been shown greater performance than single retrieval only (Roediger and Karpicke, 2006). However, Roediger and Karpicke (2006) implemented more repeated retrieval practices compared to our study, which had one retrieval practice. Furthermore, their participants were asked to recall on a final test in a week later, whereas we asked participants to recall on a final test in 3 days later.

This may, at first, seem to oppose the existing literatures on human retrieval practice effect, it should be noted that retrieval practice effect is generally implemented using several retrieval episodes, with further learning, and taking place within the same behavioural session as initial learning (Roediger & Butler, 2011; Hulbert & Norman, 2015). Current study contrasted in a several ways, in which retrieval session occurred 48 hours after learning, and only one or two occasion, and not interleaved with relearning or with feedback.

From all the results above, there are potential alternative explanations for common effects of retrieval-relearning and relearning-retrieval, which may reflect different underlying processes. First, retrieval followed by relearning might involve a reconsolidation-like strengthening effect. The relearning opportunity might act as a feedback mechanism, and retrieval with feedback is more useful than retrieval alone, to ensure a successful retrieval in the future (Roediger & Butler 2011). Feedback is critical after test or retrieval, e.g. on multiple choices test, students might learn incorrect information which they believe that it is true. If feedback is provided straight after a test, students can identify the incorrect information and learn the correct information. Behavioural psychology indicated that providing feedback straight after a test is powerful in learning (Kulik & Kulik, 1988; Skinner, 1954). However, experimental studies (e.g. Wheeler, Ewers, & Buonanno, 2003) showed the opposite effect, which delayed feedback might be even greater. Wheeler et al. (2003) found out that correct answer feedback provided immediately after each question boosted students' performance by 10%, whereas feedback after the entire test boosted the performance even greater. Second, relearning followed by retrieval could be a retrieval practice effect, one or more of which might be related to memory reconsolidation. Retrieval practice provides more long-term retention than repeated study (Karpicke & Roediger, 2008; Karpicke & Blunt, 2011). This suggested that integration of retrieval-relearning practice into educational field has the potential to boost performance in schools and reduce memory deficits among patients.

Based on all the past researches including current study, we can suggest that retrieval followed by relearning strengthened memory performance in a manner highly likely to depend upon memory destabilization-reconsolidation.

However, it remains unclear at present what exactly the retrieval and relearning processes need to be to enable memory strengthening, and so it is possible for either or both processes to be engaged in everyday memory recall.

Chapter 5

General discussion

For the past decades, memory reconsolidation phenomenon has successfully raised researchers’ attention, offering different perspectives on reconsolidation theory. Loftus (2005) raised that past researches demonstrated that episodic memories are not always accurate, being subject to false recollection. One significant explanation for false memories is due to the process of memory reconsolidation. The reactivation of a memory places memory to a liable state and allows that memory to be updated, usually adaptively and accurately. However, this normal process can be subverted to result in inaccurate or false memories (Hupbach et al., 2007). The crucial issue to determine memory enhancement or erasure that is caused by memory reconsolidation phenomenon, is to characterize the memory reactivation. Spear et al. (1973) mentioned in their rodent’s work using post-reactivation electroconvulsive shock to disrupt reconsolidation process, that it was sufficient with one element of the original memory (e.g. stimulus itself, the context in which the stimulus was presented) to trigger a reactivation. However, it seems more complicated in human memory studies. The most common reactivation method implemented in declarative memory reconsolidation studies is retrieval. Hupbach et al. (2008) mentioned that the spatial context is essential in reactivating memory. In current studies (Study 1, 2 and 3), we aimed to explore the reconsolidation effects in human episodic memory. Specifically, we replicated Hupbach’s paradigm (2007) to examine the episodic memory reconsolidation phenomenon.

Hupbach et al. (2007) used a three-days experimental design to study the episodic memory reconsolidation. On Day 1, participants were asked to learn a list of 20 objects (List 1), which was presented in a blue basket. After that, the blue basket with the objects was hidden and participants were required to recall the objects. This procedure was repeated until they have reached a criterion of learning, i.e. 17 of 20 objects were remembered or a maximum of four learning trials. On Day 2, there were two groups, i.e. a group that received a reminder that reactivated memory of List 1 before the second list-learning (reminder group), and another group that did not receive any reminder before the second list-learning (no-reminder group). Participants in both reminder and no-reminder group were asked to memorise the second list of objects (List 2) that were spread out on the table and were given 30 seconds to memorise them. The third group (interference control group) omitted the procedure on Day 2. Same learning manner as on Day 1 was implemented. In the retrieval session on Day 3, memory of List 1 was examined. Results showed that participants in the reminder group, who reactivated memory of List 1, had significantly more intrusions of List 2 items in their free recall. This result was in line with reconsolidation theory, which emphasised that reactivating List 1 memory before learning List 2 de-stabilized the original memory of List 1, making it susceptible to intrusion from List 2 items (false memories). In another Hupbach et al. (2008) study, the same experimental design was implemented to examine the conditions of reactivations that engage reconsolidation processes.

Experimental groups were specifically exposed to one reminder, either the same experimenter, the same spatial context or retrieval. Results demonstrated the spatial context reminder found the same effect as previous study in Hupbach et al. (2007), which showing the importance of spatial context in triggering memory reactivation. A later study using 5 years old children as participants replicated the results, suggesting context acted as an important reminder in novel context, but not in highly familiar spatial contexts. Instead, the other components of reminder become effective (Hupbach et al., 2011).

There has been little further study, especially into the specific sensory modalities of such context (i.e. visual, auditory and olfactory components). Therefore, in Study 1, we focused on the auditory factors in episodic memory reconsolidation, specifically aimed to demonstrate the impact of music upon episodic memory reconsolidation. We predicted that participants in same Classical music group, acted as reminder group, misattributed the highest number of intrusions (images from List 2) on their free recall. In current study, the same piece of music, *Cavatina* by Williams, which was delivered to participants in Day 1 and Day 2, was originally served as a reminder. The music was acted as a reminder to retrieval the memory of the List 1 from Day 1 and placed them in a labile state, so that the input of List 2 would modify the reactivated memory. However, current Study 1 did not support the hypothesis as participants in same Classical music group appeared to have the least intrusions compared to the other participants in the other four music groups. We could not replicate Hupbach et al. (2007) study as re-exposure to the same piece of music did not successfully reactivate the episode memory to trigger reconsolidation. More importantly, participants in the absence of music group showed high intrusions, suggesting that the current study and parameters were not amenable to observe the reconsolidation phenomenon. Instead of reconsolidation with inaccurate memories, memory strengthening was potentially found in this study. Study 1 highlighted the main point, i.e. reconsolidation process may not be as reliable as suggested in previous reconsolidation studies, supported by Klingmuller et al. (2017) and Van Schie et al. (2017).

According to Hupbach et al. (2007), reminders placed the memory of list on Day 1 into a labile state, and immediate learning of list on Day 2 appeared to alter memory for Day 1. As Study 1 did not successfully demonstrate the reconsolidation effect as predicted, we decided to follow the claim that spatial context plays an important role in memory reactivation. Artinian et al. (2007) and Sara (2010) found out that re-exposure to the same experimental context was sufficient to trigger reactivation and reconsolidation. Study 2 aimed to provide conceptual replication of studies of Hupbach et al. (2007, 2008), specifically focused on whether exposure solely to the initial learning context is sufficient to trigger reconsolidation effect on episodic memory. Considering the significant role of spatial context in memory reactivation, two important procedures should be implemented. Firstly, the reactivation group (same-experimenter-same-room group) should perform both encoding sessions in the same spatial context; whereas the no-reactivation group (different-experimenter-different-room group) must perform encoding sessions in different spatial context (different from List 1 encoding session). Secondly, all group were asked to perform free recall in the same spatial context of List 1 encoding session. If re-exposure to the same context puts the original memory into a labile state, then the learning of new information should alter the original memory. Therefore, Study 2 hypothesised that same-experimenter-same-room group acts as reminder group, and intrusion should appear the highest in the same-experimenter-same-room group. Unexpectedly, results of Study 2 did not demonstrate that phenomenon as no difference in intrusions between the Experimental and Control groups with both showing a modest number of intrusions. While Study 2 remains unclear whether the latter phenomenon is functionally related to reconsolidation, it is consistent with a body of evidence suggesting that reactivation-induced reconsolidation can maintain or even strengthen memories. Current study 2 strongly suggested that same spatial context did strengthen the memory of original list.

Since Study 2 suggested that reactivation-induced reconsolidation could maintain or even strengthen episodic memory, Study 3 aimed to investigate directly the capacity of memory reactivation to facilitate memory strengthening. Despite the order of presentation, results suggested that the strength of new learning after reactivation is critical factor in memory updating and strengthening episodic memory. Plus, relearning episode is the important element in strengthening the episodic memory despite the number of relearning episodes whereas retrieval episode did not have beneficial effects in strengthening episodic memory at all. These results supported the idea of updating existing memories and were in line with a few past studies, such as Forcato et al. (2007) and Karpicke and Roediger (2008). Memory updating is essential in our everyday life because, according to Bjork (1978), “Everyday functioning requires that we keep our memories reasonably current. To the degree that we do not somehow set aside or eliminate information no longer needed we become confused, error prone, and inefficient” (p. 236). According to Tulving, Kapur, Craik, Moscovitch, and Houle (1994), “An act of retrieval whether supported by episodic memory or semantic memory frequently constitutes an input into episodic memory.” (p. 2016). This emphasised that a retrieval involves a combination of new encoding and retrieval. The findings in Study 3 have potential implication for the understanding of memory strategies to boost weakly-learned memories. The main conclusion from our three studies could be summarized in several points. Firstly, when the original memory is reactivated using cued reminder, memory strengthening was found instead of memory reconsolidation with inaccurate memories. Secondly, reactivation-induced reconsolidation can maintain or even strengthen memories, especially in same spatial context. Thirdly, retrieval followed by relearning strengthened memory performance in a manner highly likely to depend upon memory destabilization-reconsolidation.

Initially, current studies were replicating studies of Hupbach et al. (2007, 2008), aimed to discover memory reconsolidation effect with inaccurate memories, however current studies could not replicate the studies of Hupbach et al. (2007, 2008) and did not observe the effects in line with reconsolidation theory. Taken together, current failed replication studies highlighted a few points. First, the reconsolidation process reconsolidation process may not be as reliable as suggested in previous reconsolidation studies, supported by

Klingmuller et al. (2017) and Van Schie et al. (2017). Secondly, current studies were unclear whether the phenomenon is functionally related to reconsolidation, but it was consistent with a body of evidence suggesting that reactivation-induced reconsolidation can maintain or even strengthen memories. Although behavioural interference technique used in current studies were quite similar to Schiller et al. (2010) which examined fear conditioning, the outcome was dissimilar. Schiller et al. (2010) suggested that the fear memory was updated and no longer expressed, however our human reconsolidation studies discovered that the original memory is still remain and even strengthened. Our failure to observe reconsolidation process might be related to minor changes that we made to the original Hupbach et al. (2007, 2008) design. Instead of using the same 20 objects lists (List 1 and List 2) from Hupbach et al. (2007) study, we randomly selected our own 20 objects lists from exemplar pairs paradigm developed by Brady, Konkle, Alvarez, and Olivia (2008). We also modified the presentation methods by using sequential presentation slides method and physical paper hand-out method, instead of presenting a blue basket of 20 objects or spreading out the 20 objects on the table. All these changes might be the sole or joint cause for the absence of reconsolidation phenomenon in current studies. Current studies join a growing number of other studies which failed to replicate reconsolidation phenomenon using behavioural interference technique (for example, Golkar, Bellander, Olsson, & Ohman, 2012; Hardwicke, Taqi, & Shanks, 2016; Kindt & Soeter, 2013; Soeter & Kindt, 2011; Wichert et al., 2011) or using pharmacological manipulations (for example, Bos, Beckers, & Kindt, 2014; Wood et al., 2015). Hardwicke et al.

(2016) made the strong case against human memory reconsolidation as they did not find any evidence of inaccurate or false memories predicted by reconsolidation theory even though direct replication of Walker et al. (2003) study, which investigated human reconsolidation in procedural memory.

Compared to reconsolidation in animal models which successfully demonstrated the memory reconsolidation phenomenon in the last 10 years, there is still limited evidences on human reconsolidation. The main reason for this discrepancy is the techniques used in investigating memory reconsolidation, which are difficult and unethical to apply in humans. For example, pharmacological agents, used to block the reconsolidation and used on animals, however, these agents were too dangerous to apply on humans. Therefore, the best way to demonstrate human reconsolidation is to use non-invasive way that update memory during reconsolidation rather than blocking it. Most of the animal studies have used Pavlovian conditioning (e.g. Nader et al., 2000) to examine memory reconsolidation, which suggested that the conditioned fear acquired and stored in amygdala. Therefore, Nader et al. (2000) injected protein synthesis inhibitor into the amygdala during the reconsolidation of conditioned fear as these pharmacological agents used to block reconsolidation (Judge & Quartermain, 1982). This is maybe because lack of the pharmacological agents that is safe for human use which have been found to disrupt the hippocampal reconsolidation in animal models. Without such agents, it is not possible to pharmacologically disrupt the hippocampal reconsolidation in humans (Schiller et al., 2010).

Since our studies suggested that the reconsolidation process may not be reliable as suggested by previous existing memory reconsolidation studies and current studies also demonstrated retrieval can both enhance and impair the learning of new information introduced after retrieval, which has not been addressed by other memory updating models, therefore, more direct replications will be necessary in order to determine whether our and existing findings on reconsolidation are more reliable. It is also important to discover boundary conditions of the memory reconsolidation process, such as the strength of the memory or memory updating. A few existing studies (Alberini, 2005, 2008; Alberini, Milekic, & Tronel, 2006; Lee, 2009; Nader & Einarsson, 2010; Nader & Hardt, 2009; Tronson & Taylor, 2007) have reported the influence of the age of the memory in reconsolidation phenomenon. Eisenberg et al. (2003) and Suzuki et al. (2004) found out that strong memories were more resistant to reconsolidation process but could be labile again with one condition, i.e. reminder session was prolonged. Rescorla and Wagner (1972) suggested that new information that is learned three times after reactivation are more likely to incorporated into original memory compared to the information that is learned only once. Therefore, future studies should examine multiple boundary conditions. However, this remains a question that how to differentiate simple memories that created in well-controlled lab environment from the memories related to psychiatric disorders, such as post-traumatic stress disorder (PTSD) and drug addiction, which both of them characterized by the presence of repeatedly recalled memories. According to Pitman and Delahanty (2005), PTSD can be explained using Palvovian fear conditioning, i.e. traumatic event (unconditioned stimulus, US) triggers a hormonal stress response, which mediates the memory of the trauma. Repeated recall in response of reminders (conditioned stimulus, CS) releases more stress hormones (conditioned response), and further consolidates the memory, which leading to PTSD symptoms. Since PTSD can be studied using behavioural paradigm, it is crucial that future research on memory reconsolidation will be able to bridge the gap from laboratory research to clinical practice. According to Alfei, Monti, Molina, Bueno, & Urcelay (2015), the relationship between reminder trials and the duration of conditioned stimulus exposure during conditioning might be important. Therefore, future research should also examine on the duration of reminder trials or number of reminder trials that is necessary to induce human reconsolidation phenomenon.

Memory reconsolidation phenomenon highlighted the idea of memory maintenance over time is an active process. From animal models, amnesic agents to behavioural interference paradigm, existing researches suggest that memory reconsolidation is a fundamental aspect of memory. Current and future studies on memory reconsolidation provide insights to different setting, such as public health and educational setting.

Bibliography

Abel, T., Nguye, P. V., Barad, M., Deuel, T. A., Kandel, E. R., & Bourtchouladze, R. (1997). Genetic demonstration of a role for PKA in the late phase of LTP and in hippocampus-based long-term memory. *Cell*, *88*, 615-626.

Alberini, C. M. (2005). Mechanisms of memory stabilization: Are consolidation and reconsolidation similar or distinct processes? *Trends Neuroscience*, *28*, 51.

Alberini, C. M. (2007). Reconsolidation: The samsara of memory consolidation. *Debates in Neurosciences*, *1,* 17–24.

Alberini, C. M. (2008). The role of protein synthesis during the labile phases of memory: Revisiting the skepticism. *Neurobiology of Learning & Memory*, *89*, 234–246.

Alberini, C. M., Milekic, M. H., & Tronel, S. (2006). Mechanisms of memory stabilization and de-stabilization. *Cellular and Molecular Life Sciences*, *63*, 999-100810.

Alfei, J. M., Monti, R. I. F., Molina, V. A., Bueno, A. M., & Urcelay, G. P. (2015). Prediction error and trace dominance determine the fate of fear memories after posttraining manipulations. *Learning and Memory*, *22*, 385–400.

Anderson, J. R., Fincham, J. M., & Douglass, S. (1997). The role of examples and rules in the acquisition of a cognitive skill*. Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 923–945.

Anokhin, K. V., Tiunova, A. A., & Rose, S. P. (2002). Reminder effects – Reconsolidation of retrieval deficit? Pharmacological dissection with protein synthesis inhibitors following reminder for a passive-avoidance task in your chicks. *European Journal of Neuroscience*, *15*, 1759-1765.

Artinian, J., De Jaeger, X., Fellini, L., De Saint Blanquat, P., & Roullet, P. (2007). Reactivation with a simple exposure to the experimental environment is sufficient to induce reconsolidation requiring protein synthesis in the hippocampal CA3 region in mice. *Hippocampus, 17*, 181–191.

Backman, L., Small, B. J., & Fratiglioni, L. (2001). Stability of the preclinical episodic memory deficit in Alzheimer’s disease. *Brain*, *124*, 96–102.

Balsam, P. D. (1985). The functions of context in learning and performance. In P. D. Balsam & A. Tomie (Eds.), *Context and Learning* (pp. 1-21). Hillsdale, NJ: Erlbaum.

Bell, P. A., Hess, S., Hill, E., Kukas, S. L., Richards, R. W., & Sargent, D. (1984). Noise and context-dependent memory. *Bulletin of the Psychonomic Society*, *22*, 99-100.

Bjork, R. A. (1978). The updating of human memory. *Psychology of Learning and Motivation*, *12*, 235-259.

Bos, M. G. N., Beckers, T., & Kindt, M. (2014). Noradrenergic blockade of memory reconsolidation: A failure to reduce conditioned fear responding. *Frontiers in Bahavioral Neuroscience*, *8*, 412.

Bower, G. H., & Reitman, J. S. (1972). Mnemonic elaboration in multilist learning. *Journal of Verbal Learning and Verbal Behavior*, *11*, 478-485.

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(38), 14325-14329.

Bramham, C. R., & Messaoudi, E. (2005). BDNF function in adult synaptic plasticity: The synaptic consolidation hypothesis. *Progress in Neurobiology*, *76*(2), 99-125.

Brunet, A., Orr, S. P., Tremblay, J., Robertson, K., Nader, K., & Pitman, R. K. (2008). Effect of post-retrieval propranolol on psychophysiologic responding during subsequent script-driven traumatic imagery in post-traumatic stress disorder. *Journal of Psychiatric Research*, *42*, 503-506.

Calvert, S. L., & Tart, M. (1993). Song versus verbal forms for very-long-term, long-term, and short-term verbatim recall. *Journal of Applied Developmental Psychology*, *14*(2), 245-260.

Canas, J. J., & Nelson, D. C. (1986). Recognition and environmental Context: The effects of testing by phone. *Bulletin of the Psychonomic Society*, *24*, 407-409.

Carbo Tano, M., Molina, V. A., Maldonado, H., & Pedreira, M. (2009). Memory consolidation and reconsolidation in an invertebrate model: Role of the GABAergic system. *Neuroscience*, *158*(2), 387-401.

Chan, J. C. K., & LaPaglia, J. A. (2013). Impairing existing declarative memory in humans by disrupting reconsolidation. *Proceedings of the National Academy of Sciences of the United States of America*, *110*, 9309-9313.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671-684.

Crutcher, R. J., & Ericsson, K. A. (2000). The role of mediators in memory retrieval as a function of practice: Controlled mediation to direct access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 1297–1317.

Davachi, L., Mitchell, J. P., & Wagner, A. D. (2003). Multiple routes to memory: Distinct medial temporal lobe processes build item and source memories. *Proceedings of the National Academy of Sciences of the United States of America*, *100*, 2157–2162.

Dawson, R. G., & McGaugh, J. L. (1969). Electroconvulsive shock effects on a reactivated memory trace: Further examination. *Science*, *166*(3904), 525-527.

Debiec, J., LeDoux, J. E., & Nader, K. (2002). Cellular and systems reconsolidation in the hippocampus. *Neuron, 36*, 527–538.

De Oliveira Alvares, L., Crestani, A. P., Cassini, L. F., Haubrich, J., Santana, F., & Guillfeldt, J. A. (2013). Reactivation enables memory updating, precision-keeping and strengthening: Exploring the possible biological roles of reconsolidation. *Neuroscience*, *244*, 42-48.

Deese, J. (1959). On the prediction of occurrence of particular verbal intrusions in immediate recall. *Journal of Experimental Psychology*, *58*, 17.

Desse, J. (1965). *The structure of associations in language and thought*. Baltimore, Md: Johns Hopkins Press.

Dongaonkar, B., Hupbach, A., Gomez, R., & Nadel, L. (2013). Effects of psychosocial stress on episodic memory updating. *Psychopharmacology Berl*, *226*, 769–779.

Dudai, Y. (2006). Reconsolidation: The advantage of being refocused. *Current Opinion in Neurobiology*, *16*(2), 174-178.

Dudai, Y., & Eisenberg, M. (2004). Rites of passage of the engram: Reconsolidation and the lingering consolidation hypothesis. *Neuron*, *44,* 93–100.

Duncan, C. P. (1949). The retroactive effect of electroconvulsive shock. *Journal of Comparative & Physiological Psychology*, *42*, 32–44.

Duvarci, S., & Nader, K. (2004). Characterization of fear memory reconsolidation. *The Journal of Neuroscience, 24*, 9269 –9275.

Ecker, U. K. H., Logan, J. L., & Lewandowsky, S. (2017). Reminders and repetition of misinformation: Helping or hindering its retraction? *Journal of Applied Research in Memory and Cognition*, *6*(2), 185-192.

Eich, J. E. (1980). The cue-dependent nature of state-dependent retrieval. *Memory and Cognition*, *8*, 157-173.

Eisenberg, M., Kobilo, T., Berman, D. E., & Dudai, Y. (2003). Stability of retrieved memory: Inverse correlation with trace dominance. *Science*, *301*, 1102–1104.

Engle, R. W., Cantor, J., & Carullo, J. J. (1993). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(5), 972-992.

Fagen, J., Prigot, J., Carroll, M., Pioli, L., Stein, A., & Franco, A. (1997). Auditory context and memory retrieval in young infants. *Child Development*, *68*(6), 1057-1066.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, *34*, 906–911.

Flexner, L. B., Flexner, J. B., & Stellar, E. (1965). Memory and cerebral protein synthesis in mice as affected by graded amounts of puromycin. *Experimental Neurology*, *13*, 264–272.

Forcato, C., Burgos, V. L., Argibay, P. F., Molina, V. A., Pedreira, M. E., & Maldonado, H. (2007). Reconsolidation of declarative memory in humans. *Learning and Memory, 14*(4), 295–303.

Forcato, C., Rodríguez, M. L., Pedreira, M. E., & Maldonado, H. (2010). Reconsolidation in humans opens up declarative memory to the entrance of new information. *Neurobiology of Learning and Memory, 93*(1), 77e84.

Forgeard, M., Winner, E., Norton, A., & Schlaug, G. (2008). Practicing a musical instrument in childhood is associated with enhanced verbal ability and nonverbal reasoning. *Plos One*, *3*(10), e3566.

Fozard, J. L., & Yntema, D. B. (1966). The effect of repetition on the apparent recency of pictures. *American Psychologist*, *21*, 879.

Frenkel, L., Maldonado, H., & Delorenzi, A. (2005). Memory strengthening by a real-life episode during reconsolidation: An outcome of water deprivation via brain angiotensin II. *European Journal of Neuroscience*, *22*, 1757–1766.

Galluccio, L. (2005). Updating reactivated memories in infancy: I. Passive- and active-exposure effects. *Developmental Psychobiology*, *47*, 1–17.

Gershman, S. J., Schapiro, A. C., Hupbach, A., & Norman, K. A. (2013). Neural context reinstatement predicts memory misattribution. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *33*(20), 8590–8595.

Glisky, E. L., Rubin, S. R., & Davidson, P. S. (2001). Source memory in older adults: An encoding or retrieval problem? *Journal of Experimental Psychology: Learning, Memory and Cognition*, *27*, 1131–1146.

Godden, D. R., & Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology*, *66*(3), 325-331.

Godden, D. R., & Baddeley, A. D. (1980). When does context influence recognition memory. *The British Journal of Psychology*, *71*, 99-104.

Goelet, P., Castellucci, V. F., Schacher, S., & Kandel, E. R. (1986). The long and the short of long-term memory – A molecular framework. *Nature*, *332*, 419-422.

Gold, P. E., & McGaugh, J. L. (1975). A single-trace, two process view of memory storage processes. In J. Deutsch & D. Deutsch (Eds.), *Short-term memory* (pp. 355–378). Academic Press, NY.

Golkar, A., Bellander, M., Olsson, A., & Ohman, A. (2012). Are fear memories erasable? Reconsolidation of learned fear with fear-relevant and fear-irrelevant stimuli. *Frontiers in Behavioral Neuroscience*, *6*, 80.

Gordon, W. C., & Spear, N. E. (1973). Effect of reactivation of a previously acquired memory on the interaction between memories in the rat. *Journal of Experimental Psychology*, *99*, 349–355.

Grant, H., Lane, C. B., John, C., Jennifer, F., Jane, G., Timothy, M. D., & Veronica, D. (1998). Context-dependent memory for meaningful material: Information for students. *Applied Cognitive Psychology*, *12*, 617-623.

Griffiths, D, Dickinson, A, & Clayton, N. (1999). Episodic memory: What can animals remember about their past? *Trends in Cognitive Sciences*, *3*(2), 74-80.

Gruneberg, M. M. (1973). The role of memorization techniques in finals examination preparation: A study of psychology students. *Educational Research and Reviews*, *15*, 134–139.

Hall, G., Symonds, M., & Rodriguez, M. (2009). Enhanced latent inhibition in context aversion conditioning. *Learning and Motivation*, *40,* 62–73.

Halpern, A. R., & Mullensiefen, D. (2007). Effects of timbre and tempo change on memory for music. *Quarterly Journal of Experimental Psychology*, *61*(9), 1371-1384.

Hardt, O., Einarsson, E. O., & Nader, K. (2010). A bridge over troubled water: Reconsolidation as a link between cognitive and neuroscientific memory research traditions. *Annual Review of Psychology*, *61*, 141e167.

Hardwicke, T. E., Taqi, M., & Shanks, D. R. (2016). Postretrieval new learning does not reliably induce human memory updating via reconsolidation. *Proceedings of the National Academy of Sciences of the United States of America*, *113*, 5206-5211.

Hart, J. T. (1965). Memory and the feeling-of-knowing experiments. *Journal of Educational Psychology*, *56*, 208–216.

Herlitz, A., Nilsson, L. G., & Backman, L. (1997). Gender differences in episodic memory. *Memory and Cognition*, *25*, 801–811.

Hintzman, D. L., & Caulton, D. A. (1997). Recognition memory and modality judgments: a comparison of retrieval dynamics. *Journal of Memory and Language*, *37*, 1–23.

Horowitz, L. M., White, M. A., & Atwood, D. W. (1968). Word fragments as aids to recall: The organization of a word. *Journal of Experimental Psychology*, *76*(2), 219-226.

Howard, M. W., & Kahana, M. J. (2002). When does semantic similarity help episodic retrieval? *Journal of Memory and Language*, *46*, 85–98.

Hulberete, J. C., & Norman, K. A. (2015). Neural differentiation tracks improved recall of competing memories following interleaved study and retrieval practice. *Cereb Cortex, 25*, 3994-4008.

Hupbach A. (2015). Retrieval practice does not safeguard memories from interference-based forgetting. *Learning and Motivation*, *49*, 23–30.

Hupbach, A., Gomez, R., Hardt, O., & Nadel, L. (2007). Reconsolidation of episodic memories: A subtle reminder triggers integration of new information. *Learning and Memory*, *14*, 47–53.

Hupbach, A., Gomez, R., & Nadel, L. (2009). Episodic memory reconsolidation: Updating or source confusion? *Memory*, *17*(5), 502–510.

Hupbach, A., Gomez, R., & Nadel, L. (2011). Episodic memory updating: The role of context familiarity. *Psychonomic Bulletin and Review*, *18*, 787–797.

Hupbach, A., Hardt, O., Gomez, R., & Nadel, L. (2008). The dynamics of memory: Context-dependent updating. *Learning and Memory*, *15*, 574–579.

Inda, M. C., Muravieva, E. V., & Alberini, C. M. (2011). Memory retrieval and the passage of time: From reconsolidation and strengthening to extinction. *The Journal of Neuroscience, 31*, 1635–1643.

James, E. L., Bonsall, M. B., Hoppitt, L., Tunbridge, E. M., Geddes, J. R., Milton, A. L., & Holmes, E. A. (2015). Computer game play reduces intrusive memories of experimental trauma via reconsolidation-update mechanisms. *Psychological Science*, *26*(8), 1201-1215.

Jancke, L. (2008). Music, memory and emotion. *Journal of Biology*, *7*, 21.

John, O. P., & Srivastava, S. (1999). The Big-Five trait taxonomy: History, measurement, and theoretical perspectives. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (Vol. 2, pp. 102–138). New York: Guilford Press.

Johnson, M. K., & Chalfonte, B. L. (1994). Binding complex memories: The role of reactivation and the hippocampus. In D. L. Schacter & E. Tulving (Eds.), *Memory systems 1994* (pp. 311–350). Cambridge, MA: MIT Press.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*, *114*, 3–28.

Jones, B., Bukoski, E., Nadel, L., & Fellous, J. M. (2012). Remaking memories: Reconsolidation updates positively motivated spatial memory in rats. *Learning & Memory*, *19*, 91–98.

Jones, B. J., Pest, S. M., Vargas, I. M., Glisky, E. L., & Fellous, J. M. (2015). Contextual reminders fail to trigger memory reconsolidation in aged rats and aged humans. *Neurobiology of Learning and Memory*, *120*, 7–15.

Joordens, S., & Hockley, W. E. (2000). Recollection and familiarity through the looking glass: when old does not mirror new. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 1534–1555.

Judge, M. E., & Quartermain, D. (1982). Characteristics of retrograde amnesia following reactivation of memory in mice. *Physiology and Behaviour*, *28*, 585–590.

Kang, H. J., & Williamson, V. J. (2014). Background music can aid second language learning. *Psychology of Music*, *42*(5), 728-747.

Karpicke, J. D., & Blunt, J. R. (2011). Retrieval practice produces more learning than elaborative studying with concept mapping. *Science*, *331*, 772–775.

Karpicke, J. D., & Roediger, H. K. (2008). The critical importance of retrieval for learning. *Science, 319*, 966 –968.

Kesner, R. P., Hunsaker, M. R., Warthen, M. W. (2008). The CA3 subregion of the hippocampus is critical for episodic memory processing by means of relational encoding in rats. *Behavioral Neuroscience*, *122*, 1217–1225.

Kida, S. Josselyn, S. A., DeOrtiz, S. P., Kogan, J. H., Chevere, I., Masushige, S., & Silva, A. J. (2002). CREB required for the stability of new and reactivated fear memories. *Nature Neuroscience*, *5*, 348-355.

Kilgour, A. R., Jakobson, L. S., & Cuddy, L. L. (2000). Music training and rate of presentation as mediators of text and song recall. *Memory and Cognition*, *28*, 700-710.

Kindt, M. (2018). The surprising subtleties of changing fear memory: A challenge for translational science. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1742), 20170033

Kindt, M., & Soeter, M. (2013). Reconsolidation in a human fear conditioning study: A test of extinction as updating mechanism. *Biological Psychology*, *92*(1), 43-50.

Kindt, M, Soeter, M., & Vervliet, B. (2008). Beyond extinction: Erasing human fear responses and preventing the return of fear. *Nature Neuroscience*, *12*(3), 256-258.

Klingmuller, A., Caplan, J. B., & Sommer, T. (2017). Intrusions in episodic memory: Reconsolidation or interference? *Learning Memory*, *24*(5), 216.224.

Konorski, J. (1961). The physiological approach to the problem of recent memory. In J. F. Delafresnaye (Eds.), *Brain mechanisms and learning* (pp. 115-132). Springfield, IL: Thomas.

Kulik, J. A., & Kulik, C. C. (1988). Timing of feedback and verbal learning. *Review of Educational Research, 58*(1), 79-97.

Laming, D. (1992). Analysis of short-term retention: Models for Brown-Peterson experiments. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 1342-1365.

Lee, J. L. C. (2008). Memory reconsolidation mediates the strengthening of memories by additional learning. *Nature Neuroscience*, *11*(11), 1264-1266.

Lee, J. L. C. (2009). Reconsolidation: Maintaining memory relevance. *Trends in Neuroscience*, *32*, 413-420.

Lee, J. L. (2010). Memory reconsolidation mediates the updating of hippocampal memory content. *Frontiers in Behavioral Neuroscience*, *4*, 168.

Lee, J. L. C., Milton, A. L., & Everitt, B. J. (2006). Reconsolidation and extinction of conditioned fear: Inhibition and potentiation. *The Journal of Neuroscience*, *26*, 10051–10056.

Lesch, M. F., & Pollatsek, A. (1993). Automatic access of semantic information by phonological codes in visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(2), 285-294.

Lewis, D. J. (1979). Psychobiology of active and inactive memory. *Psychological Bulletin*, *86*, 1054–1083.

Loftus, E. F. (2005). Planting misinformation in the human mind: A 30-year investigation of the malleability of memory. *Learning and Memory*, *12*, 361–366.

Lundstrom, B. N., Ingvar, M., & Petersson, K. M. (2005). The role of precuneus and left inferior frontal cortex during source memory episodic retrieval. *Neuroimage*, *27*, 824–834.

Mactutus, C. F., Riccio, D. C., & Ferek, J. M. (1979). Retrograde amnesia for old (reactivated) memory: Some anomalous characteristics. *Science*, *204*, 1319–1320.

McElhinney, M., & Annett, J. M. (1996). Pattern of efficacy of a musical mnemonic on recall of familiar words over several presentations. *Perception Motor Skills*, *82*(2), 395-400.

McGaugh, J. L. (1966). Time-dependent processes in memory storage. *Science*, *153*, 1351-1358.

McGaugh, J. L. (2000). Memory-A century of consolidation. *Science*, *287*, 248–251.

McGeoch, J. A. (1932). Forgetting and the law of disuse. *Psychological Review*, *39*(4), 352.

Melton, A. W. (1963). Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behaviour*, *2*, 1-21.

Milekic, M. H., & Alberini, C. M. (2002). Temporally graded requirement for protein synthesis following memory reactivation. *Neuron*, *36*, 521– 525.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81-97.

Misanin, J. R., Miller, R. R., & Lewis, D. J. (1968). Retrograde amnesia produced by electroconvulsive shock after reactivation of a consolidated memory trace. *Science*,*160*, 554–555.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S. L., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: More evidence for brain plasticity. *Cerebral Cortex*, *19*(3), 712-723.

Morris, R. G., Inglis, J., Ainge, J. A., Olverman, H. J., Tulloch, J., Dudai, Y., & Kelly, P. A. (2006). Memory reconsolidation: sensitivity of spatial memory to inhibition of protein synthesis in dorsal hippocampus during encoding and retrieval. *Neuron*, *50*, 479–489.

Morton, J. (1968). Repeated items and decay in memory. *Psychonomic Science*, *10*, 219-220.

Muller, G. E., & Pilzecker, A. (1900). Experimentelle Beitrage zur Lehre vom Gedachtnis. *Z. Psychology*, *1*, 1-300.

Nader, K. (2003). Memory traces unbound. *Trends in Neurosciences*, *26*, 65–72.

Nader, K., & Einarsson, E. O. (2010). Memory reconsolidation: An update. *Annals of the New York Academy of Sciences*, *1191*, 27-41.

Nader, K., & Hardt, O. (2009). A single standard for memory: The case for reconsolidation. *Nature Reviews Neuroscience*, *10*, 224–234.

Nader, K., Hardt, O., & Wang, S. H. (2005). Response to Alberini: Right answer, wrong question. *Trends Neuroscience*, *28*, 346–347.

Nader, K., Schafe, G. E., & LeDoux, J. E. (2000). Fear memories require protein synthesis in the amygdala for reconsolidation after retrieval. *Nature*, *406*, 722–726.

Nadel, L., Hupbach, A., Gomez, R., & Newman-Smith, K. (2012). Memory formation, consolidation and transformation. *Neuroscience and Biobehavioral*, *36*, 1640 – 1645.

Nadel, L., Willner, J., & Kurz, E. M. (1985). Cognitive maps and environmental context. In P. D. Balsam & A. Tomie (Eds.), *Context and learning* (pp. 385-406). Hillsdale, NJ: Erlbaum.

Nairne, J. S. (2002). The myth of the encoding-retrieval match. *Memory*, *10*, 389-395.

Nelson, T. O., Narens, L. (1990). Metamemory: a theoretical framework and new findings. In G. Bower (Eds.), *The psychology of learning and motivation, advances in research and theory* (pp. 125-173). San Diego, CA: Academic Press.

Nicholls, M. E. R., Loveless, K. M., Thomas, N. A., Loetscher, T., & Churches, O. (2015). Some participants may be better than others: Sustained attention and motivation are higher early in semester. *Quarterly Journal of Experimental Psychology*, *68*, 10–18.

Pedreira, M. E., Pérez-Cuesta, L. M., & Maldonado, H. (2004). Mismatch between what is expected and what actually occurs triggers memory reconsolidation or extinction. *Learning and Memory*, *11*, 579–585.

Potts, R., & Shanks, D. R. (2012). Can testing immunize memories against interference? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*, 1780–1785.

Przybyslawski, J., Roullet, P., & Sara, S. J. (1999). Attenuation of emotional and non-emotional memories after their reactivation: Role of beta adrenergic receptors. *Journal of Neuroscience*, *19*, 6623-6628.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 29 –37). New York, NY: Appleton-Century Crofts.

Richardson, R., Riccio, D. C., & Mowrey, H. (1982). Retrograde amnesia for previously acquired Pavlovian conditioning: UCS exposure as a reactivation treatment. *Physiology of Psychology*, *10*, 384–390.

Rodriguez, W. A., Horne, C. A., & Padilla, J. L. (1999). Effects of glucose and fructose on recently reactivated and recently acquired memories. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *23*, 1285-1317.

Rodriguez-Ortiz, C. J., De la Cruz, V., Gutierrez, R., & Bermidez-Rattoni, F. (2005). Protein synthesis underlies post- retrieval memory consolidation to a restricted degree only when updated information is obtained. *Learning and Memory, 12*, 533–537.

Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in Cognitive Sciences, 15*(1), 20-27.

Roediger, H. L., & Karpicke, J. D. (2006). The power of testing memory: Basic research and implications for educational practice. *Perspectives on Psychological Science, 1*, 181e210.

Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology-Learning Memory and Cognition*, *21*, 803-814.

Rohrer, D., Wixted, J. T., Salmon, D. P., & Butters, N. (1995). Retrieval from semantic memory and its implications in Alzheimer's disease. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21,* 1127-1139.

Rose, J. K., & Rankin, C. H. (2006). Blocking memory reconsolidation reverses memory-associated changes in glutamate receptor expression. *Journal of Neuroscience*, *26*, 11582-11587.

Sandrini, M., Cohen, L. G., & Censor, N. (2015). Modulating reconsolidation: A link to causal systems-level dynamics of human memories. *Trends in Cognitive Sciences*, *19*(8), 475e482.

Sara, S. J. (2000). Retrieval and reconsolidation: Toward a neurobiology of remembering. *Learning and Memory*, *7*, 73–84.

Schafe, G. E., Nadel, N. V., Sullivan, G. M., Harris, A., & LeDoux, J. E. (1999). Memory consolidation for contextual and auditory fear conditioning is dependent on protein synthesis, PKA, and MAP kinase. *Learning and Memory*, *6*, 97-110.

Schellenberg, E. G. (2004). Music lessons enhance IQ. *Psychological Science*, *15*(8), 511-514.

Schiller, D., Monfils, M.-H., Raio, C. M., Johnson, D. C., LeDoux, J. E., & Phelps, E. (2010). Preventing the return of fear in humans using reconsolidation update mechanisms. *Nature, 463*, 49-54.

Schneider, A. M., & Sherman, W. (1968). Amnesia: A function of the temporal relation of footschock to electroconvulsive shock. *Science, 159*(3811), 219-221.

Schwabe, L., Nader, K., & Pruessner, J. C. (2014). Reconsolidation of human memory: Brain mechanisms and clinical relevance. *Biological Psychiatry*, *76*(4), 274-280.

Schwabe, L., & Wolf, O. T. (2009). New episodic learning interferes with the reconsolidation of autobiographical memories. *PLoSOne*, *4*(10), e7519.

Sederberg, P. B., Gershman, S. J., Polyn, S. M., & Norman, K. A. (2011). Human memory reconsolidation can be explained using the Temporal Context Model. *Psychonomic Bulletin and Review*, *18*, 455-468.

Shimamura, A. P., & Squire, L. R. (1987). A neuropsychological study of fact memory and source amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 464–473.

Simons, J. S., Verfaellie, M., Galton, C. J., Miller, B. L., Hodges, J. R., & Graham, K. S. (2002). Recollection-based memory in frontotemporal dementia: Implications for theories of long-term memory. *Brain*, *125*, 2523–2536.

Skinner, B. F. (1954). The science of learning and the art of teaching. *Harvard Educational Review, 24,* 86-97.

Sloboda, J. A., & O'Neill, S. A. (2001). Emotions in everyday listening to music. In P. N. Juslin & J. A. Sloboda (Eds.), *Series in affective science. Music and emotion: Theory and research* (pp. 415-429). New York, NY, US: Oxford University Press.

Smith, S. M. (1985). Environmental context and recognition memory reconsidered. *Bulletin of the Psychonomic Society*, *23*, 173-176.

Smith, S. M. (1988). Environmental context-dependent memory. In G. M. Davies and D. M. Thomson (Eds.), *Memory in context: Context in memory* (pp. 13-34). New York: Wiley.

Smith, S. M., & Vela, E. (1992). Environmental context-dependent eyewitness recognition. *Applied Cognitive Psychology*, *6*, 125-139.

Smith, S. M., Vela, E., & Williamson, J. E. (1988). Shallow input processing does not induce environmental context-dependent recognition. *Bulletin of the Psychonomic Society*, *26*, 537-540.

Soeter, M., & Kindt, M. (2011). Disrupting reconsolidation: Pharmacological and behavioral manipulations. *Learning and Memory*, *18*(6), 357-366.

Solheim, G. S., Hensler, J. G., & Spear, N. E. (1980). Age-dependent contextual effects on short-term active avoidance retention in rats. *Behavioral and Neural Biology*, *30*(3), 250-259.

Spear, N. E. (1976). Retrieval of memory: A psychobiological approach. In W. K. Estes (Ed.), *Handbook of learning and cognitive processes: Vol. 4. Memory processes* (pp. 17-90). Hillsdale, NJ: Erlbaum.

Spear, N. E., Lewis, D. J., Mcgaugh, J. L., & Ralph, R. (1973). Retrieval of memory in animals. *Psychological Review*, *80*(3), 163–194.

Spear, N. E., & Mueller, N. E. (1984). Consolidation as a function of retrieval. In H. Weingartner & E. S. Parker (Eds.), *Memory consolidation: Psychobiology of cognition* (pp. 111-147). Hillsdale, NJ: Erlbaum.

Squire, L. R., & Alvarez, P. (1995). Retrograde amnesia and memory consolidation: A neurobiological perspective. *Current Opinion in Neurobiology*, *5*, 169-177.

Stalder, D. R. (2005). Learning and motivational benefits of acronym use in introductory psychology. *Teaching of Psychology*, *32*, 222–228.

Sternberg, R. J. (1999). A propulsion model of types of creative contributions. *Review of General Psychology*, *3*, 83–100.

Suzuki, A., Josselyn, S. A., Frankland, P. W., Masushige, S., Sliva, A. J., & Kida, S.(2004). Memory reconsolidation and extinction have distinct temporal and biochemical signatures. *Journal of Neuroscience*, *10*, 423-433.

Tamminen, J., Darby, J., Rastle, K., & Williamson, V. J. (2015). The impact of music on learning and consolidation of novel words. *Memory*, *25*(1), 107-121.

Taubenfeld, S. M., Milekic, M. H., Monti, B., & Alberini, C. M. (2001). The consolidation of new but not reactivated memory requires hippocampal C/EBPβ. *Nature Neuroscience*, *4*, 813–818.

Tronson, N. C., & Taylor, J. R. (2007). Molecular mechanisms of memory reconsolidation. *Nature Reviews Neuroscience*, *8*, 262-275.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory*, (pp. 381–403). New York: Academic Press.

Tulving, E. (1983). *Elements of episodic memory*. Oxford: Clarendon Press.

Tulving, E. (1984). Relations among components and processes of memory. *Behavioral and Brain Sciences*, *7*, 257-268.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychological Association*, *26*,1–12.

Tulving, E. (1993). What is episodic memory? *Perspectives on Psychological Science*, *2*, 67-70.

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology*, *53*, 1-25.

Tulving, E., Kapur, S., Craik, F. I., Moscovitch, M., & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proceedings of the National Academy of Sciences of the United States of America*, *91*, 2016-2020.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, *80*, 352-373.

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2012). Dynamics of context-dependent recall: an examination of internal and external context change. *Journal of Memory and Language*, *66*, 1-16.

Van Schie, K., Van Veen, S. C., Van Den Hout, M. A., & Engelhard, I. M. (2017). Modification of episodic memories by novel learning: A failed replication study. *European Journal of Psychotraumatology*, *8,* sup 1.

Walker, M. P., Brakefield, T., Hobson, J. A., & Stickgold, R. (2003). Dissociable stages of human memory consolidation and reconsolidation. *Nature*, 425, 616–620.

Wallace, W. T. (1994). Memory for music: Effect of melody on recall of text. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(6), 1471-1485.

Wheeler, M. A., Ewers, M., & Buonanno, J. F. (2003). Different rates of forgetting following study versus test trials. *Memory, 11*, 571-58.

Wheeler, M. A., Stuss, D. T., & Tulving, E. (1995). Frontal lobe damage produces episodic memory impairment. *Journal of the International Neuropsychological Society*, *1*, 525–536.

Wichert, S., Wolf, O. T., & Schwabe, L. (2011). Reactivation, interference, and reconsolidation: Are recent and remote memories likewise susceptible? *Behavioral Neuroscience*, *125*, 699–704.

Wichert, S., Wolf, O. T., & Schwabe, L. (2013). Updating of episodic memories depends on the strength of new learning after memory reactivation. *Behavioral Neuroscience*, *127*, 331–338.

Wilkes, A. L., & Leatherbarrow, M. (1988). Editing episodic memory following the identification of error. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *52A*, 165-183.

Wiltgen, B. J., & Silva, A. J. (2007). Memory for context becomes less specific with time. *Learning & Memory, 14*, 313–317.

Wood, N. E., Rosasco, M. L., Suris, A. M., Spring, J. D., Marin, M. F., Lasko, N. B....Pitman, R. K. (2015). Pharmacological blockade of memory reconsolidation in posttraumatic stress disorder: Three negative psychophysiological studies. *Psychiatry Research*, *225*(1), 31-39.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language*, *46*, 441–517.