ROLE OF MODALITY, REPETITION AND AGE IN RECOGNITION MEMORY

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ABSTRACT

Recognition memory is a part of declarative memory; defined as the ability to discriminate previously presented stimuli from novel stimuli (Squire, Wixted & Clark, 2007). This thesis reports eight experiments that investigated factors that modulate recognition memory using a recognition memory paradigm that reflects the space learning effect (Greene, 1989) and repetition. Results from chapter two varied the space between stimuli repetition across two presentations and found that stimuli that is repeated following a short delay, and then repeated again following a longer delay led to poorer recognition memory compared to other variations. Additionally, results showed impaired recognition for older adults compared to younger adults for first repetition, but not for the second repetition, where no age effects were found (Experiment 1). Electroencephalography (EEG) technique (Experiment 2) examined the old/new effects (higher mean amplitude for *old* items compared to *new* items) pertaining to familiarity, recollection and post-retrieval monitoring through the three signatures commonly found in recognition memory, i.e. FN400, late positive component (LPC) and the late frontal effect (LFE) respectively to understand the underlying processes that supports repetition. Contrary to prior research, results showed an absence of the FN400 and LPC effect. However, with respect to the LFE, there was a reverse old/new effect in the left anterior superior (LAS) region for stimuli repeated for the first time which can be attributed to decision making, memory evaluation, and confidence in line with past literature (Allan et

al, 1998; Ally & Budson, 2007; Ally et al. 2008; Dobbins & Han, 2006; Fleck, Daselaar, Dobbins & Cabeza, 2006).

Chapter 3 investigated the effects of uni-modal (auditory or visual presented alone) and multi-modal stimuli, i.e. auditory and visual modality presented together (cross-modal), on recognition memory. The results show that unlike visual and cross-modal memory retrieval, repetition does not facilitate auditory recognition memory. The results also show that participants have higher *d'* scores in the cross-modal stimuli compared to uni-modal stimuli (experiment 3). Although older participants show benefits with cross-modal stimuli, and with repetition, they still performed poorer compared to their younger counterparts (experiment 4).

Chapter four investigated semantic congruency of multi-modal pairs in recognition memory. The results show that this effect only lasts for the first repetition and is absent for subsequent repetitions, for both older and younger adults (experiment 5). ERP results showed the presence of the FN400 old/new effect for trials repeated for the second time in the LAS region indicating recognition may be supported by familiarity for items repeated for the second time. In contraction to past research, there was no LPC or the LFE effects seen (experiment 6).

Lastly, chapter five focuses on recognition memory in relation to modality mismatch. Modality mismatch is a situation that arises when information is encountered in a different modality compared to when it was initially presented (Mulligan & Osborn, 2009). The results from chapter five shows that auditory modality impairs recognition when it is either presented initially, or after a short delay. However, auditory presentations with a semantically associated pair (visual), either at initial presentation, or only if its pair was encountered after a short delay, there was no significant effect of modality mismatch at long delay (experiment 7). Results showed an absence of the FN400 effect indicating that FN400 effect is sensitive to perceptual match in line with Tsivilis et. al (2001). Lastly, experiment 8 showed that in the presence of modality mismatch, ERP results suggest that participants may rely on recollection to guide recognition process as seen by the presence of the LPC effect. Furthermore, the LPC also seems to index the amount of information to be retrieved consistent to past research (Fjell, Walhovd & Reinvang, 2005; Vilberg, Moosavi & Rugg, 2006), whereby larger amplitude were seen when the trial was in the cross-modal format compared to uni-modal format. As for the LFE component, the presence of the larger mean amplitude in the superior regions for uni-modal trials repeated for the second time suggests further post-retrieval monitoring associated with retrieval of additional information presented initially.

Overall findings of this thesis have explored the factors that affect recognition memory, namely repetition, modality and age, and attempted to determine the underlying processes supporting recognition memory when items are repeated, or pairs of stimuli are semantically associated or modality is mismatched during encoding. This is particularly implicated in learning environments, providing further understanding in how repetition can enhance memory and its effects in environments where incongruent information is received, or repeated information encountered in a different modality.

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LIST OF ABBREVIATIONS

A|C-M|V	Auditory|Cross-modal|Visual
BDI	Beck's depression inventory
C-M|A|V	Cross-modal|Auditory |Visual
C-M|V|A	Cross-modal|Visual|Auditory
d'	d prime
DPSD	Dual process signal …
EEG	Electroencephalography
ERP	Event-related potentials
fMRI	Functional magnetic resonance imaging
FN400	Frontal negativity
GDS	Geriatric depression scale
LAI	Left anterior superior
LAS	Left anterior superior
LEA	Lateral entorhinal area
LFE	Left frontal effect
LPC	Late parietal component
LPI	Left posterior inferior
LPS	Left posterior superior
LRLL	Long retention- long lag
LRSL	Long retention-short lag
MEA	Medial entorhinal area

mPFC	Medial prefrontal cortex
MTL	Medial temporal lobe
PHC	Parahippocampal cortex
PRC	Perirhinal cortex
R1	1st repetition
R2	2nd repetition
RAI	Right anterior inferior
RAS	Right anterior superior
RPI	Right posterior inferior
SRLL	Short retention-long lag
SRSL	Short retention-short lag
V|C-M|A	Visual|Cross-modal|Auditory

CHAPTER 1

GENERAL INTRODUCTION

1.1 Recognition memory

Recognition memory (a form of episodic memory) concerns being aware of previously encountered information (Mechlinger & Jäger, 2009; Squire, Wixted & Clark, 2007) and can be defined as the ability to discriminate previously presented stimuli from those that were not previously presented (Squire et al., 2007).

Two processes referred to as familiarity and recollection have been shown to support recognition memory (see Eichenbaum, Yonelinas, & Ranganath, 2007; Mecklinger & Jäger, 2009; Paller, Voss, & Boehm, 2007; Wixted, Mickes, & Squire, 2010). Familiarity refers the feeling of ‘knowing’ that the information has been encountered previously, but further information on the episodic context are not retrievable. In contrast, recollection refers to the ability to remember further contextual information of the previously encountered stimuli. Rugg and Curran (2007) define recollection as recognition accompanied by correct source memory, while familiarity is information that supports recognition, without any information about the source. In addition, while recollection is slow acting and requires effort to retrieve context, familiarity is fast acting and relatively automatic.

1.1.1 Models of recognition memory

According to a review of the literature by Wixted (2007), there are two prominent theories of recognition memory. One of the theories, known as the Dual-Process theory (Hintzman & Curran, 1994; Jacoby, 1991; Mandler, 1980) views recognition memory as consisting of two independent processes of recollection and familiarity. Evidence using electroencephalography (EEG) methods have clearly separated test items that elicit familiarity and recollection, using procedures such as remember/know and confidence judgments (see section 1.1.3 for further details on these methods) and have found that familiarity and recollection are two distinct processes (Woodruff, Hayama, & Rugg, 2006). Taken together with neuroimaging evidence by Yonelinas, Otten, Shaw and Rugg, (2005), familiarity and recollection were found to depend on independent brain regions. In the aforementioned study, participants made recognition judgments to words presented during study phase based on recollection or confidence based familiarity judgments. Correctly recognized words that were successfully recollected evoked activity in separate brain regions compared to correctly recognized words that were judged to be familiar. Specifically, recollection was shown to increase activity in the anterior medial prefrontal cortex, lateral parietal cortex, posterior cingulate, and hippocampus. On the other hand, increasing activity in the lateral prefrontal cortex, superior lateral parietal cortex, and precuneus was found to be associated with increasing confidence in familiarity judgments. This provides clear evidence to support the notion that recollection and familiarity rely on very distinct neural systems.

In contrast, the signal-detection theory (see Wixted, 2007) views recognition as a continuous variable where memory strength (e.g., ranging from weak memory signal to strong memory signal) accounts for the discrimination between new and old items. When a repeated item is encountered, if it elicits a memory signal that exceeds a certain criterion, it will be successfully recognized as '*old*'. Otherwise, it will be declared as '*new*' (see review by Yonelinas, 2002).

The signal detection theory views memory as a uni-dimensional process, while the dual-process posits that memory is composed of two distinct processes (Wixted, 2007). One of the more important and latest views that reconcile these two theories is known as the dual process signal detection model (DPSD) (Wixted, 2007); where recollection is viewed as a high-threshold categorical process where if memory strength exceeds a high criterion, recollection occurs where the participant will be able to recollect the specific details of the stimuli. On the other hand, familiarity was seen as continuous process that is only engaged when memory strength is not strong enough to elicit a recollection process (Yonelinas, 1994; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). This model, has gained much influence in psychology and in studies of cognitive neuroscience (See review by Wixted, 2007; Yonelinas, 2002).

While there has been much debate over the various models of recognition memory in terms of how familiarity and recollection contributes to recognition memory, it is widely accepted that recognition composes of both the processes of familiarity and recollection, which support the process of how an item is recognized (Wixted, 2007).

1.1.2 Functional organization of recognition memory

Much research has shown that recognition memory is supported by the medial temporal lobe, with familiarity and recollection being mediated by different structures in the medial temporal lobe (MTL) (see Eichenbaum et al., 2007; Kafkas & Montaldi, 2012;

Ranganath et al., 2004). More specifically, the hippocampus and parahippocampal cortex mediates recollection, while the perirhinal cortex mediates familiarity (Eichenbaum et al., 2007; Kafkas & Montaldi, 2012; Ranganath et al., 2004). **Figure 1-1** below shows the hypothetical functional organization with the major sub-regions of the MTL involved in memory processing.

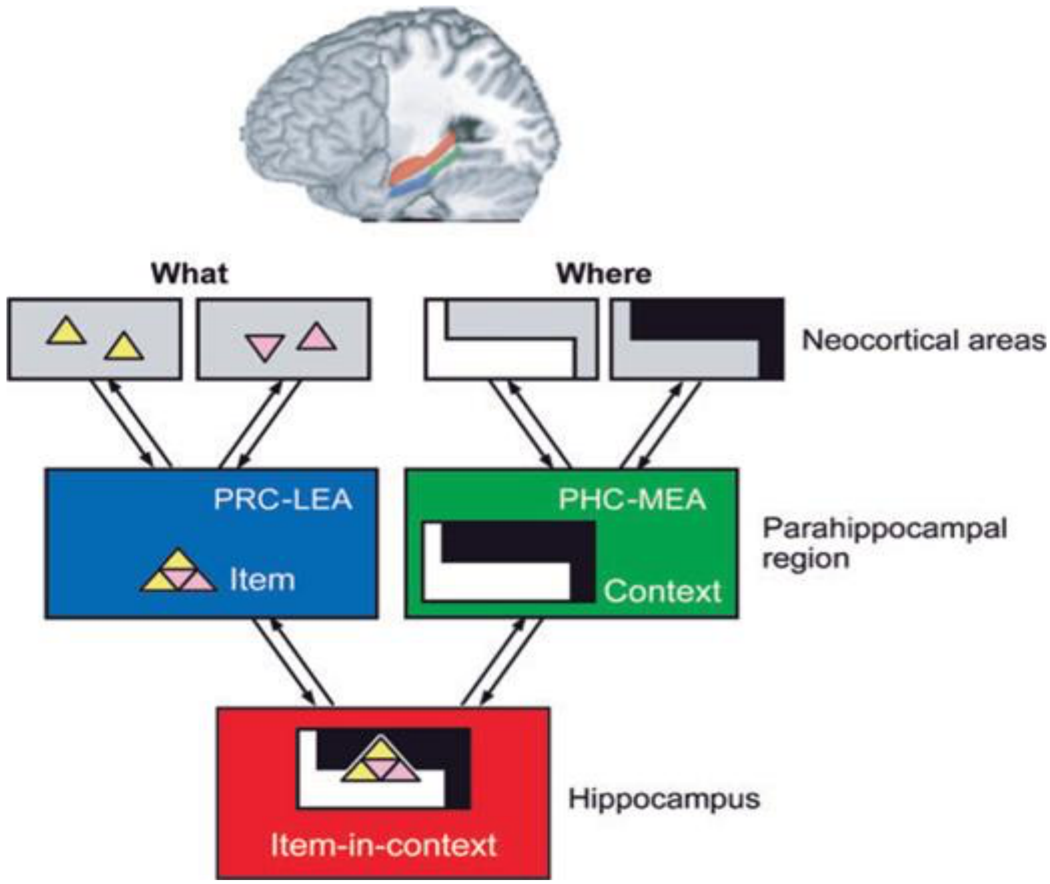

Figure 1-1: Hypothetical functional organization with sub regions of the MTL. Based on this model, information regarding object features, i.e. the context information or "what" information converges in the perirhinal cortex (PRC) and lateral entorhinal area (LEA) (PRC-LEA); while spatial information, i.e the "where" converges in the parahippocampal cortex (PHC) and the medial entorhinal area (MEA) (PHC-MEA). These two lines of information converge in the hippocampus. Reverse projections also occur where back projections to the PRC-LEA or the PHC-MEA results in the experience of recognition (Adapted from Eichenbaum et al., 2007).

The medial temporal lobe can be subdivided into the parahippocampal region (which consist of the perirhinal cortex (PRC), the entorhinal cortex and the parahippocampal cortex (PHC) and the hippocampus. The association areas responsible for processing the sensory information regarding the quality of a particular object, otherwise known as the 'what' information, sends this information to the PRC, whereas the neocortical areas sends information regarding spatial information, otherwise known as 'where' information to the PHC. Information regarding the qualities and the spatial properties of items remain segregated in the PRC and the PHC respectively. The PRC projects mainly to the lateral entorhinal areas (LEA), whereas the PHC projects mainly to the medial entorhinal area (MEA). Information regarding the quality and spatial properties, i.e. the 'what' and 'where' information then converges in the hippocampus.

Eichenbaum et al. (2007) elaborated that memory process is a two-way pathway where the hippocampus feeds information back to the entorhinal cortex, then to the perirhinal and parahippocampal cortices and finally to the neocortical association areas. For instance, when the same stimulus is encountered again, the PRC and the LEA will assess for a match to a previous template, and if there is a match, the signal will then be sent to the neocortical association areas, bringing about the sense of familiarity, without the recall of context, or the participation of the hippocampus. Furthermore, encountering the stimulus again can also cause the object-context association in the hippocampus to reactivate the representation of these associations in the PHC and the MEA, thus sending this information to the neocortical association areas that processed the spatial information initially, consequently resulting in recollection. This model is also referred to as the Binding of Item and Context (BIC) model (Diana, Yonelinas, & Ranganath, 2007) and has formed the basis of much research relating to MTL function and memory (de

Vanssay-Maigne et al., 2011; Kafkas & Montaldi, 2012; Montaldi & Mayes, 2010; Ranganath et al., 2004).

While the hippocampus is widely believed to be involved in recollection, its role in familiarity has been the subject of much disagreement. Wixted and Squire (2010) argued that studies that found the exclusive role of the hippocampus in recollection were confounded by memory strength when familiarity and recollection was viewed as a continuum representing memory strength, where weak memories are seen as familiarity, and strong memories seen as recollection (Squire, Wixted, & Clark, 2007; Wixted & Squire, 2010). However, when this memory strength is controlled (by comparing strong recollection with strong familiarity), there is evidence that the hippocampus is involved in both recollection and familiarity (Jeneson, Kirwan, Hopkins, Wixted, & Squire, 2010; Smith, Wixted, & Squire, 2011; Wais, Wixted, Hopkins, & Squire, 2006; Wixted & Squire, 2010). However, more research is needed in this area to resolve this disagreement, as studies where memory strength was controlled for even when strong familiarity was evoked, undetected recollection may have also occurred consequently resulting in hippocampal activity (Wixted & Squire, 2010). Additionally, when the memory strength was controlled for, Kafkas and Montaldi (2012) still found the hippocampus and the PRC plays contrasting roles in supporting recognition memory.

1.1.3 Recognition memory paradigms

Recognition memory has typically been tested via two paradigms, known as continuous recognition paradigm, and study/test recognition paradigm. In a continuous recognition task (eg. Lehmann & Murray, 2005; Thelen, Cappe, & Murray, 2012), items are presented continuously, with repeating items intervening at varying or fixed intervals.

Participants are asked to continuously discriminate whether the item is "*new*", i.e appearing for the first time, or that it is "*old*", i.e. repeated. In contrast, in the study/test paradigm (e.g., Ally and Budson, 2007; Curran & Cleary, 2003), the study phase and the test phase are distinct. In the study phase, participants are exposed to items (presented for the first time), and the test phase consists of some of the items that were in the study phase, as well as previously unseen filler items. Participants are then required to discriminate repeated items from new items.

In terms of differentiating between recollection and familiarity, some paradigms employ confidence assessments; remember/know procedure or recalling some aspect of the source material. In a related study by Woodruff, Hayama and Rugg, (2006), participants had to indicate how confident they were that an item is new or old, based on a scale that ranges from a minimum of 1 (Sure New) to a maximum of 5, 6 or 7 (Sure Old). According to the authors, if participants indicated an item as "old" and gave the maximum rating, they are using recollection, but if they give a lower confidence rating then they are relying on the process of familiarity. As for remember/know procedure, in a study by Leynes, Bink, Marsh, Allen and May (2003), after participants correctly discriminated an item is 'old', they were required to indicate if they 'remember' or 'know' that the item is old. 'Remember' indicates recollection, whereas 'knowing' indicates familiarity. Lastly, in some study designs, such as in Wilding and Rugg (1998), participants were required to indicate whether the item was spoken in a male voice or female voice as source information after making an old/new discrimination. Recollection would be classified as correct recognition and correct source information, while familiarity would be classified as correct recognition, but incorrect source information.

1.1.4 Factors affecting recognition memory

1.1.4.1 *Space effect*

The space effect coined by Ebbinghaus (1885) posits that items learned over a longer time interval leads to better learning compared to material learned in short intervals, otherwise known as mass learning (Greene, 1989). Much research has consistently highlighted the benefits of space learning over massed learning (e.g. Benjamin & Tullis, 2011; Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008).

One of the earlier explanations for the space effect was offered by Hintzman (1974) who reasoned that subjects pay less attention to items when they are massed (presented after a short interval) compared to when they are spaced, consequently leading to poorer processing and thus, poorer memory performance. This is also known as the deficient processing hypothesis. One explanation as to why mass presentation hinders memory is due to repetition priming and suppression (see Toppino, Fearnow-Kenney, Kiepert, & Teremula, 2009). With repetition, less neuronal activation will be observed with repeated stimuli compared to novel stimuli due to repetition suppression, thus processing strength for subsequent items is reduced. However, when items are spaced, repetition suppression can be overcome, thus leading to higher processing of items, resulting in better memory performance.

Neurophysiological and neuroimaging data has tested deficient processing hypothesis by exploring this mechanism deeper (James, Morand, Bareellona-Lehmann, Michel, & Schnider, 2009; Van Strien, Verkoeijen, Van der Meer, & Franken, 2007; Zhao, Wang, Liu, Xiao, & Jiang, 2014). For instance, James et al. (2009) found that it was not just that participants were paying less attention to massed items that was leading to the poorer memory performance, but the mass presentation was interfering with long-term consolidation. Participants were presented with pictures in a continuous recognition task and the items were repeated immediately (massed), or after 9 intervening items (spaced) while EEG was recorded. Although recognition accuracy was higher for pictures repeated immediately compared to after 9 intervening items; following a 30-minute interval, participants had difficulty retrieving these immediately repeated pictures. However they were more likely to recognize the pictures that were repeated after 9 intervening items. Additionally, the EEG data showed that immediate repetition evoked activity in the MTL and this brain structure is known to be crucial for successful recognition performance. As participants exposed to massed repetition engages its activity, this consequently interfered with the process of consolidation into long-term memory. Hence, although immediate repetition improves recognition, it comes at a cost of long-term memory consolidation, as items that are repeated at a longer interval are better remembered compared to items that are repeated at a shorter interval.

In a related study by Van Strien et al., (2007); participants made old/new discriminations to words presented in massed repetitions (immediate) or spaced (6 intervening words) repetition. They were then administered with a free recall task. Results showed that in the continuous recognition task, participants were quicker and more accurate for items that were in the massed condition compared to items in the spaced condition. However, in the free recall task, participants recalled significantly higher number of words in the spaced repetition condition compared to massed words. Integrating findings from the event related potential (ERP) results showed that compared to spaced repetition, massed repetition leads to more automatic and less controlled processing (or deficient processing). Additionally time-frequency analysis revealed that massed repetition resulted in greater theta band power which reflects short-term storage resulting in better recognition; however due to the lack of additional elaboration seen with spaced repetition, delayed free recall was affected. On the other hand, the decrease in upper alpha power was seen with spaced repetition is thought to be associated with elaborate encoding after word retrieval, which contributes to better delayed recall. Furthermore, in the same study, participants were also quicker to respond to classifying massed words compared to spaced words. They argue that this was due to a strong and fast match to the template already present in short term memory store, where unlike spaced repetition, the template exists in long-term store and the appropriate template will replace the latest template. In the context of pattern recognition, exposure to a stimuli would result in a representation of the stimuli stored in memory, much like 'templates' (Lutz & Huitt, 2003). Here, subsequent encounter to the same stimuli would result in an attempt to match this stimuli to a 'templates' already stored in memory, where successful matching will result in recognition.

In a more recent study, Zhao et al. (2014) investigated neuro-imaging and electrophysiological correlates on the space effect using Chinese characters in Chinese speakers. These words were presented visually at two types of repetitions; either spaced (S1, S2, S3) at 25 to 35 items or massed repetitions (M1, M2 and M3) at 1-3 inter-item intervals. See **Figure 1-2** for an illustration of the experimental procedure.

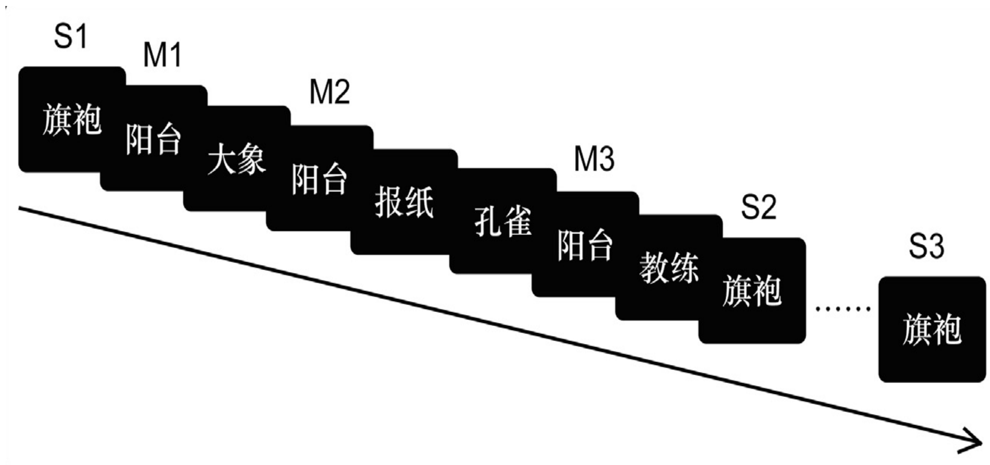

Figure 1-2: The experimental procedure for the study by Zhao et al. (2014). The English translations of Chinese words in the figures are, from left to right, cheongsam, balcony, elephant, balcony, newspaper, peacock, balcony, coach, cheongsam, cheongsam. S denotes spaced repetition, while M denotes massed repetition, whereas the numbers 1, 2 and 3 refers to the number of times the item was presented. For example, S1 refers to stimuli presented for the first time, which will later be repeated after a long interval (25-35 items) at S2 and again at S3 after a similarly long delay. M1 refers to stimuli presented for the first time, which will later be repeated after a short interval (1-3 items) at M2 and again at M3 (Adapted from Zhao et al., 2014).

In the encoding phase, participants made living/non living judgments for each presented word. One day later, participants were tested via a recognition memory test. Results found that participants' memory were enhanced with spaced repetitions compared to massed repetitions. Additionally, two separate experiments using EEG and fMRI found that with respect to electrophysiological data, spaced stimuli recorded a reduced familiarity event related potential (ERP) effect indicating weaker retrieval strength. With respect to fMRI results, spaced stimuli resulted in a greater neural response in regions related to memory, specifically the left fusiform, left superior parietal lobule and the orbitofrontal cortex. This indicates that spacing reduces the retrieval process, but enhances the encoding process, consequently resulting in greater storage strength (Zhao et al., 2014).

1.1.4.2 *Modality*

The human senses consist of five main types of modalities, ie visual, auditory, olfaction, tactile and taste; and in everyday life we are exposed to all these different sources of information. The traditional view holds that vision is the more dominant sensory modality in people with no sensory impairments, in terms of captivating attention (Posner, Nissen, & Klein, 1976). Earlier experiments established a bias to respond to visual sensory information rather than to auditory information. An early study by Colavita (1974) tested participants ability to discriminate auditory (tone) and visual (light) by pressing the 'tone' key or 'light' key. In addition to uni-modal tones/light stimuli, bimodal stimuli (tones and light presented together) were also presented. Participants were more likely to hit the 'light' key, while ignoring the auditory stimuli, lending researchers to believe there is a bias or dominance towards visual information when visual and auditory information are presented together. This effect has subsequently been termed the Colavita visual dominance effect, showing robust findings across many experiments.

In the context of recognition memory, recent studies have compared recognition memory performance across different modalities to show that auditory recognition memory is generally poorer compared to visual (Cohen, Horowitz, & Wolfe, 2009) and even tactile (Bigelow & Poremba, 2014). For instance Cohen et al. (2009) found auditory recognition memory for a range of sounds (e.g., complex auditory sounds, such as talking in a pool; to isolated sounds, such as dog barking) to be generally poorer compared to visual memory. Recognition memory performance did not improve even when pairing these sounds to pictures during the encoding stage. Furthermore, a study by Bigelow &

Poremba (2014) compared visual (videos of scenes and events), auditory (complex everyday sounds) and tactile (common physical objects hidden from view presented to participants to touch and manipulate) recognition memory and found that performance on recognition memory for auditory stimuli was significantly poorer compared to visual and tactile modality when tested the next day, and even one week later; with no significant difference in recognition memory performance between visual and tactile modalities.

However, in everyday life, we do not process incoming information independently. Information is typically presented in many modalities comprising of visual, auditory, tactile, olfactory etc. As such, it is possible that we have evolved to receive and operate on information presented in multi-sensory environments (Shams & Seitz, 2008). It is only in the past decade, much research has been dedicated into understanding cross-modal interactions, which has shed light on the influences of other sensory modalities on visual perception and processing (Shams & Kim, 2010) which will be explored in the next section.

1.1.4.3 *Multisensory integration*

Our interaction with the world depends on successful integration of information from the various senses (such as vision, audition, tactile and olfaction) also known as multisensory integration and this has an effect on our perception, decisions and behavior (Cappe, Rouiller, & Barone, 2009; Stein, Stanford, & Rowland, 2009). The different sensory modalities provide additional, complementary information about an object which can enhance perception and also lead to faster, more accurate recognition, detection and classification (Amedi, Von Kriegstein, Van Atteveldt, Beauchamp, & Naumer, 2005; Calvert et al., 1999; Cappe et al., 2009).

The importance of multisensory integration in enhancing perception in daily functioning with better accuracy can be seen in many aspects of life. For example, in a lecture, the use of visual aids along with a lecturer speaking can facilitate not only perception, but also understanding. Similarly, a novice learning a new language has an easier time if they are talking to someone face-to-face compared to over the telephone.

Classical views of multisensory integration posits the different sensory systems converge into the polysensory associative areas of the frontal, temporal and parietal lobes (Cappe et al., 2009). This view holds that that multisensory integration is dependent on information from sensory-specific cortices. This sensory-specific information are merged to form a unified percept in the specialized higher-level association cortices in the frontal, temporal or parietal cortices (See reviews by Cappe et al., 2009; Ghazanfar & Schroeder, 2006; Murray et al., 2015).

However, this view that multi-sensory integration takes place exclusively at higher-level association areas has been challenged as evidence drawn from neuroimaging data supports the idea that multisensory integration also takes place by sharing the information between lower-level uni-sensory cortices that were traditionally thought to be uni-sensory (Amedi, Malach, Hendler, Peled, & Zohary, 2001; Calvert et al., 1999; Foxe et al., 2002; von Kriegstein, Kleinschmidt, Sterzer, & Giraud, 2005).
Electrophysiological data, using EEGs have also recorded multisensory integration at short latencies (evidence of early processing) in sensory specific cortical structures (Foxe et al., 2002; Giard & Peronnet, 1999; Molholm et al., 2002; Murray et al., 2005). The

implication of these early sensory effects in multisensory interactions strongly suggest a pathway mediated by direct heteromodal connections (see review by Cappe et al., 2009).

Reviewing evidence from neurobiological studies, it has been argued that the neocortex is essentially multisensory, organized to maximize the processing of sensory inputs to facilitate a cohesive and unified perception of the world (see reviews by (Atteveldt, Murray, Thut, & Schroeder, 2014; Ghazanfar & Schroeder, 2006; Schroeder & Foxe, 2005a). **Figure 1-3** below illustrates the cortical loci involved in multisensory processes.

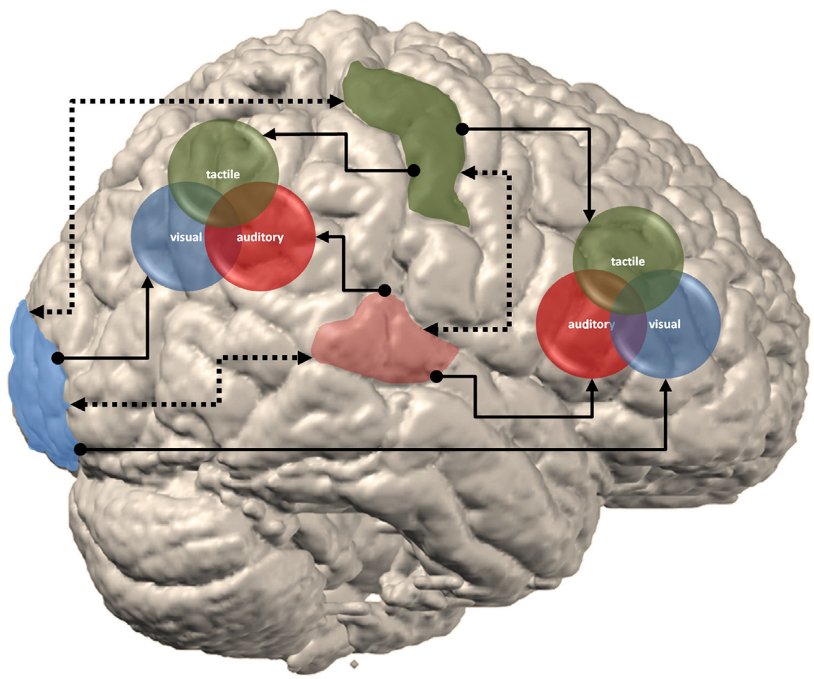

Figure 1-3: The blue region represents the visual cortex; red region represents the auditory cortex; and green region represents the somatosensory cortex. The coloured disk represents the higher order association cortices. The occipital lobe is shown on the left side, with the frontal lobe in on the right side. The higher order association cortices are depicted as superimposed coloured discs (Adapted from Murray et al., 2015)

The solid lines (as indicated in **Figure 1-3**) represent where the lower-level information is restricted to higher order association cortices in the parietal and prefrontal cortices. For instance, low-level information in the visual cortex (blue shade) is subjected to processing in the higher order visual association cortex (blue disc); low-level information in the auditory cortex (red shade) is subjected to processing in the higher auditory association cortex (red disc). The dotted lines depict where interactions can also occur directly between the low-level cortices.

Murray et al. (2015) argue that the claim by Ghazanfar & Schroeder (2006) that the neocortex is essentially multisensory is yet to be substantiated. Based on brain imaging and brain mapping it is clear that visual cortex is multisensory and has an effect on behavioral responses. Studies using fMRI and PET have shown convergence and integration in the primary visual cortex; electroencephalography, magnatoencephalography and trancranial magnetic stimulation methods that have demonstrated the role of the primary visual cortex in multisensory integration in early post-stimulus stages, as well as its impact on behavior and perception (See review by Murray et. al., 2015).

Research on multisensory integration in recognition memory has suggested that information presented in two modalities (also known as cross-modal) leads to faster response times and higher accuracy in uni-sensory discrimination during a continuous recognition task (Lehmann & Murry, 2005). Lehmann and Murray (2005) investigated the effects of multisensory experience on visual recognition memory discrimination. The experimental paradigm consisted of two blocks, made up of auditory trials and somatosensory trials. In the auditory block, participants were presented with either visual image alone (V) or visual images paired with a brief 1000 Hz tone (AV). All repeated presentations were uni-sensory, presented in the visual modality alone, hence there were two conditions (V- and V+). The somatosensory block was similar to the auditory block, except that instead of the tones, a somatosensory pulse was delivered using a conduction vibrator held between their thumb and index fingers was paired with the visual images (SV). **Figure 1-4** below illustrates the experimental paradigm of the study.

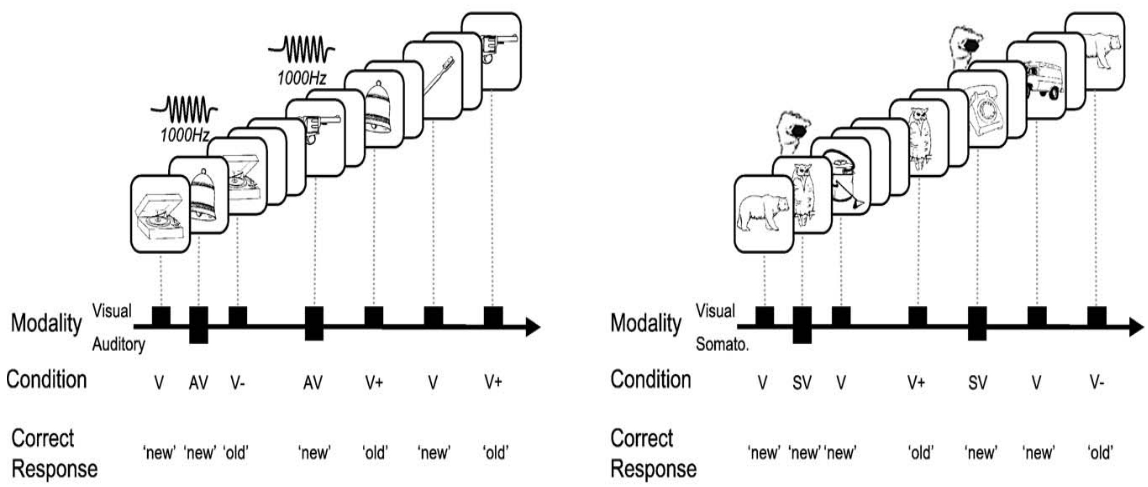

Figure 1-4: Experimental paradigm of the study by Lehman & Murray (2005) exploring multisensory integration of visual and auditory (AV) stimuli are presented in the left panel; wheras the multisensory integration of visual and somatosensory stimuli (SV) are presented in the right panel. V: new items in visual modality; AV & SV: new items in cross-modal modality; V-: repeated V items in unimodal modality; V+: repeated cross-modal items in unimodal modality (adapted from Lehman & Murray, 2005)

Lehman & Murray (2005) found that when 'new' items were multisensory for both the auditory and somatosensory conditions, participants responded faster. However, there were no differences in response time for repeated items. With respect to accuracy, participants made more errors when initial presentation was paired with a tone, rather than just images alone. However, there were no significant differences in accuracy rates for the somatosensory condition.

1.1.4.4 *Semantic congruency*

While the presence of multisensory stimuli has been established to have an effect on performance compared to uni-sensory stimuli, it is important that these multisensory information be semantically congruent, or related in some meaningful way to facilitate performance. This is known as the congruency effect, referring to the finding that information presented in a semantically compatible context, or that fit preexisting information is better remembered compared to information presented in a semantically incompatible context (Bein et al., 2015; Craik & Tulving, 1975; Maril et al., 2011; Schulman, 1974; Staresina, Gray, & Davachi, 2009).

The role of semantic relatedness or congruency has been emphasized in many cognitive theories which argue that semantically congruent information plays a crucial role in the formation of an elaborate memory trace, thereby facilitating the retrieval process. One of the earlier and most prominent views that explains the congruency effect, is referred to as the 'depth-of-processing effects' (F. I. M. Craik & Tulving, 1975). The 'depth-of-processing effects' also referred to as the level of processing framework, which basically views that episodic memory is an automatic processes and the strength of memory trace laid down depends on how deeply one processes the information. The greater the degree of semantic processing, the more elaborate the memory trace laid down facilitating retrieval (F. I. M. Craik & Tulving, 1975; Moscovitch & Craik, 1976). An early example of this is Schulman's (1974) study on congruency, where words that were processed in the context of a congruent encoding question (eg. is DOG an animal?) led to better memory compared to words that were processed in the context of an incongruent encoding question (is DOG a type of plant?).

Another prominent view explaining semantic processing is the Spreading Activation (SA) model (Anderson, 2013; Collins & Loftus, 1975). In this model, concepts are arranged in semantic memory as single units or 'nodes', linked to each other in an interconnected semantic structure. Semantically related concepts are arranged closer together compared to semantically unrelated concepts. When one concept is activated, this activation spreads to the surrounding concepts, raising its activity level of the surrounding concepts above its baseline activity. Thus, the level of activation needed to activate those concepts is less than what is needed to bring it above threshold for processing (Lerner, Bentin, & Shriki, 2012). When one encounters information that is semantically congruent (eg. *Monkey* & *Banana*), according to the SA model, the concept of *Monkey* will be activated and this will also activate the concept of *Banana*, increasing its activity level above baseline. Similarly, the activation of the concept of *Banana*, will cause the spreading of activation to the concept of *Monkey*, thus the activation of the two concepts are enhanced for semantic processing due to their shared activation. In contrast, when presented with incongruent information (eg. Monkey and Tea), the activating the concept of *Monkey* will not cause the activation to spread to the concept of *Tea*, and vice versa due to their semantic distance. Hence, the level of activity for both the concepts may be elevated independently, but not to the same extent as when the information is congruent, which in turn can facilitate recognition.

Studies on recognition memory using continuous recognition tasks have found that congruently paired information from two modalities (cross-modal) during initial presentation facilitates uni-modal visual recognition memory (Lehmann & Murray, 2005; Murray, Foxe, & Wylie, 2005; Murray et al., 2004; Thelen & Murray, 2013) or in the uni-modal auditory recognition memory (Moran et al., 2013; Thelen, Talsma, & Murray, 2015).

In another experiment by Lehmann & Murray (2005), participants underwent a continuous recognition test where initial items were presented in three different conditions: 1) visual images alone (V), 2) visual images paired with a congruent sound (AVc), 3) visual images paired with an incongruent sound (AVc). Repeated stimuli were only presented as visual images alone, comprising of three levels, 1) repeated visual images, as presented initially (V-), 2) repeated visual images that had been initially presented with a congruent sound (V+c), 3) repeated visual images that had been initially presented with an incongruent sound (V+i). Please see **Figure 1-5** below for the schematic diagram of the experimental conditions and procedure.

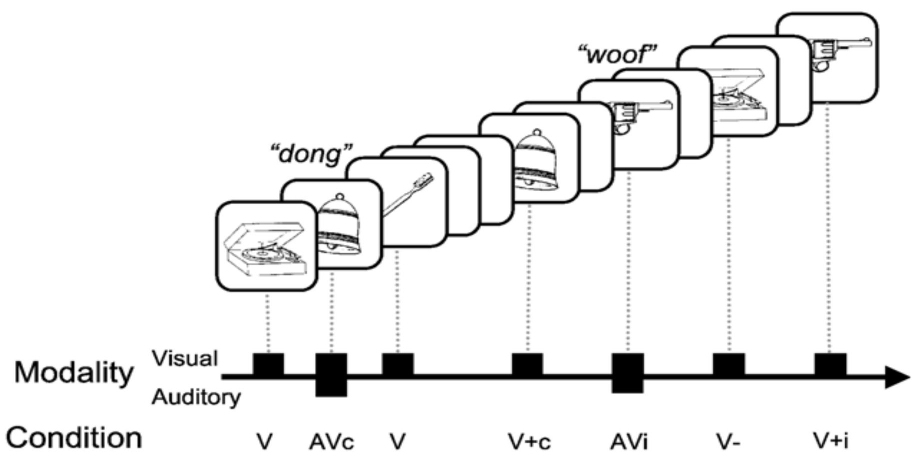

Figure 1-5. Experimental paradigm of the study by Lehman & Murray (2005). V: new items in visual modality; AVc: new visual images paired with congruent sound; AVi: New images paired with incongruent sound; V-: repeated V items in visual modality; V+c: repeated congruent cross-modal items in unimodal visual modality; V+i: repeated incongruent cross-modal items in unimodal visual modality (adapted from Lehman & Murray (2005).

Results showed that while there was no difference in accuracy results in the discrimination of the initial items (new), participants were significantly more accurate in the discrimination of repeated (old) visual images that had initially been presented with the congruent sound (V+c) compared to visual images alone (V-) or visual images that had been presented with the incongruent sound (V+i). In terms of response times, they did not differ significantly between the conditions for the repeated trials. However, for initial presentations (new) response times were faster for visual images presented alone, compared to when they were presented with any auditory stimuli (AVc, and AVi). However, it was argued that participants slowed down in the AVc and AVi conditions, as they may have anticipated the presence of auditory stimuli this could account for the lack of a significant difference in response times for the repeated trials.

A related study by van Kesteren et al. (2013) using fMRI showed how the processing and integration of congruent and incongruent information relies on distinct neural networks. In their study, participants were exposed to congruent and incongruent pairs of objects and scenes and asked to rate how congruent the objects and scene were. With increasing ratings of congruency, recognition memory improved and also correlated with increasing encoding-related activity in the medial prefrontal cortex (mPFC). In contast, the MTL was involved in the processing of incongruent information where higher levels of activity correlated with decreasing levels of congruency. This supports the idea that processing of incongruent information relies on automatic processing in the medial temporal lobe (MTL) (van Kesteren et al., 2013). Additionally, the mPFC was also implicated in relation to visual and tactile information where higher retrieval performance was found to correlate with activity in the mPFC and the somatosensory cortex in response to successful retrieval of congruent visual tactile information, compared to incongruent information.

1.1.4.5 *Modality match effect*

Our experiences are often encountered in different modalities compared to when it was first presented, for example, reading a famous poem and then later recognizing it when you hear someone say it. This change in perceptual format e.g., information recognized in a different perceptual form compared to when it was initially presented, has been found to have an effect on recognition (Ecker, Zimmer, & Groh-Bordin, 2007a, 2007b; Gardiner, Gregg, Mashru, & Thaman, 2001; Groh-Bordin, Zimmer, & Mecklinger, 2005; Nyhus & Curran, 2009; Reder, Donavos, & Erickson, 2002).

Perceptual changes can be in the form of minor changes in information presented at study and test, such as altering the text font (Graf & Ryan, 1990; Nyhus & Curran, 2009; Reder et al., 2002), text colour (Ecker et al., 2007a, 2007b; Groh-Bordin, Zimmer, & Ecker, 2006), voice (Karayianni & Gardiner, 2003) or the size of the stimuli (Gardiner et al., 2001). In these studies, it was found that recognition memory was better when the perceptual format was same at study and test. Apart from better accuracy, when items are in the same perceptual format between study and test, there is a decrease in processing speed referred to as perceptual fluency (Zimmer & Ecker, 2010).

The finding that perceptual changes has an effect on memory is in line with prominent theories such as the Encoding Specificity Theory (Tulving & Thomson, 1973) and Transfer Appropriate Processing (TAP) theory (Morris, Bransford, & Franks, 1977) that argue the importance of perceptual information to remain constant during study and test phases to facilitate retrieval. The Encoding Specificity Theory (Tulving & Thomson, 1973) emphasizes the relationship between the conditions during encoding and retrieval of information, whereby the cues available during encoding should also be present during retrieval to facilitate recognition. The theory emphasizes that the efficiency to remember information depends on the encoding operations performed on the information perceived resulting in the formation of a memory trace. However, in order to retrieve the information effectively, recognition is facilitated if the conditions or cues that were available during encoding match that at retrieval.

While the encoding specificity theory emphasizes the cues available during study and test to facilitate memory performance, TAP (Morris et al., 1977) emphasizes the relationship between the process undertaken when information is encoded and when it is retrieved. According to this theory, successful retrieval is a function of the degree the processes engaged during retrieval is similar to that engaged during encoding (Rugg, Johnson, Park, & Uncapher, 2008). Research has shown that when study items and test items match in modality (auditory and visual), participants show better recognition memory compared to when they are not presented in the same modality (Leynes et al., 2003; Mulligan, & Hirshman, 1995). This is known the modality-match effect (Mulligan & Osborn, 2009).

Studies investigating whether perceptual fluency can enhance performance present a prime before the test items, and find that perceptual fluency only had an effect on recognition when the modality of study and test stimuli matched (Miller, Lloyd, & Westerman, 2008; Westerman, Lloyd, & Miller, 2002; Westerman, Miller, & Lloyd, 2003), a finding that is consistent in both younger and older adults (Thapar & Westerman, 2009).

However, there are some mixed findings which suggest that modality-match effects may be sensitive to the type of recognition memory judgments used (Mulligan, Besken, & Peterson, 2010). For instance a study by Leynes et al. (2003) presented participants with spoken words (auditory) or visual words during the study phase; in the recognition phase, they were asked to discriminate *new* words from *seen* words and *heard* words (source memory task). Results showed an effect of modality-match where participants showed poorer source recognition when the stimuli at study and test were incongruent (i.e. visual words studied, presented as spoken words during recognition and vice versa) compared to when the modality matched. However, when only recognition was taken into consideration, regardless of source memory (by pooling together *seen* and *heard* items), modality-match had an effect on recognition of only the visual stimuli but not the auditory stimuli, indicating that modality-match has an effect on recognition of visual items but less sensitive to recognition of auditory items.

Additionally, Mulligan et al., (2010) investigated the effects of modality-match on the type of recognition test by varying auditory and visual words and study. Participants either completed a standard old new recognition test; or did a source memory test similar to Leynes et al. (2003) where they had to indicate *New*, *Seen* or *Heard*; or a remember/know (RK) judgment following a standard old/new recognition test. The results showed that the modality-match effect was sensitive to the type of test, where in the RK decisions and source memory task, recognition accuracies were recorded to be higher for modality-match conditions, but no modality-match effect was observed for the standard recognition test. The researchers argue that source memory instructions may cause recognition to be more perceptually driven compared to a standard recognition task.

Another reason for these mixed findings could be attributed to saliency of the stimuli as shown in the experiment by Mulligan & Osborn (2009). Here, saliency refers to how well the target item stands out relative to other items within the same block. Mulligan and Osborn (2009) manipulated saliency of stimuli by intermixing auditory and visual items within a block (which would render the items more salient); and presenting auditory and visual stimuli in different blocks during study and test (which would render the items less salient). Mulligan & Osborn (2009) found the modality-match effect in both the auditory and visual trials when they were salient compared to when they were not salient.

1.1.4.6 Role of attention

The role of attention in memory has not been acknowledged sufficiently where it plays a crucial role in memory formation. As memory has limited capacity, attention determines what information gets encoded (Chun & Turke-Brown, 2007). The effects of attention in recognition memory has been shown in studies by manipulating participant's ability to pay attention during encoding, and assessing recognition performance. A study by Beaman, Hanczakowski and Jones (2014) showed that the presence of auditory distraction during encoding of words impaired recognition of words. Using distractors was based on the idea that auditory distraction served to reduce the attention allocated towards encoding of stimuli, leading to poorer memory performance.

However, a more frequent way to study the role of attention on memory is by having participants complete two tasks simultaneously, resulting in divided attention (Chun & Turk-Browne, 2007). Divided attention has been shown to impair memory across many types of tests including recall or recognition (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). In a typical experiment such as in Uncapher and Rugg, (2005), participants studied word lists while concurrently doing a secondary task. This secondary task was either easy (responding to an auditory voice) or difficult (responding to numbers that differed in oddity or evenness from previous trials). Participants then made old/new discriminations to studied words during the test phase. Results showed that recognition was poorer when secondary task was difficult compared to easy.

Furthermore, using fMRI has led to uncovering the mechanism of divided attention on memory where, it was found that although divided attention impaired recognition in the behavioral tasks, results showed that it did not modulate activity in the left inferior prefrontal cortex (LIPC), the region involved in encoding words into long-term memory. Instead, difficult secondary task reduced activity in regions involved in the cognitive control (the dorsolateral prefrontal cortex and the superior parietal regions). Hence, what is seen is that divided attention affects the probability of whether or not encoding related process supports later episodic memory, but not the actual encoding process in the LIPC.

More specifically, the findings by Leynes et al. (2003) suggest that attention could have played a role in enhancing memory, as visual items presented with auditory items within the same block could render the visual items to be salient as opposed to presenting the visual items alone. This was investigated by Mulligan et al. (2010) where they manipulated stimuli to be more salient causing enhanced attention, which was found to facilitate the modality-match effect for both auditory and visual stimuli.

As for the study by Mulligan and Osborn (2009), the discrepancy of findings of the modality-match effect based on the type of the recognition test employed could be explained by the crucial role of attention. Participants in these studies made two types of decisions, either a standard old/new test (which may tap into familiarity) or a source memory task (which taps into recollection). According to Jacoby (1991), recollection places more demands on attention as opposed to familiarity, which is a fairly automatic process. As such, it is expected that in situations where familiarity is sufficient, such as in standard old/new tests, participants may be able to show better recognition compared to a source memory task, which places more demands on attention.

As attention and memory are interrelated, this thesis will consider the effects of attention and its role in facilitating recognition memory.

1.2 Effects of aging

1.2.1 Recognition memory

It has been widely documented that with healthy aging comes a myriad of challenges to cognitive processing, including deterioration in some aspects of memory.

According to reviews by Balota, Dolan and Duchek (2000); and Luo and Craik (2008) the effect of ageing on all aspects of memory has not been consistent. For instance, older adults are likely to show declines in working memory and episodic memory, but not in semantic memory. Although it has been established that episodic memory performance decreases with age, research has shown mixed findings based on the type of episodic memory tasks used. For instance, in tests of free recall, participants are asked to recall as many stimuli or information they were exposed to in the study phase, older adults tend to perform worse compared to younger adults. In contrast, there are little or no age differences in tests of recognition memory, where participants are asked to discriminate between 'old' and 'new' stimuli (See reviews by Balota et al., 2000; Danckert & Craik, 2013). Danckert and Craik (2013) suggested that the main reason for this discrepancy is that the process of familiarity is largely spared allowing older adults to rely on this process during recognition as a cue. In contrast, in tests of recall, participants are not given any aid/cue and have to depend entirely on recollection. Additionally, Balota et al. (2000) suggested that that in recognition tasks, the presence of the environmental support serves as a cue, whereas recall tasks are more demanding for older adults, as the retrieval of memory is more self-initiated.

Although Balota et al. (2000) reported small or no age differences in tests of recognition, there is still considerable support in the literature that older adults do show poorer recognition memory compared to their younger counterparts in continuous recognition tests (Ally et al., 2008; Friedman, 2003; Nielsen-Bohlman & Knight, 1995; Swick & Knight, 1997). However, this is not always the case when the stimuli used are pictures compared to words. For instance, in a study by Ally et al. (2008) when words were used as the stimuli, older adults tended to perform poorer compared to their younger counterparts (marginally significant). However, when pictures were used, there were no significant differences in recognition performance between the age groups. This could be due to the picture superiority effect (Nelson, Reed, & Walling, 1976), an established phenomenon that states pictures are better remembered compared to words. The study by Ally et al. (2008) found that both age groups showed the picture superiority effect. However, older adults showed more benefits compared to younger adults. Furthermore, ERP findings showed that when pictures were used, the neural processes supporting recognition memory, i.e. the familiarity and recollection process was similar between older and younger adults. However with words, these processes were attenuated in the older adults, indicating impairments with recollection and familiarity when word stimuli were used. The results show that picture stimuli compensates for these impairments allowing a more effective memorial performance in older adults.

As mentioned earlier, continuous recognition memory tasks consist of repeated items presented in the same block as the newly presented items. However, the space (or lag) between the new and repeated items (old) can be manipulated to investigate how older adults and younger adults compare. Research has shown that both older and younger adults show poorer memory retrieval as a function of increasing lag between initial and repeated presentations (Kılıç, Hoyer, Howard, & Howard, 2013; Nielsen-Bohlman & Knight, 1995; Rugg, Mark, Gilchrist, & Roberts, 1997; Swick & Knight, 1997).

Additionally, ERP data by Rugg et al. (1997) provided some insight into the effects of age on neural processing of older and younger adults in terms of immediate and delayed recognition. They compared older and younger participants using word stimuli that were repeated at a short lag of 1 (immediate recognition), or longer lags of an average of 10 trials (delayed recognition). Results suggest that immediate recognition was spared in ageing but not in delayed recognition, where older adults performed significantly poorer compared to younger adults. While the ERP data showed the typical repetition effects in both lags for younger adults (although they were more attenuated at the longer lags); for older adults, this effect was present only at the short lag, but absent at the longer lag. This could indicate that indicate that older adults were processing these items as new, compared to younger adults.

As described earlier in section 1.1.4.1, studies by James et al. (2009) and Zhao et al. (2014) showed the benefits of space effect, whereby repetitions of stimuli following short lags although may lead to better retrieval at first repetition, interferes with consolidation of information into long-term memory that spaced repetitions benefit from. With regards to older adults, a key study by Kılıç et al. (2013), compared older and younger participants' ability to benefit from space learning. Participants were asked to make confidence ratings to new (P1) and old (P2 and P3) items in a continuous recognition memory task. The difference between P2 and P3 was that P2 represents items presented for the second time (first repetition), while P3 represents items presented for the third time (2^{nd} repetition). Lag refers to the number of items between P1 and P2 whereas retention interval refers to the number of items between P2 and P3. See **Figure 1-6** for further details of the experimental paradigm.

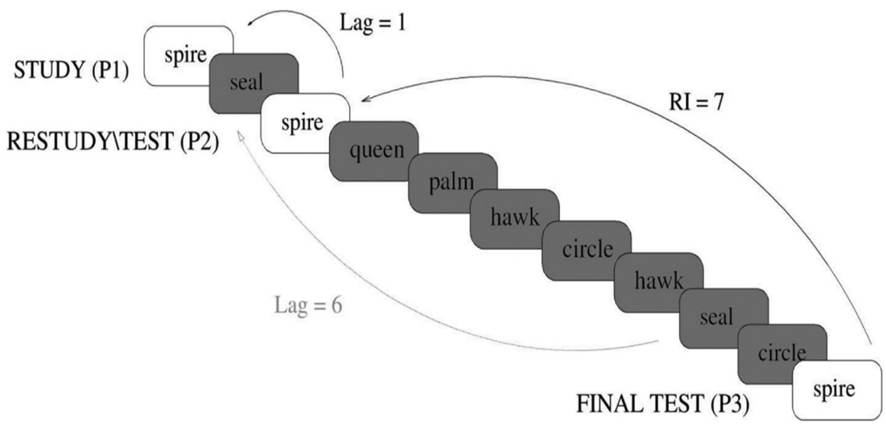

Figure 1-6: The experimental paradigm in the study by Kılıç et al. (2013), comparing older and younger adults ability to benefit from space effect. Lag refers to the number of intervening items between the first presentation (P1) and second presentation (P2), whereas retention interval (R1) refers to the number of intervening items between the second presentation (P2) and the third presentation (P3). In this diagram, Lag=1 refers to one intervening item between P1 and P2, Lag=6 refers to 6 intervening items between P1 and P2. R1=7 revers to 7 intervening items between P2 and P3. (Adapted from Kılıç et al., 2013).

The results showed that compared to their younger counterparts, older adults were less confident in their old judgments compared to their younger counterparts in the P2 and P3 items as a function of increasing lag and retention interval respectively. Similar to their younger counterparts, older adults also demonstrated the benefits of spaced learning, as demonstrated by their ratings on the P3 items, where both older and younger participants were more likely to give high confidence ratings. These findings support the idea that any age related difficulties related to item retrieval at P2 served to enhance memory consolidation and facilitate retrieval at P3.

1.2.2 Multisensory integration

There is increasing support in the literature that older adults benefit from multisensory integration, more than their younger counterparts. In a recent study by Diaconescu, Hasher and McIntosh (2013), older and younger adults performance was compared across two tasks, 1) a simple detection task where older and younger participants had to respond to stimuli as soon as they detected it; and 2) a semantic classification task where older and younger participants made inanimate and animate judgments of pictures and sounds that were presented either uni-modally or multi-modally. Overall, results showed that older adults performed significantly slower than younger adults in both tasks. However, in the semantic classification task, older and younger participants did not differ in terms of classifying the visual stimuli. While participants were significantly faster in detecting cross-modal and visual stimuli compared to auditory stimuli in both tasks; compared to younger adults, the presence of the cross-modal stimuli in the classification task facilitated older adults performance more than just the presence of the auditory stimuli alone. As this facilitation was seen more in classification of auditory stimuli and not for visual stimuli, this supports the idea that visual dominance is preserved in ageing.

Similarly, older participants also show benefit in multisensory integration in the discrimination of coloured circles (Laurienti, Burdette, Maldjian, & Wallace, 2006). Older and younger subjects had to discriminate between coloured circles presented visually; through spoken words (auditory); or multisensory (visual and auditory presentations). While both age groups were significantly faster in discriminating the multisensory presentations; older adults were significantly slower than younger adults, older participants also showed a larger benefit compared to younger adults when multisensory stimuli was used. In the uni-sensory conditions, discriminating visual stimuli led to faster response time; and response times for older adults to multisensory stimuli were similar to younger adults' response time to visual stimuli. This suggests that although ageing is accompanied by deterioration in sensory processing, integration of information from multisensory channels allows for some form of compensatory mechanism.

It could be argued that older adults show enhanced benefit in multisensory integration compared to their younger counterparts, due to general cognitive slowing (Cerella, 1985; Peiffer, Mozolic, Hugenschmidt, & Laurienti, 2007; Salthouse, 2000). General cognitive slowing occurs in older adults as more cognitively demanding tasks leads to slower response times due to the slowing of sensory motor and cognitive processing which consequently leads to a increase in processing time in all cognitive areas (Peiffer et al., 2007). Therefore, older adults should theoretically show enhanced benefit in multisensory integration, as the redundant information from different senses should lead to a reduction in cognitive load. This should then result in a faster response time compared to using uni-sensory stimuli (Peiffer et al., 2007).

Peiffer et al. (2007) investigated if the enhanced benefit is due to general cognitive slowing, by eliminating the need for higher order cognitive processing and used a simple audio-visual detection task, so as to eliminate the need to engage in higher order cognitive processing. Results showed that older adults and younger adults show similar response times on uni-sensory trials. Moreover, older adults surprisingly responded faster compared to their younger counterparts in the multisensory trials, which strongly support that multisensory integration is enhanced in older adults compared to younger adults; and importantly age related differences could not be attributed to general cognitive slowing, but due to alterations in the multisensory processing stream.

In addition, older adults also showed enhanced benefit to multisensory integration when somatosensory information was used. Mahoney, Li, Oh-Park, Verghese and Holtzer (2011) investigated this in a study where older and younger participants had to respond to randomly presented uni-sensory stimuli, i.e. auditory (brief tones), visual (visual asterisks presented on a screen) or somatosensory (vibrations delivered to the index or middle fingers); or three pairs of multisensory stimuli, comprising of auditory and somatosensory stimuli (AS); auditory and visual stimuli (AV); and visual and somatosensory stimuli (VS), by pressing a foot pedal as soon as they detect the presence. Results showed that participants responded significantly faster to multisensory pairs compared to uni-sensory pairs and while younger adults show enhance benefit in AV and AS stimuli, older adults show greater benefit in response to VS stimuli.

1.2.3 Structural changes and functional reorganization

From neurological standpoint, it has been established that healthy ageing leads to many underlying structural changes in brain regions, leading to a functional decline in many cognitive areas (Kennedy & Raz, 2009; Madden, Bennett, & Song, 2009; Ziegler et al., 2010). One major change is on the deterioration of white matter integrity that is accompanied with the ageing process and implicated in tests of episodic memory performance (Kennedy & Raz, 2009; Ziegler et al., 2010). Apart from problems in episodic memory, Bucur et al. (2008) also showed that white matter integrity is implicated in perceptual slowing in the retrieval of episodic memory, as evidenced by longer response times in older adults.

Although these structural changes accompanied by healthy ageing affects cognitive performance, older adults do show some form of compensatory mechanism to overcome the effects of ageing (Ally et al., 2008; Laurienti et al., 2006). Neuroimaging studies have shown increases in prefrontal activation, as a means of compensation (Park & Reuter-Lorenz, 2009). This increase in prefrontal activation is argued to be one of the many ways the brain goes through functional reorganization by forging new and alternative pathways to compensate for impaired cognitive function (Damoiseaux et al., 2008; Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008; Persson, Lustig, Nelson, & Reuter-Lorenz, 2007).

A very comprehensive theory put forth by Park & Reuter-Lorenz, (2009), known as the Scaffolding Theory of Age and Cognition (STAC) incorporates the key findings from neurocognitive research, and includes both the concepts of neuroplasticity of the ageing mind and neurocognitive decline associated with age. Additionally, it is compatible with previous models of aging such as the Hemispheric Asymmetry Reduction in Older Adults (HAROLD) (Cabeza, 2002) and the Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH) (Reuter-Lorenz & Cappell, 2008).

The HAROLD model refers to the findings of age-related over-activation of brain areas indicative of compensatory processing. This is a change in neural circuitry and is compensatory because older adults use more and different brain regions to perform the same tasks as younger adults, leading to a dedifferentiation of brain regions. Dedifferentiation refers to a decline in region specialization faced by older adults compared to younger adults. For instance, different regions in the ventral visual area typically respond to different categories of stimuli, such as faces, places, and alphanumeric characters. A study by Park et al. (2004) however, found that older adults showed a decline in region specialization as regions that respond to faces were also responsive to places; unlike younger adults where these regions respond selectively to different categories of stimuli. Another finding is an over-activation of prefrontal regions to compensate for the reduction in activity of the posterior regions, also known as the anterior-posterior shift (Cabeza, 2002; see review by Reuter-Lorenz & Park, 2010). For instance Davis et al. (2008) found that older adults show an under-activation in medial temporal lobe structures, with an over-activation in the prefrontal structures. Similarly, in a study Diaconescu et al. (2013) using MEG, found that older adults showed more reduction in cortical and subcortical gray matter volume. However they also demonstrated more recruitment of the posterior prefrontal and medial frontal cortex in classifying cross-modal stimuli compared to uni-modal stimuli.

The CRUNCH Model (Reuter-Lorenz & Cappell, 2008) similarly accounts for the differences in pattern of over-activation and under-activation between older adults and younger adults in response to cognitive tasks. According to this model, when task demands are low, older adults engage more neural circuits and show frontal and bilateral recruitment and activation compared to younger adults (who show more focal activations) in order to perform the same task. However, when cognitive task demand increases, younger adults start to recruit more frontal and bilateral regions to meet the task demands. However, older adults have already reached the maximum limit of neural resources at the lower task demand, therefore compared to younger adults, they show an under- activation of brain regions in line with declines in performance.

According to the STAC model (see **Figure 1-7**), some of the cognitive challenges faced by older adults may be due to amyloid deposition, atrophy, deterioration in white matter and dopamine depletion, leading to functional changes such as dedifferentiation, medial temporal lobe recruitment and increased default lobe activity.

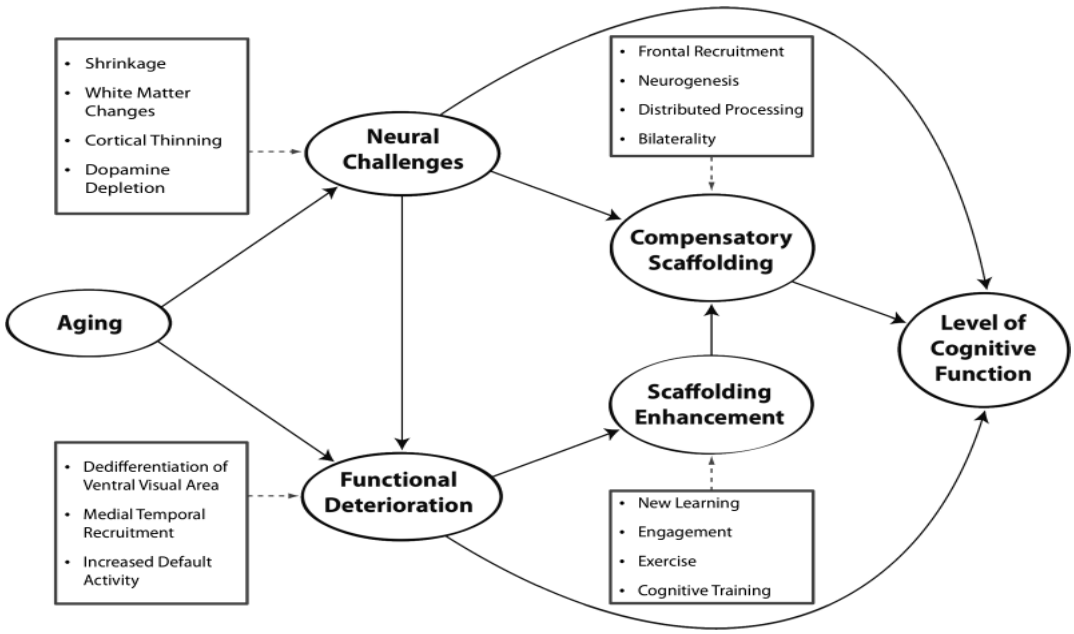

Figure 1-7: The diagram of the Scaffolding Theory of Age and Cognition (STAC) illustrates the magnitude of neural decline brought about by ageing, together with engagement in building new compensatory scaffolds interacts to predict the overall level of cognitive function (Adapted from Park & Reuter-Lorenz, 2009).

The default network comprises of the prefrontal, medial and the lateral parietal brain region and are implicated in self directed focus, reflective memories and environmental attention (Buckner, Andrews-Hanna, & Schacter, 2008; Raichle et al., 2001). Older adults show less connectivity among these regions, but show augmented activation in their frontal region, which indicates this disconnection of default mode leads to a compensatory mechanism manifested in heightened activity of frontal region (Damoiseaux et al., 2008; Persson et al., 2007).

The STAC (Park & Reuter-Lorenz, 2009) posits that these neural changes lead to disruptions in processing, whereby the brain will compensate by creating an alternative neural circuit, or scaffold. While this process may be less efficient than the original network seen in young adults, it allows older adults to compensate and maintain a high level of cognitive function by recruiting other areas mainly in the frontal cortex, but might include other regions such as the parietal, medio-temporal and occipital regions. According to the model, while this compensatory scaffolding is affected by ageing due to the decline in neurogenesis (generation of nerve cells), synaptogenesis (formation of synapse between nerve cells) etc., experiences such as new learning, sustained engagement in mentally challenging activity, cardiovascular exercise and cognitive training can enhance compensatory scaffolding by enabling the brain to build new scaffolding to maintain high levels of cognitive function.

1.3 Introduction to electroencephalography (EEG)

EEG technology has frequently been used to study neural networks underlying cognitive activity and is the one of the most commonly used electrophysiological technique to study memory (Rugg & Wilding, 2000; Sanei & Chambers, 2007). EEG is a measure of brain electrical activity by using a set of surface electrodes positioned in contact with the scalp by using a conducting gel, salt paste or solution. Electrical activity generated on the surface of the scalp when a participant is engaged in a cognitive task will then be picked up by these electrodes and together with the reference electrode will be fed into amplifiers, which enhances the voltage difference between each electrode and the reference electrode (Purves et al., 2012). These signals are then digitized and recorded for analysis.

The electrophysiological basis of EEG lies in the electrical signals caused by the summation of postsynaptic potentials at the apical dendrites of pyramidal neurons in the cerebral cortex (Luck, 2005; Purves et al., 2012; Sanei & Chambers, 2007). Postsynaptic potentials occur when neurotransmitters bind to receptors on dendrites of the postsynaptic cell causing an excitatory input where ion channels on the membrane of the apical dendrite of the postsynaptic cell open allowing positively charged sodium ions to enter into the postsynaptic neuron, leading to a graded change in potentials (cell membrane becomes more negative in relation to its relative baseline at - 70 millivolts), known as depolarization (Luck, 2005; Purves et al., 2012). When positively charged ions enter the neuron, a net negative charge on the region of the apical dendrites occurs and to complete the circuit, repolarization occurs at the cell body where current will flow out of the cell body and basal dendrites where it repolarizes to -70 millivolts, resulting in a net positive charge outside the cell body (Luck, 2005). The net negative charge in the region outside the apical dendrites and the net positive charge in the region outside the cell body cause a small 'dipole' to occur, conducting a current (Luck, 2005). See **Figure 1-8** for an illustration of a pyramidal neural during neurotransmission.

There are three main factors that are crucial to allowing these postsynaptic potentials to be detected on the surface of the scalp and recorded (Luck, 2005). First, recording of postsynaptic potentials lasts for tens to hundreds of milliseconds. Second, postsynaptic potentials occur instantaneously at the dendrites and cell body instead of travelling towards the axons. Third, if neurons are randomly aligned with each other, or receive opposing signals (excitatory and inhibitory) there is a possibility that the charges might cancel each other out. However, the dendrites of cortical pyramidal cells are oriented perpendicularly to the cortical surface where excitatory synaptic input occurs at these dendrites, and receive the same type of signal, allowing their dipoles to summate and to be measured at the scalp.

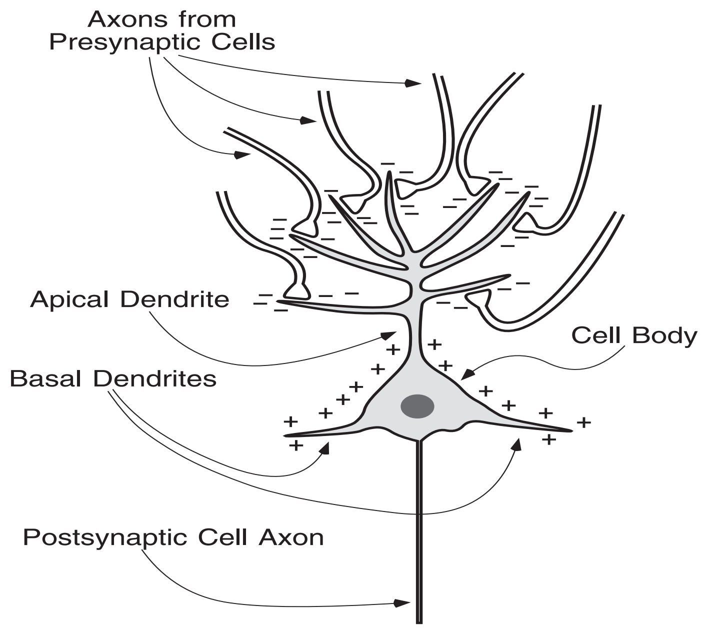

Figure 1-8: A schematic diagram of pyramidal cell during neurotransmission. A synaptic input at the membranes of apical dendrites of pyramidal cells occurs when presynaptic cells release an excitatory neurotransmitter into the postsynaptic neuron. This results in an extracellular negative charge. In the cell body, repolarization occurs, causing an extracellular net positive charge (Adapted from Luck, 2005).

While the EEG itself is a course measure of brain activity comprising of hundreds of different neural sources of activity, it is difficult to assess the specific neural processes, which is the objective in cognitive neuroscience research. Most researchers focus on event related potentials (ERPs), embedded within the EEG signal. ERPs are specific neural responses time-locked to a certain sensory, cognitive or affective event being tested, and can be isolated for analyses from the EEG signal (Luck, 2005; Sanei & Chambers, 2007).

Since the 1960's, ERPS have been invaluable in providing insights into perceptual, cognitive and motor functions and despite advances in other neuro-imaging techniques it remains a very important tool in cognitive neuroscience (Otten & Rugg, 2005). As ERPs are relatively smaller than background EEG (approximate 1-30 μV) (Sanei & Chambers, 2007), EEG samples from several trials of a particular experimental condition need to be averaged, to produce an ERP waveform that represent an estimate of the time-locked neural activity being measured. Thus, ERP waveforms from two or more experimental conditions can be compared to determine if the experimental conditions engage different cognitive and neural networks (Rugg & Allan, 2000).

The major advantage of ERPs is the temporal resolution whereby the neural correlates associated discriminating between different classes of stimuli from different experimental conditions, or engaging different cognitive processes can be studied to the millisecond range (Rugg & Allan, 2000; Rugg & Wilding, 2000). Furthermore, ERP waveforms can be derived 'off-line', after the experimental trials have been categorized into the different conditions. Therefore, this allows easy comparison of waveforms pertaining to several different categories of experimental stimuli (Rugg & Allan, 2000).

1.3.1 ERP old/new effects in recognition memory

Ally & Budson (2007) proposed a model of recognition memory based on ERP data (see **Figure 1-9**). Based on this model, when a participant is exposed to a stimulus, early automatic processing takes place related to sensory stimulation and priming (if the item is a perceptual match). This is followed by familiarity that takes place roughly around 300-500 ms, regardless if the stimulus at test and study is of the same perceptual match (as research has shown that familiarity processing at 300ms is not dependent on perceptual match between study and test). However, in line with past research (see Schloerscheidt and Rugg, 2004), which argues that this effect is modulated by the strength of the familiarity signal, this effect is followed by parietal activity that begins about 450-550 ms, lasting about 400-500 ms and indexes the time required to achieve recollection. Parietal activity lasts for the duration of time of recollective process. The last component occurs if additional effort is needed to achieve specific recollection lasting till approximately 1800 ms.

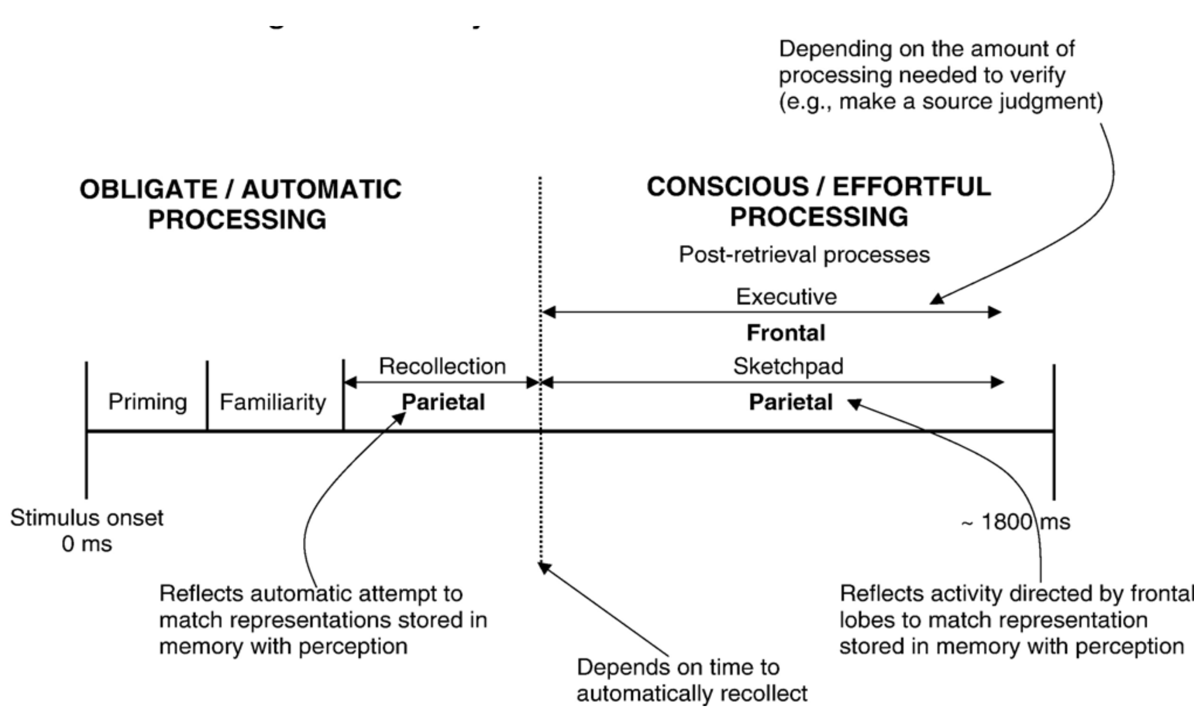

Figure 1-9: Model of recognition memory, showing the process of familiarity, recollection, and post-retrieval processes occurring at specific time intervals (adapted from Ally & Budson, 2007)

ERP studies on recognition memory normally involve studying the waveforms elicited by a paradigm requiring participants to discriminate between repeated or 'old' presentations from first or 'new' presentations. These 'old' presentations that are correctly recognized, are known as 'hits', while 'new' presentations that are correctly responded as a 'new' item are known as 'correct rejections'. According to a review by Rugg and Curran (2007), ERPs in recognition memory have shown to have distinct patterns, whereby the waveforms elicited from correctly recognizing an items as 'old' are found to be more positive going, i.e. it has a higher positive amplitude, compared to correctly classifying an item as 'new'. This difference in waveforms is known as the ‘old/new effect’ frequently found in recognition memory research (see review by Rugg & Curran, 2007).

Three types of ERP old/new effects have been frequently reported in recognition studies. These are known the early frontal effect, or the FN400 associated with familiarity; the parietal or the late positive component (LPC effect) associated with recollection; and lastly the late frontal effect (LFE), associated with post-retrieval monitoring (Allan, Wilding, & Rugg, 1998; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Nyhus & Curran, 2009; Rugg & Curran, 2007). Further elaboration of these components is given in the following sections.

While these regions of electrophysiological activity may be seen to be in contrast to established models of recognition memory with respect to regions involved, whereby within the medial temporal lobe, the hippocampus and parahippocampal cortex mediates recollection, and the perirhinal cortex mediates familiarity (Eichenbaum et al., 2007; Kafkas & Montaldi, 2012; Ranganath et al., 2004, see **Figure 1-1**), these are largely due to the suitability of measurements between functional magnetic resonance imaging (fMRI) and EEG. EEG is assumed to be limited to provide such precise spatial resolution into deeper brain structures as fMRI (Hoppstädter, Baeuchl, Diener, Flor, & Meyer, 2015; Huster, Debener, Eichele, & Herrmann, 2012). Specifically, with respect to the hippocampus, its cortical layers are folded spherically. This consequently leads to a cancellation of negative and positive electrical charges, known as a ‘closed field geometry’ (Nunez & Srinivasan, 2009). Hence EEG is not able to pick up the scalp potentials from the hippocampus (Hoppstädter et al., 2015). However, a recent study by

Hoppstädter et al. (2015) combined both fMRI and EEG simultaneously in recording a recognition memory paradigm in order to determine the modulations in brain activations in response to the mid-frontal old/new effect (familiarity) and the late parietal old/new effect (recollection), thus establishing the link between hemodynamic and electrophysiological correlates of familiarity and recollection in recognition memory. Results from the study showed that activity in the hippocampus and the parahippocampal region was associated with the parietal old/new effect (recollection); and the prefrontal cortex and right intraparietal sulcus was found to be associated with the frontal old/new effect (familiarity) in line with past studies that have shown activation in the region around the intraparietal sulcus to be associated with familiarity (Henson, Hornberger, & Rugg, 2005; Hutchinson et al., 2014). Overall there is ample hemodynamic and electrophysiological evidence to suggest that the processes supporting recognition memory, i.e. familiarity and recollection are two different processes, supported by different regions as shown by fMRI and separated by time course as shown by EEG.

1.3.1.1 *Frontal negativity (FN400)*

The early frontal effect, commonly known as FN400 is an ERP old/new effect elicited as negative going wave for correctly classified new items, compared to correctly recognized old items at approximately 300-500 ms post stimulus onset, at the mid frontal regions specifically in the right and left anterior inferior regions (RAI and LAI), and right and left anterior superior regions (RAS and LAS) (Allan, Wilding, & Rugg, 1998; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Nyhus & Curran, 2009; Rugg & Curran, 2007). For an overview of the location of these regions see **Figure 1-10** for a schematic diagram of the electrode montage.

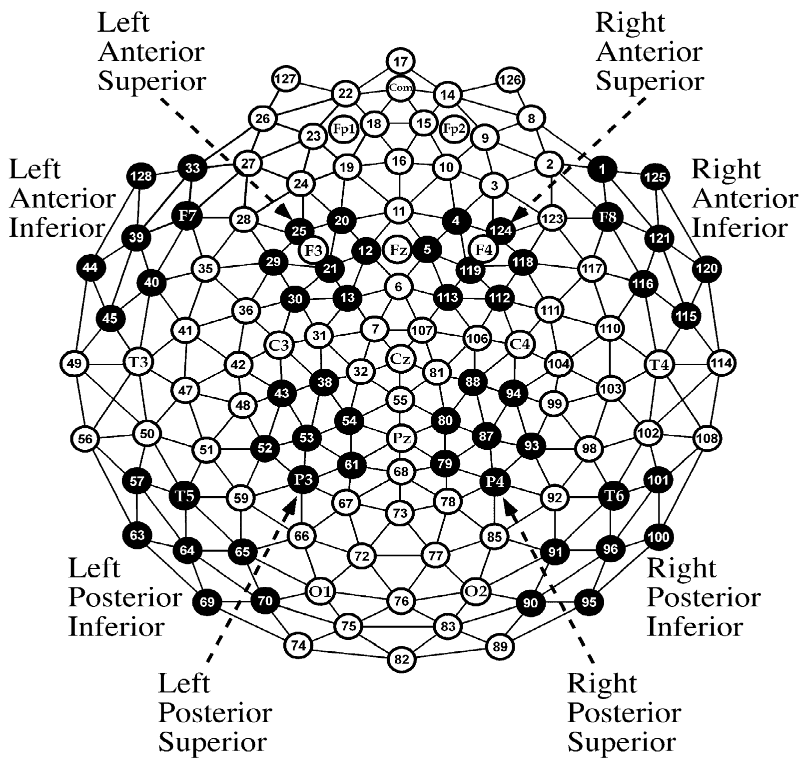

Figure 1-10: Approximate channel locations on the Geodesic Sensor Net illustrating the eight regions of interest. Each region of interest includes a cluster of 7 electrodes in the region. The mean amplitudes for each cluster are averaged to give the mean amplitude of the particular region. Left Anterior Superior (LAS); Right Anterior Superior (RAS); Left Anterior Inferior (LAI); Right Anterior Inferior (RAI); Left Posterior Inferior (LPI); Right Posterior Inferior (RPI); Left Posterior Superior (LPS); Right Posterior Superior (RPS) (Adapted from Curran & Cleary, 2003).

One of the hallmark studies was carried out by Rugg et al. (1998) where participants performed deep encoding (by generating sentences) and shallow encoding (alphabetic judgment) to words presented during the study phase, and subsequently tested in a recognition test. The idea was that deep encoding would facilitate both recollection and familiarity, while shallow encoding would facilitate familiarity based recognition only. For items correctly classified as old, a positive wave at the mid frontal sites was elicited relative to correctly rejected new items, leading the researchers to postulate that this wave was driven by familiarity.

According to the dual process theory, familiarity is fast acting and can occur before recollection. Therefore it might be reasonable to assume that perceptual match between study and test may drive recognition memory due to this mediation by familiarity. However, the FN400 was not specific to perceptual match in the study by Curran & Dien (2003) where they varied auditory and visual items at study, but the recognition phase was only in the visual modality. ERP old/new effects found that the components associated with familiarity (FN400) were not specific to modality and hence supports the familiarity process being independent of modality. Therefore, FN400 effects should be seen even when items at study and test are not perceptually identical.

Further, other studies involved in separating brain potentials related to familiarity involved discriminating between studied and similar type of stimuli from new stimuli. For instance, in a study by Curran (2000), participants discriminated between new words not studied before, studied words, and similar words where the plurality of studied words was changed at test (eg. *Truck* presented at study, and *Trucks* presented at test). As studied and similar words should evoke the process of familiarity more than new words, there should not be a significant difference in mean amplitude of studied and similar words, compared to new words. Curran (2000) found that new items elicited significantly larger negative mean amplitude than both the similar and studied words (that did not differ significantly), in the anterior superior regions. However, there was an effect of polarity reversal in the posterior inferior regions for new items, where it elicited larger positive mean amplitude relative to the studied and similar items (which also did not differ significantly). In extension of this experiment, where participants discriminated between studied pictures, its mirror reversals (similar lures), and new pictures (Curran & Cleary, 2003); and words and semantically similar words (lures) (Nessler, Mecklinger, & Penney, 2001) found the same pattern of effects, which supports the notion that the FN400 is familiarity related.

Other methods employed to elicit familiarity-based recognition depend upon the type of recognition memory task used. When participants were asked to make confidence based judgments, it was found that the FN400 increased gradually with confidence ratings of how confident they were the item was previously studied (Addante, Ranganath, & Yonelinas, 2012; Woodruff et al., 2006; Yu & Rugg, 2010). Another way to dissociate familiarity and recollection is to use the remember/know procedure (where 'know' is assumed to reflect familiarity and 'remember' to reflect recollection). In a study by Wolk et al. (2006), participants studied words during the study phase, followed by a test phase either immediately after, i.e an average of 39 minutes, or the next day (24 hours). In the test phase, participants were to make remember/know discriminations. 'Know' discriminations, associated with familiarity correlated with the typical old/new effect seen at 300-500 ms, where 'know' responses were significantly more positive than correct rejections (new), which was maintained even after 24 hours. This was consistent to a previous study (Curran & Friedman, 2004) where FN400 old/new effects persisted to pictures studied from an retention interval of 30 mins to 1 day, leading the researchers to postulate the FN400 old/new effect, apart from being a correlate of familiarity, might be involved in long term memory consolidation.

Overall, there is considerable support that the FN400 ERP is an index of familiarity, characterized by a positive going wave for items characterized as old (studied), compared to items that are correctly classified as new (unstudied). In line by previous research (Allan, Wilding & Rugg, 1998; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Nyhus & Curran, 2009; Rugg & Curran, 2007), it occurs at the right and left anterior inferior regions (left anterior inferior (LAI), right anterior inferior (RAI)); and the right and left anterior superior regions (left anterior superior (LAS), right anterior superior (RAS)).

1.3.1.2 *Late positive component (LPC)*

The late postive ERP component (LPC) occurs approximately 400-500 ms post stimulus onset and extends to 800 ms post stimulus onset in the parietal regions, typically associated as the neural correlate of the recollection process in recognition memory (Allan & Rugg, 1997; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2001; Allan et al., 1998, Nyhus & Curran, 2009; Rugg & Curran, 2007). See **Figure 1-11** below for an example of waveform showing the LPC component, where correctly recognized old items elicit significantly higher mean positive amplitude compared to correctly rejected new items.

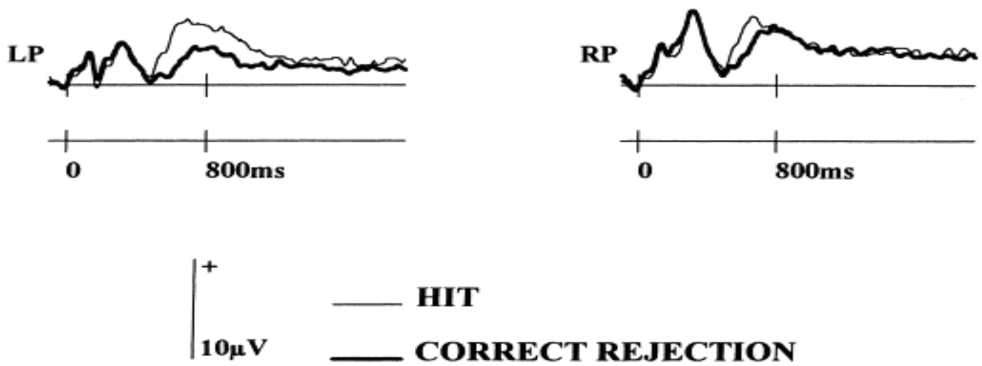

Figure 1-11: Left and right late positive component, LPC. As can be seen, correctly recognized items (hits) elicited a positive going deflection compared to correctly rejected (new) items, at approximately 500-800 ms post stimulus onset. (Adapted from Allan & Rugg, 1997).

Similar to studies on the FN400 component, research has dissociated the process of familiarity and recollection and has found different neural signatures associated with recollection. As elaborated earlier, in the study by Curran (2000) participants discriminated between new words not studied before, studied words, and similar words where plurality of studied words was changed at test. While it was found that similar lures and studied words elicited the FN400 effect with higher mean amplitude compared to new items; the LPC component showed a different pattern where the studied words elicited a higher mean amplitude compared to new and similar lures. In other words, while presentation of similar items may trigger the familiarity (FN400) signal, it did not trigger the recollection signal (LPC) as the studied items. Similarly, when pictures were used, participants who were able to discriminate between studied pictures and lures, also showed this effect relative to the similar pictures, where studied pictures elicited the LPC effect, and not for the similar pictures (Curran & Cleary, 2003). These strongly suggest the LPC component is a correlate of recollection.

Furthermore, using different procedures such as confidence judgments and remember/know procedures, previous studies have found strong indication that the LPC is a correlate of recollection. For instance, studies have found the presence of the LPC effect when participants made high confidence judgments and unlike the FN400, this effect was not modulated by strength of confidence judgments, supporting the notion that recollection and familiarity rely on distinct neural networks, and that recollection is not merely a strong familiarity signal (Addante et al., 2012; Woodruff et al., 2006; Yu & Rugg, 2010). Additionally, as elaborated earlier on the FN400 in section 1.3.1.1, Wolk et al. (2006) found that when participants made *remember* judgments indicating that they remember the stimuli as previously presented, the LPC effect was recorded, and similar to the FN400, this was found at retention intervals of both 39 minutes and 24 hours (Wolk et al. 2006).

Further support that the LPC component is a correlate of recollection comes from a pharmacological studies, when participants were administered with *midazolam*, an amnesic inducing drug that selectively impairs recollection but not familiarity (Hirshman, Fisher, Henthorn, Arndt, & Passannante, 2002), showed a diminished LPC effect that correlated with behavioral measures of recollection (Curran, DeBuse, Woroch, & Hirshman, 2006). Previous research (Allan & Rugg, 1997; Allan, Wilding & Rugg, 1998; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Nyhus & Curran, 2009; Rugg & Curran, 2007) has shown it occurs in the right and left posterior inferior regions (left posterior inferior (LPI), right posterior inferior (RPI), and the right and left posterior superior regions (left posterior superior (LPS), right posterior superior (RPS)). Please see **Figure 1-10** for a schematic diagram of the electrode montage located at these regions.

1.3.1.3 *Late frontal effect (LFE)*

Apart from the FN400 and the LPC, which are reported prominently as old/new effects in memory literature, there is another component that occurs relatively late. This component is known as the late frontal effect (LFE), reported as a more positive going wave for correctly classified 'old' items compared to correctly rejected 'new' items, approximately 1000 ms post stimulus onset, and lasts until 1500-1800 ms post stimulus onset at frontal sites (Allan & Rugg, 1997; Allan, Wilding, & Rugg, 1998; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Nyhus & Curran, 2009).

This component has been implicated in the process following recollection, where memory content is evaluated and operated on further, such as making judgments of contextual details (Allan et al., 1998; Ally & Budson, 2007; Wilding & Rugg, 1996). This is known as post-retrieval monitoring, believed to be supported by the dorsolateral prefrontal cortex, and defined as a process of operating on the information retrieved and held in working memory, for the evaluation of task relevance and information (Achim & Lepage, 2005).

An early study showing an example of post-retrieval monitoring signified by the LFE can be seen in the study by Wilding and Rugg (1996), where participants were asked to make old/new discriminations to spoken words presented at study, and then indicate if the word had been presented in the male or female voice, following discrimination. Results were classified as 'hit/hit' if the word was correctly classified as 'old' with the correct source judgment, 'hit/miss', if the word was correctly classified as old, but without the correct source judgment; and lastly correct rejections, which are words correctly classified as new. See **Figure 1-12** below for the waveforms that show a positivity of the hit/ hit category compared to the hit/miss and the correct rejections. This positivity of the hit/hit waveform, compared to the other two conditions show that following recollection, further operations had taken place for the retrieval of correct source context, signified by this late frontal old/new effect.

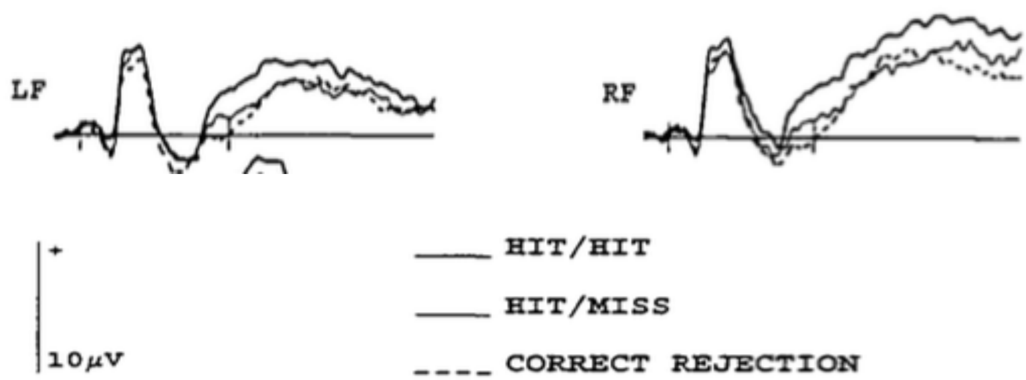

Figure 1-12: Waveform showing the LFE component, with an enhanced positivity for the Hit/Hit condition compared to the Hit/Miss and Correct Rejection conditions (adapted from Wilding & Rugg (1996),

Interestingly, the presence of the late component or LFE is observed even in the absence of the recollection component, suggesting its role in effortful processing, where the executive processes of the frontal lobes may engage in further retrieval attempts when recollection is difficult (Ally & Budson, 2007; Budson et al., 2005; Goldmann et al., 2003; Li, Morcom, & Rugg, 2004; Morcom & Rugg, 2004), highlighting the relationship between the FN400, LPC and LFE. These three components should be analyzed together to understand the relationship among the processes underlying recognition memory (Ally & Budson, 2007). In the aforementioned study, the researchers varied words and pictures at study and test to examine the memorial process of pictures and words in recognition memory. Their findings revealed that when words were used, there was an enhanced familiarity effect, shown by the enhanced FN400. On the other hand, the use of pictures enhanced recollection shown by the enhanced LPC. What was interesting however, was that post retrieval processing was engaged even when there was no enhanced recollection. Thus the underlying relationship appears to be that pictures at study enhanced the recollection process, thus precluding the process of post retrieval monitoring. In contrast, when an item is familiar and fails to elicit the recollection process, further post retrieval processing kicks in to operate on retrieved memory content to retrieve further source details.

To sum, the LFE is an index of post-retrieval monitoring process, responsible to operate on information retrieved. There is support that it is engaged when retrieval is difficult, and may signify more effortful processing. Similar to the FN400, it occurs at the right and left anterior inferior regions (left anterior inferior (LAI), right anterior inferior (RAI)); and the right and left anterior superior regions (left anterior superior (LAS), right anterior superior (RAS)), with a dominance on the right hemisphere (Allan, Wilding, & Rugg, 1998; Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Nyhus & Curran, 2009). Please see **Figure 1-10** for a schematic diagram of the electrode montage located at these regions.

1.4 Aims and rationale of this thesis

The aim of this thesis is to examine factors that affect recognition memory, among younger and older participants. Specifically, while studies have shown that recognition is enhanced if items are repeated after a long lag compared to mass presentation where items are repeated following a short interval (Benjamin & Tullis, 2011; Cepeda et al., 2008; Zhao et al., 2014), there is a lack of studies in understanding the space effect when the items presented for the third time are repeated following a short or long retention interval. Furthermore, past studies have failed to account for the effects of education or ethnicity, as participants are mainly university students. As access to education is not equal among the different ethnicities (Tzannatos, 1991; Zakariya, Ramli, & Zulkifli, 2014), it is expected that this may be translated to differences in cognition functioning (Angel et al., 2010). Furthermore, effects of age across the space effect is also worth investigating to determine if older adults show the same benefit over repetitions and lag as younger adults. Lastly, the neural correlates supporting recognition memory upon repetition and space can be investigated to further understand the processes by which recognition memory is supported across these repetitions.

Therefore, the first experiment (chapter 2, experiment 1), will investigate the spacing effect in both younger and older adults in a continuous recognition memory task, where items were presented for the first time (new), presented again (R1) following either a short lag or long lag, and presented for the third time (R2) after a short or long retention interval. This will be further investigated using EEG to see how the process of familiarity, recollection and post retrieval monitoring contributed to recognition, through analyzing the FN400, LPC and LFE components (chapter 2, experiment 2).

Another factor that affects recognition memory is modality of the stimuli. Past studies have shown that participants have better recognition memory performance for visual stimuli compared to auditory stimuli (Bigelow & Poremba, 2014, Cohen et al., 2009). It has also been shown that stimuli presented in two modalities (cross-modal) leads to better recognition performance compared to stimuli presented in only one modality (uni-modal) (e.g. Lehmann & Murray, 2005; Moran et al., 2013; Thelen et al., 2015). However, it has not been established how recognition memory performance differs upon subsequent repetition among the modalities.

To answer this, chapter 3 will examine the effects of modality (visual, auditory and cross-modal (visual + auditory) on recognition memory (experiment 3), to determine how modality affects recognition memory though the repetitions. Furthermore, although older adults show enhanced multisensory integration compared to younger adults (Laurienti et al., 2006, Mahoney et al., 2011; Peiffer et al., 2007) and with improved recognition with repetition, it is not clear how older adults differ from younger adults in recognition of cross-modal stimuli across repetitions. Therefore, this chapter also aims to determine age effects in cross-modal repetition in older adults (experiment 4).

While the literature shows that cross-modal stimuli leads to better memory compared to uni-modal stimuli, these cross-modal stimuli should also be semantically related to enhance memory performance (Lehmann & Murray, 2005, Murray et al., 2005, Murray et al., 2004, Thelen et al., 2012). Theoretically, semantically related information enhances memory performance due to the formation of a more elaborate memory trace (Craik & Tulving, 1975; Moscovitch & Craik, 1976). The past studies mentioned however have only shown enhanced recognition for semantically congruent stimuli compared to semantically incongruent stimuli upon the first repetition. Thus, it is not clear if the benefit of semantic congruent information over semantically incongruent information still persist over repetitions. Therefore the role of semantic congruency of cross-modal pairs will be examined in chapter 4 to determine if the effects semantic congruency is consistent following repetition (experiment 5). Further, this will be extended to understand the underlying processes supporting recognition memory over repetitions when information is congruent and incongruent through analyzing the FN400, LPC and LFE components in experiment 6. This is important to understand the role of familiarity, recollection and post retrieval processing of semantically congruent and incongruent information across repetitions in recognition memory.

Lastly, information may not be encountered in the same modality as it was encoded. Studies have shown that items tested in the same modality as they were studied leads to better recognition compared to when they did not match in modality (Leynes et al., 2003; Mulligan & Hirshman, 1995). This superior recognition of items that match in modality over those that did not match is known as the modality-match effect (Mulligan & Osborn, 2009). It is not clear however, how modality-match affects recognition memory over repetition, which will be examined in in chapter 5. In this chapter, modality mismatch on recognition memory will be examined to determine how modality mismatch affects recognition memory over three types of modalities, namely auditory, visual and cross-modal modality, over the two repetitions (R1 and R2). Experiment 7 looks at behavioral performance, whereas the final experiment (experiment 8) is an EEG study to investigate the effects of modality mismatch on the underlying neural processes of familiarity, recollection and post-retrieval monitoring in contributing to recognition memory by analyzing the FN400, LPC and LFE components respectively.

CHAPTER 2

REPETITION AND SPACING IN VISUAL RECOGNITION MEMORY

2.1 Experiment 1: Repetition and spacing in visual recognition memory across age groups

2.1.1 Introduction

One of the ways to measure recognition memory is via a continuous recognition memory task. Participants are typically asked to discriminate repeated stimuli (old) from stimuli presented for the first time (new). An important aspect in designing continuous recognition memory tests is the space (lag) between 'new' and 'old' items, which could be measured in terms of number of intervening items, or time between presentations. It has typically been reported that as lag between 'new' and 'old' items increases, participants' performance decreases (Friedman, 1990; Henson, Rylands, Ross, Vuilleumeir, & Rugg, 2004; Kim, Kim, & Kwon, 2001; Palmeri, Goldinger, & Pisoni, 1993)

For instance, Kim et al. (2001) found that participants recognized words significantly faster and more accurately when they were presented immediately after the first presentation, compared to after five intervening items, where they found slower search times; this suggests they needed to use template matching and memory searching for the delayed items. Whether this effect of lag was due to the passage of time, or intervening items was investigated in a study by Henson et al. (2004) and found that participants' recognition performance for visual objects decreased as a function of intervening items, as well as time between initial presentation and repeated presentation. The effects of lag was also seen in recognition memory performance for spoken words where in a study by Palmeri et al. (1993) spoken words were repeated after lags of 1, 2, 4, 8, 16, 32, and 64 intervening words. With increasing lags, participants recorded slower response time and lower recognition accuracy.

However, the effects of lag with pictures on recognition memory have not been very consistent. For instance, effects of lag were found in James's et al. (2009) study using black and white line drawings where items repeated immediately was better recognized and recorded faster response times than items presented for the first time, and after 9 intervening items. Although Friedman (1990b) found effects of lag with words, the same pattern did not emerge when pictures were used instead (Friedman, 1990a). Friedman (1990a) claimed that pictures led to better encoding compared to using words. Similarly, Ally and Budson (2007) varied words and pictures systematically during the study and test phase, and found that when pictures were used in the study phase, it led to better discrimination compared to when words were used in the study phase. This could also relate to the picture superiority effect, which refers to the finding that pictures are often better remembered compared to words (Nelson et al., 1976; Snodgrass & Asiaghi, 1977). Older adults also showed greater benefits in recognition when pictures are used compared to words, as it allows a compensatory mechanism for their impaired memory process (Ally et al., 2008).

One technique that can be used to improve recognition memory is to repeat the stimuli (also known as repetition priming (Henson, 2003)). Although the effect of lag has been consistently documented, it is important to note that poorer item retrieval on 2nd presentation as a function of lag does not indicate poorer memory performance. Zhao et al. (2014) suggests that spaced learning reduces the effects of repetition priming by enhancing encoding strength, such that at first repetition, accuracy for spaced learning and massed learning (See chapter 1, section 1.1.4.1 for further explanation) was comparable; but with repetition, memory performance was significantly higher for spaced learning compared to massed learning.

Although research generally shows that older adults show poorer performance in recognition compared to younger adults (Ally et al., 2008; Friedman, 2003; Kılıç et al., 2013; Nielsen-Bohlman & Knight, 1995; Swick & Knight, 1997), like their younger counterparts, older adults show benefits in terms of space learning. For instance, the study by Kılıç et al. (2013) found that items that were difficult to retrieve during 2nd presentation were better remembered during the 3rd presentation for both older and younger adults.

Past studies have normally shown the effects of spaced learning via a recognition memory test where items were first repeated following a short or long lag (first repetition), and then repeated again (second repetition) after some interval. For the sake of clarity, the interval between the first and second presentation will be referred to as lag, and the interval between the second and third presentation will be referred to as retention. As past studies have manipulated lag only and tested its effects on performance at the third presentation, it is not clear how short or long retention would affect recognition memory at the 3rd presentation (2nd repetition) and whether this effect is modulated with age. Therefore in this experiment, we aim to determine the effects of lag, retention interval and age on recognition memory performance.

Finally, this study will also account for possible cultural differences in memory performance among Malaysians. Malaysia is a multicultural society comprising of three main races, i.e. Malays, Chinese and Indians. Despite having greater access to higher education (Tzannatos, 1991), Malays lag behind their Chinese counterparts in having higher education qualifications and better jobs. Indians have more limited access to higher education than Malays and lag even further behind in having higher education qualifications (Zakariya, Ramli, & Zulkiflee, 2014). Lower education levels have been shown to be related to a lower level of cognitive functioning, including tests of episodic memory (Angel, Fay, Bouazzaoui, Baudouin, & Isingrini, 2010; Lachman, Agrigoroaei, Murphy, & Tun, 2010). One reason for this could be because those with higher levels of education have access to advantages and resources to participate in cognitively challenging tasks to overcome the effects of aging (Lachman et al., 2010). As it has been established that education levels have an effect on memory performance, and that the different ethnicities of the Malaysian population do not have equal access to education or have equal attainment of higher education, it is important to account for cultural differences in this study to ensure that differences in memory performance is not due to these factors.

2.1.2 Methods

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus.

2.1.2.1 *Participants*

Sixty younger adults and 59 older adults were recruited for this study. Data of 2 younger adults, and 9 older participants were discarded as they either reported depressive symptoms (younger and older adults) or reported cognitive impairments (older adults) (See section 2.1.2.2.1 for further details on the screening criteria, and appendix A.9 for mean scores of participants). This resulted in a total number of 58 younger adults between the ages of 18-30, and 50 older adults between the ages of 60-70. Younger participants were compensated with RM 5; whereas older participants were compensated with RM10 for their participation. Older adults were compensated more than younger adults in view that participation in this task might be relatively more difficult for older adults. Additionally, all older adults were screened for cognitive functioning via the mini mental status exam, which was not administered to the younger adults. Overall the time for older adults to complete the experimental phase was consequently longer than younger adults. Please see **Table 2-1** below for participant characteristics.

Table 2-1: Characteristics of participants in experiment 1, including information pertaining to age, sex, ethnicity and education breakdown.

	Younger Adults (n=58)	Older Adults (n=50)
Age (years)	mean=22.52 (SD= 3.89)	mean=67.74 (SD= 6.24)
Sex (n)		
Male	14	19
Female	44	31
Ethnicity		
Malay	20	18
Chinese	19	13
Indian	19	19
Education (years)	mean=14.69 (SD= 2.95)	mean= 7.96 (SD=4.02)
Malay	mean=12.25 (SD= 2.17)	mean= 7.06 (SD=3.57)
Chinese	mean=15.37 (SD= 2.41)	mean=5.85 (SD= 4.88)
Indian	mean=16.58 (SD=2.43)	mean=10.26 (SD= 2.54)

2.1.2.2 *Materials*

2.1.2.2.1 Questionnaires

Previous research has established that both younger and older adults with depression show episodic memory deficits (Airaksinen, Wahlin, Forsell, & Larsson, 2007; Bäckman & Forsell, 1994), including on tests of recognition memory (Ramponi, Murphy, Calder, & Barnard, 2010; Watts, Morris, & MacLeod, 1987). As such, for all studies reported in this thesis, participants are screened for depressive symptoms and their responses are excluded from the dataset if they show depressive symptoms.

In addition, as this experiment looks into recognition memory of healthy older adults, it is important that the older participants do not have any cognitive impairments. This is so that any difference in recognition memory can be attributed to healthy ageing, and not to cognitive impairments. As such, all older adults were screened for cognitive impairments. The details of these scales used to screen for depression and cognitive impairments are given below:

Beck's Depression Inventory: The Beck's Depression Inventory (*BDI*; *see appendix A.1* for questionnaire; Beck, Steer, & Brown, 1996) is a 4-point likert type questionnaire with 20 questions assessing depressive symptoms among younger adults. The scale has been reported to have good internal consistency (Cronbach's alpha = 0.56 to 0.87) within a Malaysian sample (Quek, Low, Razack, & Loh, 2001). All younger participants completed the BDI and were only included in the study if they obtained a score of 17 and below. Although the Bahasa Malaysia (BM) version of the scale is available, all younger participants in the study were proficient in English. As such they were administered with the English version of the scale.

Geriatric Depression Scale: The Geriatric Depression Scale (GDS; see appendix A.2 and A.3 for questionnaire; Sheikh & Yesavage, 1986) is 15-item questionnaire assessing depressive symptoms among older adults. All older participants were to complete the GDS by indicating yes/no to every item. Higher scores indicate higher depressive symptoms. The scale shows good internal consistency (Cronbach's alpha= 0.86). The GDS-Malay (see appendix A.4 and A.5 for questionnaire, Teh & Hasanah, 2005) was administered to older adults that were not proficient in English and prefered to communicate in Bahasa Malaysia (BM). Validation study of this questionnaire in the Malaysian population showed good psychometric properties (Cronbach alpha= 0.83) (Teh & Hasanah, 2005). Participants who completed the GDS-Malay were only included in the study if their scores on the GDS were 8 and below.

Mini Mental Status Examination: The Mini Mental Status Examination (MMSE, see appendix A.6 for questionnaire; Folstein, Folstein, & McHugh, 1975) consists of 11-questions that tests five areas of cognitive functions, namely orientation, registration, attention and calculation, recall and language. The MMSE-Malay version (see appendix A.7 for questionnaire, (Za, Zahiruddin, & Ah, 2007) was administered to older adults that were not proficient in English and prefered to communicate in Bahasa Malaysia (BM). All older participants completed the MMSE. Although a score of 23 and below indicates cognitive impairment (Folstein, Folstein, McHuge, & Fanjiang, 2001) this cut-off criteria was reduced to 20 to allow leniency to participants who performed poorly due to language barriers, and education levels rather than cognitive impairment (see Ibrahim et al. 2009; Jitapunkul, Kunanusont, Phoolcharoen and Suriyawongpaisal (2001); and Kahle-Wrobleski, Corrada, Li and Kawas (2007) and Za et al., (2007) that justifies relaxing this criteria for population whose first language is not English).

2.1.2.2.2 Stimuli

The stimuli of the experiment were 2D line drawings in standard block colours (blue, red, yellow, green) of familiar images presented against a black background (see appendix B.1 for a sample of the items). These images were obtained from the Alzheimer's disease evoked potential test (ADEPT) database (Kilborn et al., 2009) and were pretested in a sample of 5 younger and 5 older adults for familiarity and suitability prior to the experiment. Presentation of stimuli was controlled using E-Prime software version 2.0 (Schneider, Eschman, & Zuccolotto, 2002) and a laptop computer (HP EliteBook 8460p) with a 14” display was used to run the experiment.

2.1.2.3 *Design*

The design of the experiment was a 2 x 2 x 4 mixed design approach with age (younger adults vs older adults) as the between subjects factor, and lag (short lag vs long lag) and retention interval (short retention-short lag (SRSL) vs short retention-long lag (SRLL) vs long retention- short lag (LRSL), and long retention-long lag (LRLL)) as the within subject factors.

There were a total of 275 stimuli in the two experimental blocks. This consisted of a total of 116 new items, 92 R1 items and 67 R2 items in the experiment. The 92 R1 items represents 40 short lag items and 52 long lag items. The 67 R2 items represents 10 SRSL items, 16 SRLL items, 21 LRSL items and 20 LRLL items. In addition, there were 5 practice blocks consisting of 10 stimuli, which include 6 new items and 4 R1 items in each block. The stimuli in the practice blocks were not repeated in the experimental blocks and only served to familiarize participants with the experimental task.

Stimuli were presented either for the first time (new), repeated for the 1st time (R1) and (R1) and then repeated again for the 2nd time (R2). R1 items were repeated either between 0-19 intervening items (short lag) or after 20-100 intervening items (long lag). Following either short lag or long lag some of these items were repeated for the 2nd time following either a short retention interval of between 0-19 intervening items following R1 (SRSL or SRLL), or after a long retention interval of between 20-100 intervening items following

R1 (LRSL or LRLL). In this study, lag refers to the space between first presentation and second presentation, whereas retention refers to the space between the second and third presentation.

Figure 2-1 below illustrates the different lags and retention types in this study.

The dependent variables in this study were percentage errors on R1 and R2, and the discriminability index (*d'*) scores. The percentage errors were calculated by computing the total errors made on R1 and R2, expressed as a percentage. *d'* is calculated as the difference in *z* transforms of the proportion of correct *old* discriminations made (hit rates) and proportion of incorrect *old* discriminations (false alarms).

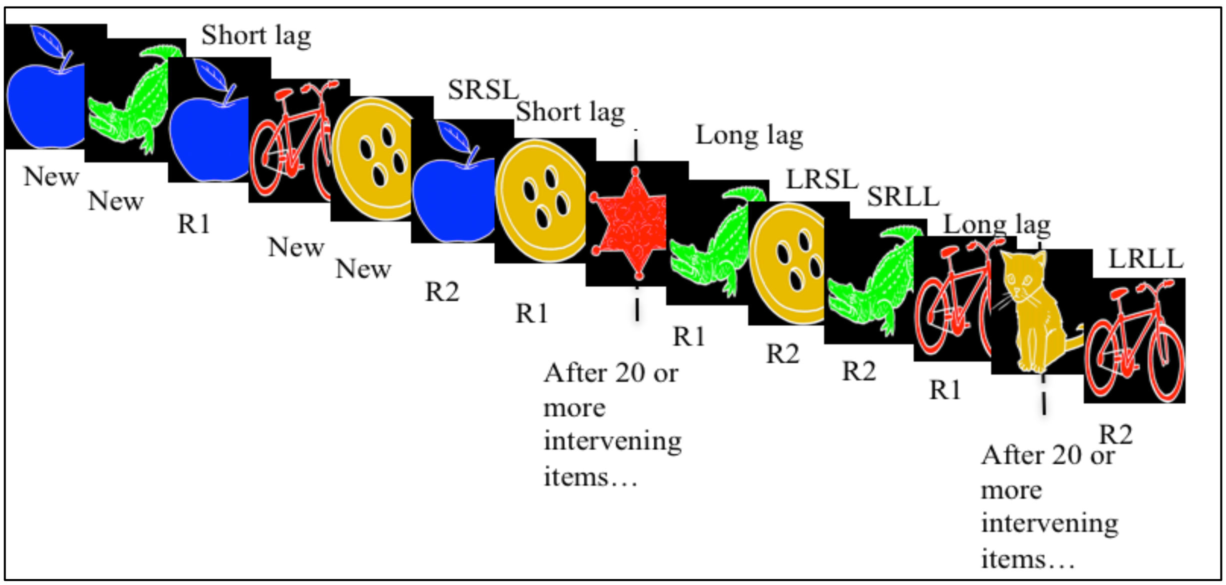

Figure 2-1: Illustration of the experimental manipulation of lags (short and long) and retention interval (short retention-short lag (SRSL), short retention-long lag (SRLL), long retention-short lag (LRSL), and long retention-long lag (LRLL).

2.1.2.4 *Procedure*

All participants were given written and verbal instructions describing the experimental procedures. After giving informed consent, participants were seated at about 60 cm from the laptop screen and fixated at a cross at the center of the screen. The experiment began with 2 practice blocks, followed by 1 experimental block, 1 practice block and a final experimental block. There was an option to take a break between the blocks.

Before the start of the experiment, all participants were informed that stimuli from one block would not be repeated in another, and to respond as quickly and accurately as possible. Each block began with 500 ms blank interval of a black background, followed by a text display with instructions. Once participants were ready, they were required to press the space bar to continue. For every trial, participants were presented with a blank screen for 500 ms, a fixation cross for 500 ms and a target stimuli that appeared until a response is made. Participants were to indicate whether the target stimuli were new or old (repeated presentation (R1 or R2)), by either pressing the ‘n’ key (labeled new) or ‘v’ key(labeled old) on the keyboard. The target stimuli appeared until participants made an old/new decision. See **Figure 2-2**. Following the experiment, younger participants completed the BDI, whereas the older participants completed the MMSE and the GDS.

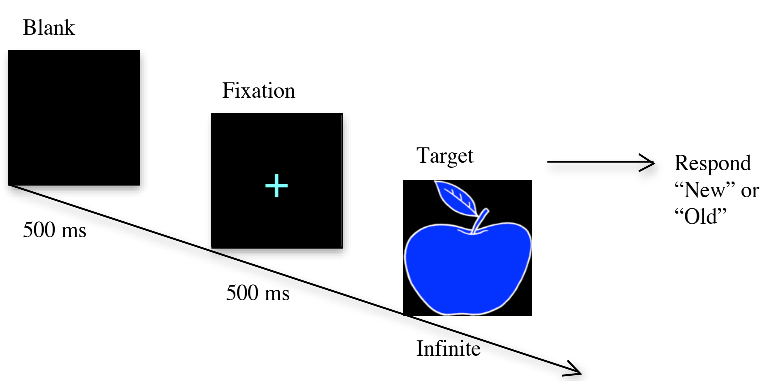

Figure 2-2: The procedure used for each trial in both experimental blocks

2.1.3 Results

Younger and older adults were compared in terms of their performance (percentage errors made on R1 and R2) and *d*'. An independent samples *t*-test analyses showed that younger and older adults differed significantly in the number of years of education attained, $t_{(88.65)}$=9.78, $p < 0.001$.This factor was entered as a covariate in subsequent analyses. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses as trials quicker than 80 ms may reflect speedy responses that indicate random responding. On the other hand, 2500 ms may be too slow a response. In cases of violations of sphericity for any variables used in the following ANOVAs, degrees of freedom were corrected using Greenhouse-Geisser corrections where applicable.

2.1.3.1 *Effects of age and lag (R1) on percentage errors*

A 2x2x3 mixed design ANCOVA with age group (younger adults vs older adults) and ethnicity (Malay vs Chinese vs Indian) as the between subjects factors; and lag (short lag vs long lag) as the within subjects factor, was conducted. As homogeneity of regression slope assumption was violated for percentage errors in short lag, given by a significant interaction term of age group x years of education, $F_{(2,105)}$= 10.75, $p<0.001$, and percentage errors in long lag, $F_{(2,105)}$= 6.48, $p=0.002$, results of the ANCOVA will not be accurate. Additionally, as the covariate did not have an effect on the dependent variable, $F_{(1,101)}$= 2.73, $p=0.10$, years of education was removed as a covariate and the data was reanalyzed using ANOVA.

The results showed a main effect of age group, $F_{(1,102)}$=19.02, p<0.001, η_p^2 = 0.97. For items presented for the 2nd time (R1), younger participants made significantly fewer errors (mean= 17.53, SD= 13.92) compared to older participants (mean= 28.86, SD=14.11). There was also a main effect of lag, $F_{(1,102)}$=29.87 p< 0.001, η_p^2 = 0.23 where participants made fewer errors in the short lag trials (mean=20.47, SD= 15.15) compared to the long lag trials (mean= 25.37, SD= 16.18), p< 0.01. There was no age x lag interaction observed, p= 0.13. **Figure 2-3** shows the mean percentage errors of older and younger participants in short and long lag condition.

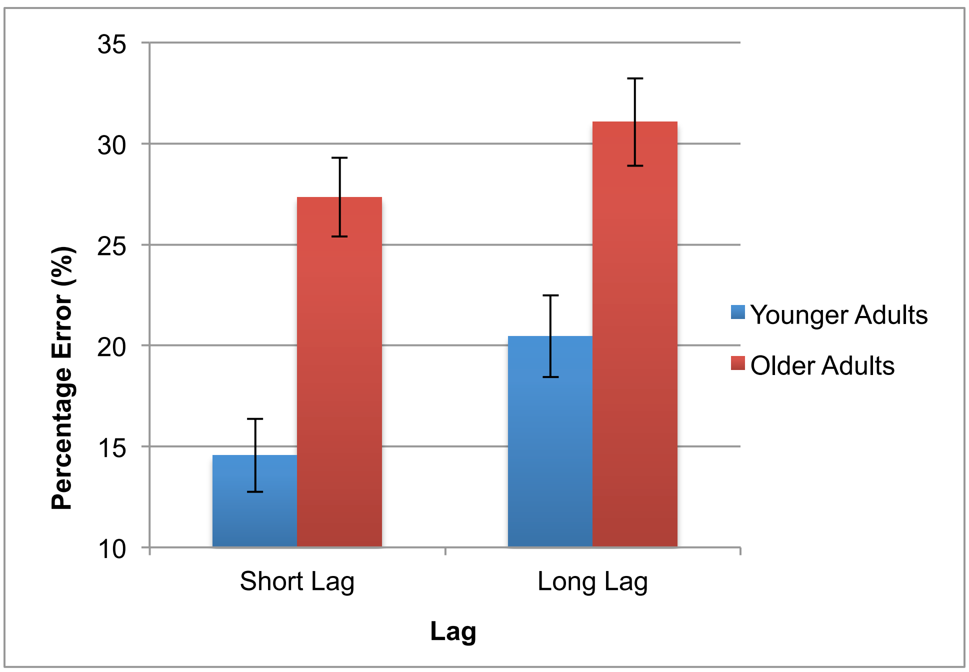

Figure 2-3: Graph summarizing the mean percentage error for older and younger participants for R1 trials (short and long lags). Error bars represent standard error.

2.1.3.2 *Effect of retention interval (R2) on percentage errors*

A 2x3x4 mixed design ANCOVA with age group (younger adults vs older adults) as the between subjects factor and retention interval (SRSL vs SRLL vs LRSL vs LRLL) as the within subjects factor was conducted. Homogeneity of regression slope assumption was assumed for percentage errors for all levels of retention interval, all p values > 0.05. However, the main effect of the covariate was not significant, $F_{(1,101)}$= 1.58, p=0.21.

Results show that there was no overall main effect of age group, $F_{(1,101)}$= 0.01, p=0.91. However, there was a significant main effect of retention interval, $F_{(2.67, 269.50)}$ = 3.03, p=0.04, η_p^2 =0.03. Pairwise comparisons (Bonferonni adjusted) revealed that participants made significantly more percentage errors in the LRSL retention interval (mean= 11.90, SD=12.07) compared to all other retention intervals (SRSL: mean=5.37, SD=11.39; SRLL: mean=4.75, SD= 9.14; LRLL: mean= 5.93, SD=10.37), all p<0.001. There were no significant differences in percentage errors made among all other retention intervals (p>0.05). **Figure 2-4** below shows the mean percentage errors of participants in the four types of retention intervals. No other main effects or interaction effects were significant, p> 0.05.

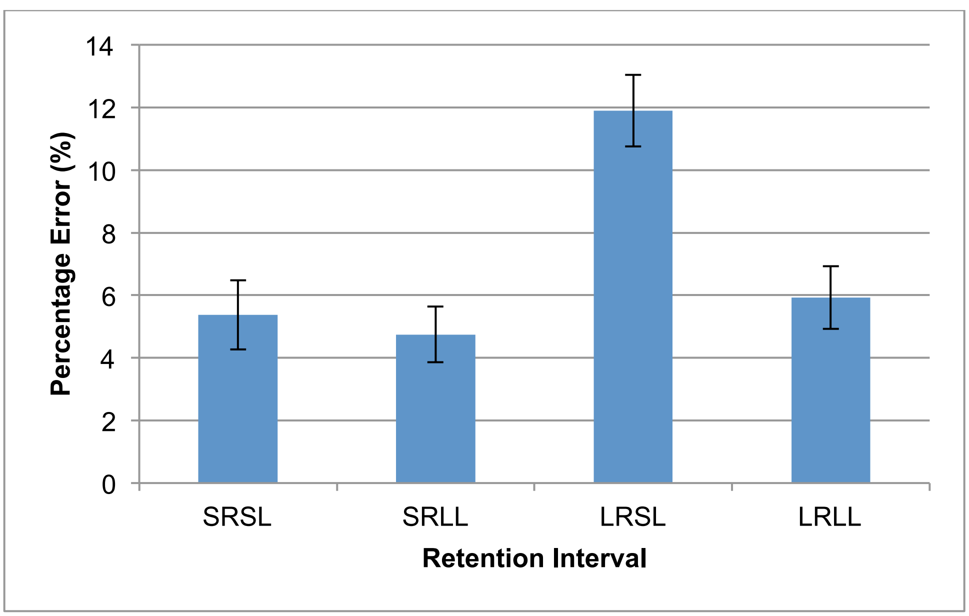

Figure 2-4: Graph summarizing the mean percentage error for older and younger participants on the four types of retention intervals. SRSL= short retention-short lag; SRLL= short retention-long lag; LRSL= long retention- short lag; LRLL=long retention-long lag. Error bars represent standard error.

2.1.3.3 *Effects of age on d'*

d' is a measure of discriminability taking into account participants' response bias, specifically regarding hit rates and false alarms. Hits refer to accurate response of a repeated item as old, while false alarm refers to an inaccurate response of an unrepeated item as old. High discriminability is given by high hit rates and a low false alarm rate. Participants who show a liberal response bias of incorrectly indicating *old* for the stimuli will consequently incur high false alarm rate, resulting in a lower *d'* score. It is important to account for this to ensure age related performances in memory are not due to response bias.

A paired samples *t*-tests analyses revealed a significant difference between older and younger adults, with the younger adults recording significantly higher *d'* scores (mean=3.06, SD=0.68) compared to older adults (mean=2.45, SD= 0.43), $t_{(98.35)}=5.62, p< 0.001$.

2.1.4 Discussion

The results found no effect of ethnicity on recognition memory performance. Although Malaysia is a multicultural society comprising of three races, the three races are very distinct from each other including cultural aspects of learning and access to education. However, participant characteristics of this study showed that among the older adults, years of education did not seem representative of what was reported by Zakariya et al. (2014) where the mean years of education reported seemed higher among the Indians, followed by Malays and the lowest among the Chinese. Furthermore, although education levels were added as a covariate, it did not have a significant effect on the results. As there were no effects of ethnicity, future studies in the thesis will not consider effects of ethnicity.

Consistent with previous studies (Ally et al., 2008; Friedman, 2003; Kılıç et al., 2013; Nielsen-Bohlman & Knight, 1995; Swick & Knight, 1997), it was found that older adults showed significantly poorer performance on both short and long lags compared to younger adults, and participants showed better memory performance when the interval between initial and repeated presentation was short (short lag), compared to when they were relatively longer (long lag). However, in line with the space effect, both older and younger participants showed benefit of space learning, as R1 items that were presented for the 2^{nd} time at a longer lag were better remembered compared to items presented at a shorter lag.

In terms of short retention, there was no significant difference in recognition memory performance at second repetition (R2) for either short lag (SRSL) or long lag (SRLL) items. In contrast, for long retention, items that were presented at short lag (LRSL) led to poorer performance compared to items presented at long lag (LRLL), and also for both conditions of short retention (SRSL and SRLL).

It is interesting to note that although shorter lag for R1 led to better memory performance; this pattern was reversed at R2 after a long retention interval (LRSL). In addition, older adults and younger adults performed equally on the 2^{nd} repetition, indicating that memory impairments accompanied by ageing is seen in the first repetition but is overcome by repetition. According to Dankert and Craik (2013), older adults' performance in recognition memory has shown to be unaffected due to familiarity as they can rely more on this process in recognition tests. This suggests that with repetition, older adults are able to compensate for this impairment as repetition may enhance familiarity, consequently leading to better recognition.

As the condition of long retention-short lag (LRSL) led to poorer performance in recognition memory compared to all other conditions, with no difference in performance among the 3 conditions, it would be interesting to explore this paradigm and the factors that influence it. Hence, the rest of the studies in this thesis will use a simpler modified memory paradigm where items are presented for the first time (new) some repeated after a short interval of intervening items (R1) and repeated again for the third time after a longer interval (R2). The modifications include controlling the spacing between the stimuli, i.e. 5-7 intervening items for the first repetition (R1) and 37-39 intervening items for second repetition (R2). In addition, each repetition type will consist of more items, i.e. 55 new items, 50 R1 items and 55 R2 items, in order to find more robust effects in ERPs and behavioral data.

As this study only looked at behavioral data, it would not be able to give much insight in understanding underlying neural processes supporting recognition memory. Using event related potentials (ERPs) would be beneficial to understand the underlying processes supporting recognition memory, particularly the role of familiarity and recollection. In the next experiment, the effects of repetition and lag on these neural correlates in supporting recognition memory were investigated.

2.2 Experiment 2: ERP old/new effects of spacing and repetition in visual recognition memory

2.2.1 Introduction

The objective of this study is to explore the event related potentials (ERP) underlying recognition memory by modifying the recognition memory paradigm used in experiment 1. Prior research using ERPs has found three neural signatures in old/new recognition tasks. The first, known as the frontal old/new effect (FN400) has been consistently associated with familiarity is found where items correctly classified as 'new' elicits a negative going wave compared to items correctly classified as 'old', usually around 300-500 ms post stimulus onset at the frontal sites (Curran & Cleary, 2003; Curran, Tepe, & Piatt, 2012; Rugg & Curran, 2007; Rugg & Yonelinas, 2003).

The second neural signature associated with recollection is known as the parietal old/new effect, or the late parietal component (LPC), where items correctly classified as 'old' elicits a more positive going wave compared to items correctly classified as 'new' at 500-800 ms post stimulus onset at the parietal sites (Curran & Cleary, 2003; Curran et al., 2012; Rugg & Curran, 2007; Rugg & Yonelinas, 2003).

The third component, the late frontal effect (LFE) occurs at the frontal sites at approximately 1000 -1800 ms post stimulus onset and has been implicated with post-retrieval monitoring processes such that it is responsible for holding information in working memory and evaluating memory content for details relevant to the task (Allan et al., 1998; Ally & Budson, 2007; Ally et al., 2008). Post retrieval monitoring is needed when there are difficulties in retrieval or when additional information is needed (Achim & Lepage, 2005)

The objective of this study is to determine the effects of repetition on the ERP correlates of recognition memory, namely the FN400, the LPC and the LFE to dissociate the effects of familiarity, recollection, and post-retrieval monitoring.

2.2.2 Methods

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus.

2.2.2.1 *Participants*

Thirty younger adults between the ages of 18- 30 participated in the study. Data from a total of 7 younger participants were excluded, because 1 showed depressive symptoms (See section 2.2.2.2 or further details on the screening criteria, and appendix A.9 for mean scores of participants). Data from 6 younger participants were excluded due to technical difficulties during EEG recording resulting in a final number of 23 younger adults (mean age= 21.00, SD= 2.16), comprising of 8 males and 15 females. All participants were students from the University of Nottingham Malaysia Campus with normal or corrected-to-normal vision. Participants who took part in experiment 1 did not participate in this experiment.

2.2.2.2 *Materials*

2.2.2.2.1 Questionnaires

Similar to experiment 1, all participants completed the BDI and were only included in the study if they obtained a score of 17 and below.

2.2.2.2.2 Stimuli

The stimuli used in the experiment were identical to the stimuli used in Experiment 1, and presentation of stimuli was controlled using E-Prime software version 2.0 (Schneider et al., 2002) and a desktop computer.

2.2.2.3 *Design*

The design of the experiment was a 3 way repeated measures design, with repetition (new vs R1 vs R2) as the within subjects factor. The dependent variables assessed in the experiment were accuracy level (represented by percentage error) and response time (RT) in milliseconds. Stimuli were presented for the first time (new), repeated for the 1st time after 5-7 intervening items (R1) and then repeated again for the 2nd time after 37-39 intervening items (R2). There were 3 practice sessions consisting of 10 trials (6 new and 4 R1 items) to ensure participants understood the instructions before proceeding to the experiment. There were a total of two experimental blocks, consisting of 270 stimuli in the two experimental blocks. In each experimental block, there were 55 new items, 50 R1 items and 30 R2 items, amounting to 135 trials in every block. In total, across the 2 experimental blocks, every participant responded to 110 new items, 100 R1 items and 60 R2 items.

2.2.2.4 *Procedure*

2.2.2.4.1 Behavioral task

The procedure for this experiment was identical to experiment 1. See **Figure 2-2** for the flow diagram of the experimental procedure. However, there were some modifications made where the fixation cross was presented for 1000 ms, and the target stimuli (image) was presented for 3000 ms. Participants responded ‘new or ‘old’ within the time frame using a button box to minimize movement. An absence of responding during the time frame would cause the next trial to start, with ‘no response’ being recorded.

2.2.2.4.2 Electroencephalogram (EEG) recording and pre-processing

Prior to recording, an appropriate sized 128-channel Geodesic Sensor Net™ (Tucker, 1993) based on the measurement of the circumference of the participants’ head was selected and prepared for the experiment. There were three sizes of EEG nets available differing in the size of the circumference, i.e. small (54-56 cm), medium (56-58 cm) and large (58cm and above). The EEG cap was prepared by soaking it in an electrolyte solution, comprising of distilled water, potassium chloride and a small amount of baby shampoo). This is to ensure the electrodes on the EEG cap were soaked with the electrolyte solution to enable the conduction of electrical potentials from the participants’ scalp to the EEG system. The small amount of baby shampoo was included in order to break down any oils on the participants’ scalp, which may interfere with conduction of signal.

Participants’ head was measured to locate the vertex (central point on top of their head). This was done by first measuring the nasion (lower depression at the top of the nose, between the eyebrows) to the inion (small bump at the back of the head) marking at the halfway point with a soluble marker. The left and right pre-auricular points (the depression just in front of the ear, near where the lower jaw joint is) were then measured and the halfway point was marked with a soluble marker. Where these two halfway points met was the vertex; it was marked with ‘X’ and made the reference point to place the central reference electrode, which is marked with VREF. The saturated EEG cap was then placed on the participant’s head, ensuring the electrode marked with VREF was placed on the vertex marked with ‘X’, and held in place with gentle radial compression, where the net was adjusted to each participant’s head comfortably.

Participants were seated in a Faraday chamber, which provided electromagnetic shielding to reduce noise in EEG data. The data acquisition computer and the stimulus control computer were placed outside the Faraday cage within the control of the experimenter. For stimulus presentation, a 19” LCD monitor was placed in the Faraday chamber, where participants were seated 60 cm away from it, with a button box for response.

Impedances across all 128 channels were kept below 50 KΩ. Checks were carried out during each break. In the instance the impedence was below 50 KΩ, a pipet filled with electrolyte was used to saturate the electrode sponge and maximum electrode contact with the scalp was ensured. The EEG signal was digitized online at 250 Hz and band-pass filtered between 0.1 and 200 Hz. The ground electrode was positioned at the vertex (i.e. along the midline, anterior to Fz).

Following acquisition, EEG data were segmented off-line into single-trial epochs of 1700 ms (200 ms pre-stimulus) and low-pass filtered at 40Hz using NetStation software version 4.5.7 (Electrical Geodesics Inc., Eugene, Oregon). EEG data was segmented into three categories, namely correct responses to new, R1 and R2 trials.

Incorrect responses to the three categories were not computed as there were too few trials to form reliable ERPs.

Blink and eye movement artifacts were detected and marked using the Artifact Detection tool, which includes bad channels of above 200µv, eyeblinks above 140µv and eye movements above 55µ, which were then replaced using data interpolated from the remaining channels. Epochs containing artifacts in one or more channels, as well as noisy channels, were detected and omitted from further analysis. The EEG was re-referenced to the average reference (using Polar Average Reference Effect (PARE)). Finally, stimulus-locked ERPs were created with a 100ms pre-stimulus baseline. Time windows were specified based on the literature (Curran & Cleary, 2003), namely the frontal old/new effects (FN400) occurring at 300-500 ms post stimulus onset; the parietal old/new effect occurring at 500-800 ms post stimulus onset; and the late frontal effect (LFE) occurring at 1000-1500 ms post stimulus onset. Mean amplitudes for the FN400 and the LFE were averaged from 7 channels from each of their respective time windows in 4 regions of interest namely the Right Anterior Inferior (RAI), the Right Anterior Superior (RAS), Left Anterior Inferior (LAI) and the Left Anterior Superior (LAS). Mean amplitudes for the parietal effect were averaged from 7 channels from the 500-800 ms time windows in 4 regions of interest, i.e .the Right Posterior Inferior (RPI), Right Posterior Superior (RPS), the Left Posterior Inferior (LPI) and Left Posterior Superior (LPS). For more information about the 7 electrodes for each region used please see **Figure 2-5**.

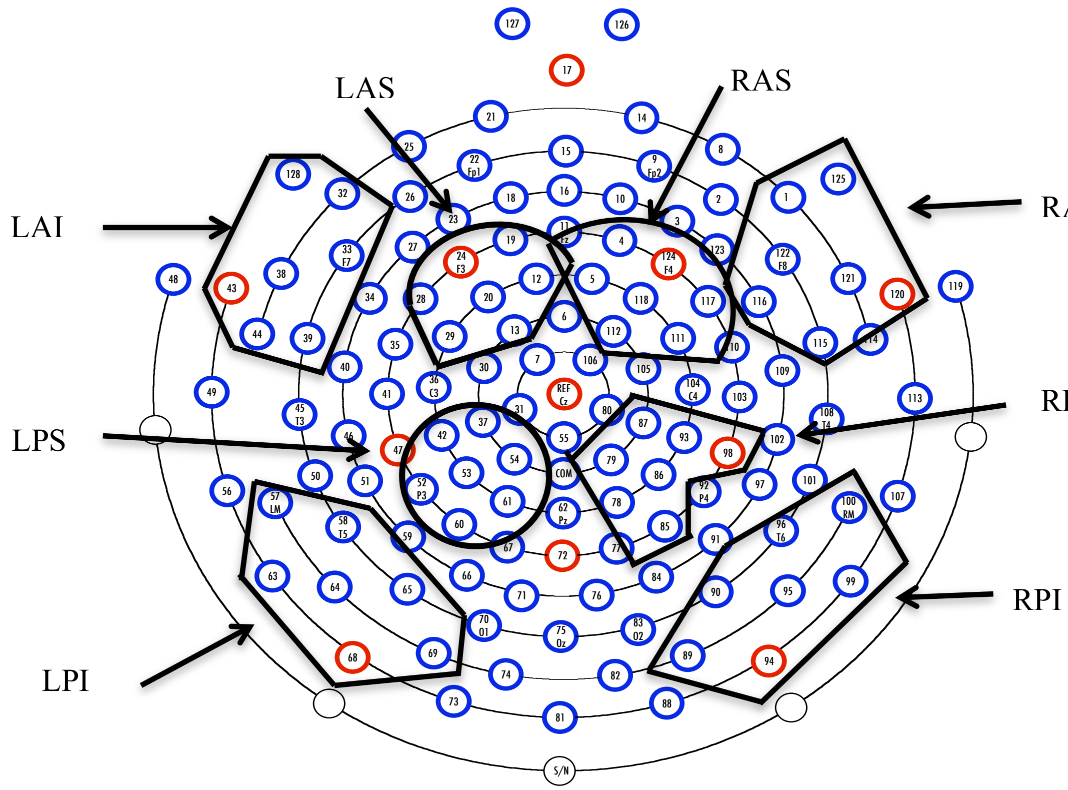

Figure 2-5: Electrode selection making up the eight regions of interests: left anterior inferior (LAI), left anterior superior (LAS), left posterior inferior (LPI), left posterior superior (LPS), right anterior inferior (RAI), right anterior superior (RAS), right posterior inferior (RPI), right posterior superior (RPS). For each region of interest, mean amplitudes recorded from a cluster of 7 channels/electrodes were averaged.

2.2.3 Results

2.2.3.1 *Behavioral results*

Participants' recognition performance was assessed in terms of mean percentage errors made and response time. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses. In cases of violations of sphericity, degrees of freedom were corrected using Greenhouse-Geisser corrections.

2.2.3.1.1 Effects of repetition on percentage error

A repeated measures ANOVA with repetition (new vs R1 vs R2) as within-subjects factors was conducted. There was a significant effect of repetition, $F_{(2, 44)}$= 10.20, p< 0.001, η_p^2 =0.32. Post-hoc paired samples t-tests (Bonferroni corrected p<0.0167) found that participants committed significantly more errors on the R1 trial type (mean=8.01%, SD= 8.64) compared to the new trial type (mean= 3.39%, SD= 4.12), $t_{(22)}$=3.95, p<0.001, and the R2 trial type (mean=4.93%, SD= 8.05%), $t_{(22)}$= 3.95, p<0.001. There were no significant differences in errors committed between the new and R2 trial type (p>0.0167). **Figure 2-6** below shows mean percentage errors made on new, R1 and R2 trials.

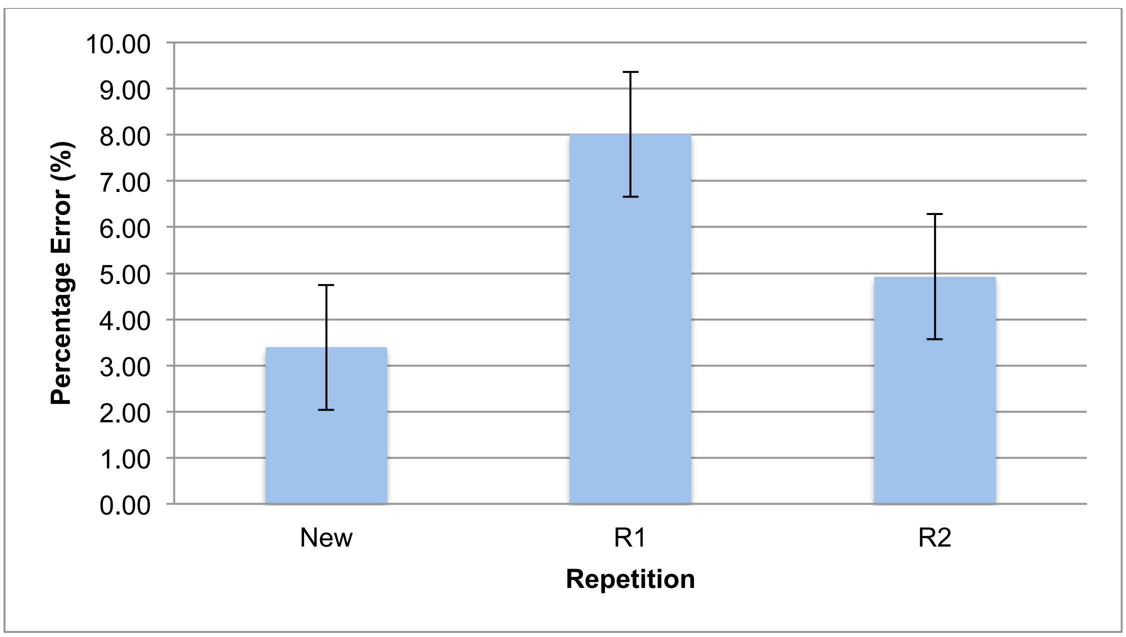

Figure 2-6: Graph summarizing the mean percentage error for participants on the three types of repetition. Participants made significantly more percentage errors on R1 trials compared to both new and R2 trials. New: trials presented for the first time; R1: trials repeated for the first time after 5-7 intervening items; R2: trials repeated for the second time after 37-39 intervening items. Error bars represent standard error.

2.2.3.1.2 Effects of repetition on response time

A repeated measures ANOVA with repetition (new vs R1 vs R2) as within-subjects factors was conducted. There was a significant main effect of repetition, $F_{(1.34, 29.37)}$=4.18, p=0.04, η_p^2 =0.16. However, post-hoc paired samples t-tests (Bonferroni corrected p<0.0167) found no significant differences between all three repetition types (p>0.0167).

Figure 2-7 below shows participants' mean response times on new, R1 and R2 trials.

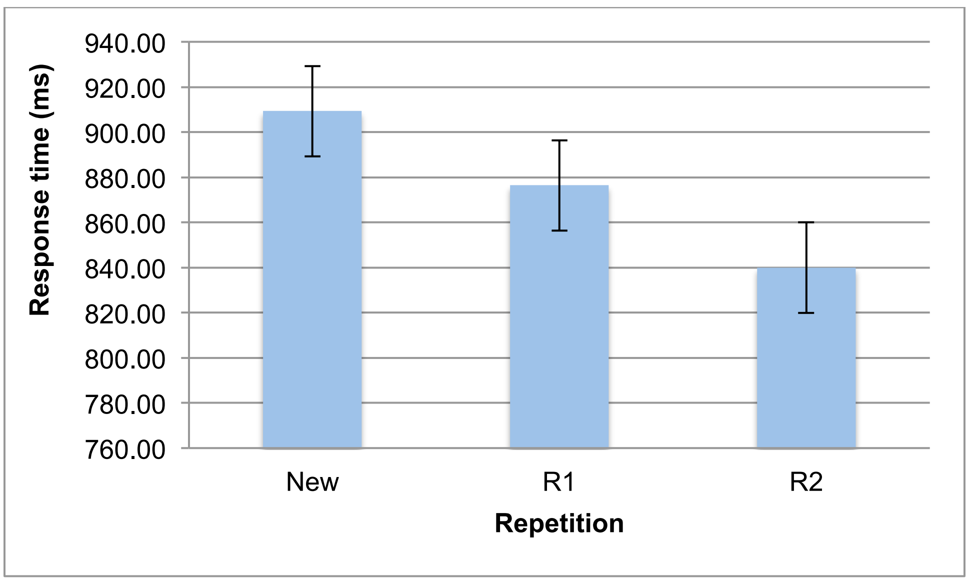

Figure 2-7: Graph summarizing the mean response time (ms) for participants on the three types of repetition. Participants were significantly slower in responding to both R1 and R2 trials. New: trials presented for the first time; R1: trials repeated for the first time after 5-7 intervening items; R2: trials repeated for the second time after 37-39 intervening items. Error bars represent standard error.

2.2.3.2 *ERP results*

Mean amplitude results pertaining to the three time windows representing the FN400, the LPC and the LFE are presented below. Only relevant grand-averaged waveforms are presented.

2.2.3.2.1 FN400

A 3x4 repeated measures ANOVA was conducted with repetition (new vs R1 vs R2) and region (RAI vs RAS vs LAI vs LAS) as the within subjects factors on the time window of 300-500 ms post target onset, with mean amplitude as the dependent measure.

Results found no main effects of repetition, (p= 0.71), region (p=0.15), or a repetition x region interaction (p=0.80).

2.2.3.2.2 LPC

A 3x4 repeated measures ANOVA was conducted with repetition (new vs R1 vs R2) and region (RPI vs RPS vs LPI vs LPS) as the within subjects factors on the time window of 500-800 ms post target onset, with mean amplitude as the dependent measure. There was a significant main effect of region, $F_{(1.57, 34.51)}$=7.20, p<0.001, η_p^2 =0.25, pairwise comparisons (Bonferroni adjusted) revealed higher mean amplitudes in the RPS region (mean= 4.85, SD= 4.51) compared to RPI (mean=1.26, SD=3.94), p=0.01 and LPI region (mean= 1.58, SD = 2.57), p= 0.04, shown below in **Figure 2-8**. There was no main effect of repetition (p=0.68), or a repetition x region interaction (p=0.33).

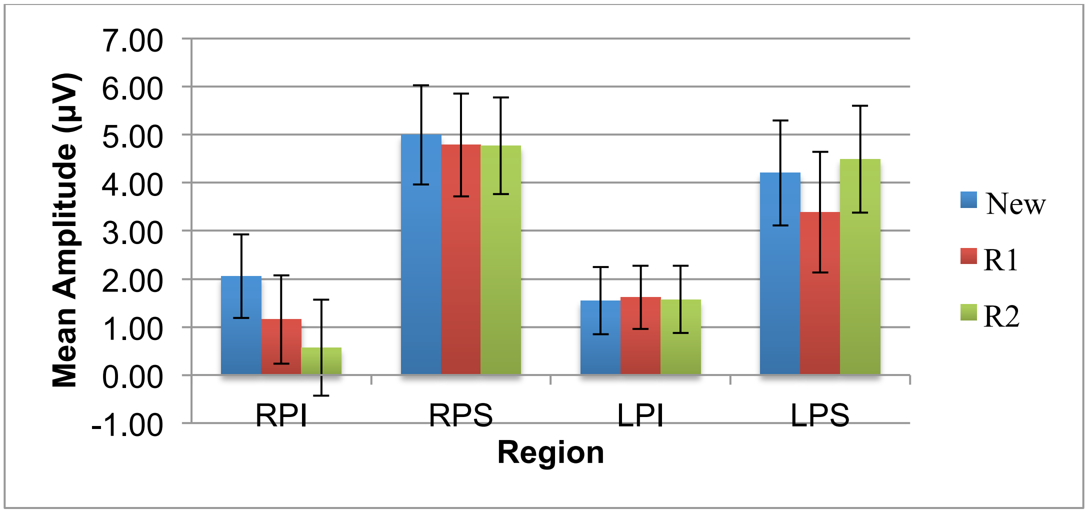

Figure 2-8: Graph displaying the effect of region for the LPC (500-800 ms) time window. RPI= right posterior inferior; RPS= right posterior superior; LPI= left posterior inferior; LPS= left posterior superior. Error bars represent standard error.

2.2.3.2.3 LFE

A 3x4 repeated measures ANOVA was conducted with repetition (new vs R1 vs R2) and region (RAI vs RAS vs LAI vs LAS) as the within subjects factors on the time window of 1000-5000 ms post target onset, with mean amplitude as the dependent measure. There was a significant main effect of region, $F_{(2.32,\ 36.70)} = 3.11$, p=0.03, η_p^2=0.12. Pairwise comparisons revealed higher mean amplitude in the RAS region (mean= 1.02, SD= 3.09) compared to the LAS region (mean=-0.73, SD=3.87), p=0.04. There was no difference in mean amplitudes for other regions, p> 0.05.

While the main effect of repetition was not significant (p=0.34), there was a significant interaction effect of repetition x region, $F_{(2.56,\ 56.31)}$=3.57, p=0.03, η_p^2 =0.14. Further analysis of the repetition x region interaction effect revealed that there was a significant main effect of repetition in the LAS region, $F_{(2,44)}$=3.79, p=0.03. See **Figure 2-9**. Post-hoc paired samples t-tests (Bonferroni corrected p<0.0167) found a reverse old/new effect, where new trials recorded significantly higher mean amplitude (mean=0.97, SD= 4.97) compared to the R1 trials (mean= -2.24, SD= 4.60) $t_{(22)}$= 3.09, p=0.005. See **Figure 2-10** for the reverse old/new effect at the LAS region. There were no other significant differences among all other trial types in all other regions, p>0.05.

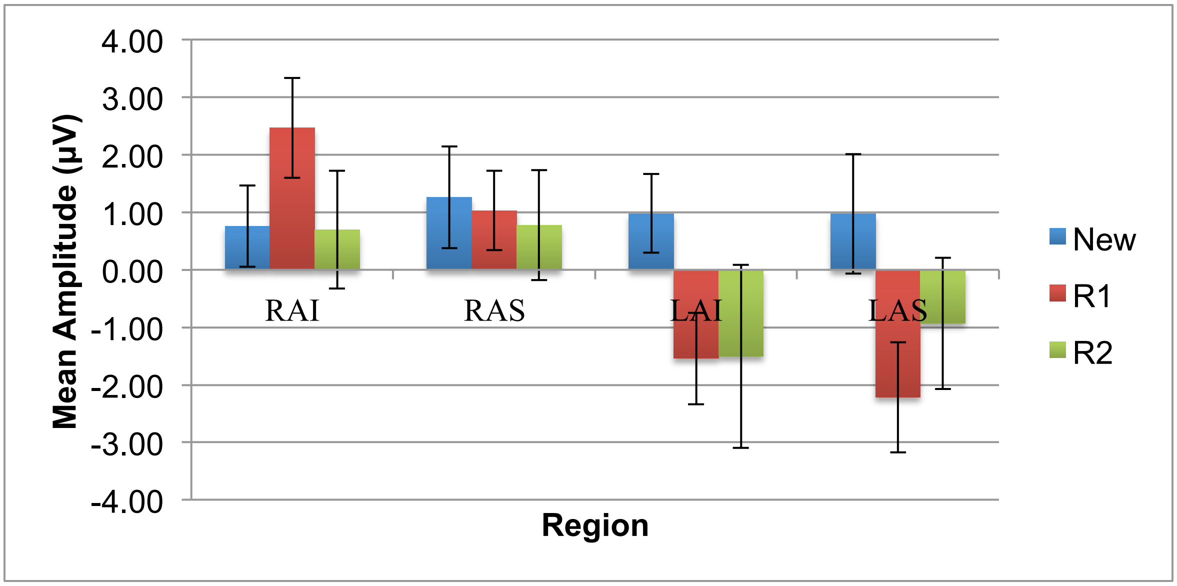

Figure 2-9: Graph displaying the region x repetition interaction effect for the LFE (1000-1500 ms) time window. RAI= right anterior inferior; RAS= right anterior superior; LAI= left anterior inferior; LAS= left anterior superior. Error bars represent standard error.

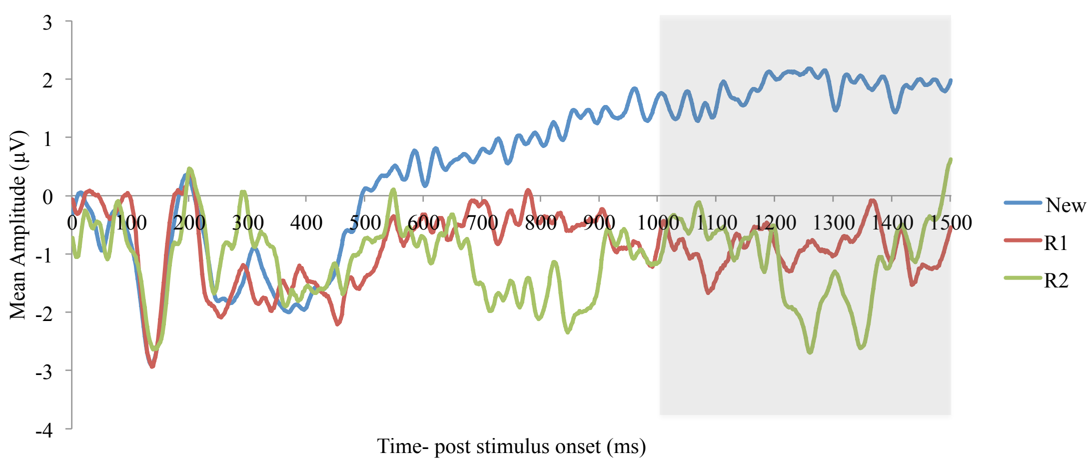

Figure 2-10: Grand average waveform in the LAS region. Time window highlighted to show the old/new effect.

2.2.4 Discussion

The behavioural results indicated that participants made significantly more percentage errors on R1 trials compared to new and R2 trials, which did not differ in errors. Additionally, participants responded slower for new items compared to R1 and R2 items, which is consistent with Kim et al. (2001) who found longer response time for items that were new compared to repeated immediately.

Contradictory to previous research, there was no effect of repetition on mean amplitudes in the time window representing the FN400 component. There was an effect of region in the time window representing the LPC component. There was significantly higher mean amplitude in right posterior superior (RPS) compared to the left posterior superior (LPS) site. As for the LFE, the mean amplitude for new items was significantly higher compared to the R1 items but only in the left anterior superior (LAS) region,

2.3 General Discussion

The main objectives of both experiments were 1) to determine if there were effects of ethnicity given the multicultural context of Malaysia, since the stimuli used were not created in Malaysia, but in a Western context 2) to determine an appropriate recognition memory paradigm 3) to determine if the memory paradigm can detect age-related changes in performance and 4) to explore the underlying ERP correlates of recognition memory. With regards to experiment 1, the results showed there were no effects of ethnicity; hence future studies would not investigate ethnicity further as a factor.

In line with previous research (Friedman, 1990b; Henson et al., 2004; Kim et al., 2001; Palmeri et al., 1993) results also indicated that participants recognition memory performance decreased as lag increased. However, it was not in agreement with (Friedman, 1990a), who found effects of lag when words were used as stimuli, but was not present when pictures were used instead, reasoning that pictures allowed better encoding to overcome the effects of lag.

However, a major difference with this experiment compared to prior experiments is that the number of intervening items was not fixed, but allowed to vary due to the randomization process. Hence, items that were repeated after 19 or less intervening item were classified as short lag, whereas items repeated after 20 – 100 intervening items were classified as long lag. In retrospect, too much of variation is a limitation in the study.

In relation to past studies (Ally et al., 2008; Friedman, 2003; Kılıç et al., 2013; Nielsen-Bohlman & Knight, 1995; Swick & Knight, 1997) the findings also showed that older adults performed significantly poorer compared to younger adults at both lags. However, in agreement to Kılıç et al. (2013), older adults did show benefits of space learning as well as repetition, as these age effects disappeared on 2nd repetition (R2), where the main effect of age was not significant on all four conditions of retention. However it should be noted that due to the fewer trials in retention, there might not have been sufficient power to detect a main effect, hence this finding should be interpreted with caution.

With respect to the third presentation, one of the strengths of this study was that it was able to compare the effects of long retention to short retention, as prior studies only looked at the effect of lag interval on retention (James et al., 2009; Kılıç et al., 2013;

Zhao et al., 2014). Results found that participants were able to show better performance in the short retention interval, regardless of the length of lag, as equally as long retention of long lag items (LRLL). Hence, while results do concur with prior findings (James et al., 2009; Kılıç et al., 2013; Zhao et al., 2014) that long lag items, although led to poorer recognition memory performance on 1st repetition (R1) this definitely does not indicate poorer memory as these items were better recognized during the second repetition (R2) compared to short lag items. In agreement with Kılıç et al. (2013), poorer memory retrieval could lead to better retention.

Overall, due to the LLSR having a significantly higher percentage error compared to all other conditions, with no difference in percentage errors between the other three conditions, this recognition memory paradigm was further refined. In addition, the number of intervening items was also fixed to between 5-7 intervening items to represent the 1st repetition (short lag) and 37-39 intervening items to represent the 2nd repetition (long retention).

Experiment 2 found that although there were no differences in response time between the two repetitions (R1 and R2); participants were significantly slower to respond to new items compared to the repetitions. This is in line with Kim et al. (2001) who reasoned that the longer response time could be attributed for memory search for whether the item had been encountered before a ‘new’ response can be made. With respect to percentage error, findings show that participants made more errors with first repetition (R1) compared to second repetition (R2).

Findings were also in agreement with past research (James et al., 2009; Kılıç et al., 2013; Zhao et al., 2013) that although participants show difficulties in recognition during the 2nd repetition (as shown here by their higher percentage error), on third repetition, they were able to show significantly better memory performance, given by lower percentage error.

The analyses of the underlying ERP correlates were subsequently analyzed guided by prior work studying ERP correlates of recollection and familiarity in recognition memory (Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Doyle, 2001; Curran & Cleary, 2003; Nyhus & Curran, 2009).

Firstly, there appeared to be no effects in the FN400, this could be due to the use of pictures in the experiment whereby the use of pictures could have led to an emphasis on recollection rather than familiarity. For example, Friedman, (1990a) found that pictures led to better encoding compared to words, which could be why participants were making discriminations based mainly on recollection rather than familiarity. A particularly interesting finding that may shed some light on our lack of an effect in the FN400, was the finding by Ally and Budson (2007) that varied words and pictures during study and test. When words were used during study, the frontal effect was enhanced. On the other hand, when pictures were used during study, the parietal effect was enhanced instead. This lends further support that using pictures in recognition memory facilitate the recollection mechanism in recognition memory rather than the familiarity mechanism in recognition memory. In support of this, there was enhanced mean amplitude in the LPC time window representing recollection. The lack of effects in the RPI and LPI regions can be in line with past research that did not look at these sites as the recollection effect may be observed only in the posterior sites. However, in contradiction to past research (eg. Ally & Budson, 2007; Ally et al., 2008; Curran, 2000; Curran & Cleary, 2003) although there was an overall enhanced mean amplitude in the RPS, there were no old/new effects observed in this region. This was surprising because the behavioral findings obtained show a distinction in performance between the new items and the repeated items, where participants were slower to respond to new items compared to repeated items, and made more errors in responding to R1 items compared to both new and R2 items. The lack of a significant difference between the new and repeated items can be attributed to the large standard error.

An interesting finding was the interaction effect of repetition x region in the LAS region for the LPC effect that is associated with post-retrieval monitoring of source content. Only in the LAS region, there appears to be a dissociation of new and R1 trials where new trials were significantly more positive going than R1 trials. This is known as the reverse old/new effect (Ally & Budson, 2007) as typical old/new effects are represented as repeated items recording significantly higher mean than new items. It has also been suggested that the LFE is associated with decision- making or memory confidence (Dobbins & Han, 2006; Fleck, Daselaar, Dobbins, & Cabeza, 2006). This is in line with current results where R2 trials stimulate decision-making or evaluation of memory in participants before deciding if the item was repeated, as behavioral results show that participants made more errors for R1 trials compared to new or R2 trials. For instance, encountering a repeated item for the first time could lead participants to have lower confidence and question their decision in discriminating the item as new. However, items that were repeated for the 2^{nd} time (R2) were responded with greater confidence, given by lower percentage error rate, which could indicate an absence of a memory evaluation or decision-making, and a more automatic process.

As the recognition memory tested in this chapter was purely in the visual modality, it would be interesting to explore how repetition can affect recognition memory in different modalities, particularly as modalities that we encounter in everyday life are mainly visual and auditory. This brings about the following question: How does repetition affect recognition memory across different modalities?

CHAPTER 3

MODALITY AND REPETITION IN CROSS-MODAL RECOGNITION MEMORY

Research has found that multisensory stimuli compared to uni-sensory stimuli (visual, auditory and somatosensory) leads to facilitation in simple reaction time tasks (Mahoney et al., 2011; Molholm et al., 2002). Additionally, ERP and functional imaging data has shown successful integration of multi-modal information across sensory systems occurring early in the cortical processing hierarchy when participants were presented with multisensory stimuli compared to uni-sensory stimuli (Foxe et al., 2002; Martuzzi et al., 2007; Molholm et al., 2002; Schroeder & Foxe, 2005b). In regards to recognition memory, there has been much evidence to support that initial encounters in multi-sensory modalities (cross-modal) improves subsequent discrimination in a uni-modal modality, compared to initial encounters in the uni-sensory modality (Lehmann & Murray, 2005; Moran et al., 2013; Murray et al., 2004; Thelen et al., 2015; Von Kriegstein & Giraud, 2006).

From a neural perspective, it has been shown that exposure to multisensory stimuli incorporates a distinct neural network, which can be activated with just repetition of visual stimuli alone using (Nyberg, Habib, McIntosh, & Tulving, 2000). For instance when participants were to make old/new discriminations to repeated visual stimuli, stimuli that had been previously exposed to both visual and auditory stimuli led to higher activation in the visual object recognition areas (right lateral-occipital complex), compared to repeated visual stimuli that had been presented uni-modally (Murray et al., 2005). In a similar recognition memory paradigm, discrimination of visual stimuli that had been previously presented cross-modally elicited waveforms approximately 60-136 ms earlier at post- stimulus onset compared to visual stimuli that had been presented uni-modally (Murray et al., 2004). As modality of stimuli has been shown to have an effect on recognition memory, the aim of this chapter is to investigate the effects of different modalities on recognition memory and how this is modulated with age. Experiment 3 compares recognition memory performance, across three types of modalities, namely visual, auditory and cross-modal (visual and auditory); while experiment 4 looks at the effects of age on the cross-modal recognition memory test to see if older adults show a larger benefit when information is presented from two modalities and with repetition

3.1 Experiment 3: Effects of modality and repetition on recognition memory

3.1.1 Introduction

The aim of this study is to compare recognition memory performance across the three modalities, namely visual, auditory and cross-modal, and to determine the effects of repetition among the three modalities.

While past studies has shown that participants show poorer recognition memory performance in the auditory modality compared to visual modality (Bigelow & Poremba, 2014; Cohen et al., 2009), and also benefits of using cross-modal stimuli (Lehmann & Murray, 2005; Moran et al., 2013; Murray et al., 2004; Thelen et al., 2015; Von Kriegstein & Giraud, 2006) it is not clear how recognition memory performance differ upon subsequent repetition. It is hypothesized that with repetition, performance in the auditory modality can improve and there should not be significant differences in recognition memory performance among the three modalities on the R2 repetition trials. This experiment will only look at recognition memory performance among younger adults, as age effects will be explored in the following experiment.

3.1.2 Method

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus.

3.1.2.1 *Participants*

Forty-eight participants were recruited for this study. Data from 3 participants were discarded as they either reported depressive symptoms or suffered from auditory or visual problems (See section 3.1.2.2.1 for further details on the screening criteria, and appendix A.9 for participants mean scores). This resulted in a total number of 45 participants. Participants were split into three groups, comprising of 15 participants in each group, i.e. visual (mean age=19.87, SD=2.29), auditory (mean age= 21.73, SD= 3.65) and cross-modal (mean age= 21.13, SD= 2.80). Participants were compensated with RM 5 for their participation. Participants in the visual and cross-modal condition did not participate in experiment 1 and 2.

3.1.2.2 *Materials*

3.1.2.2.1 Questionnaires

As experiment 1 and 2, participants completed the BDI to screen for depressive symptoms.

3.1.2.2.2 Stimuli

The stimuli of the experiment consisted of images and auditory clips of spoken words obtained from the ADEPT database (Kilborn et al., 2009). The visual stimuli were identical to that presented in experiment 1 and 2. See appendix B.2 for list of auditory stimuli, and appendix B.3 for sample cross-modal stimuli. Presentation of stimuli was controlled using E-Prime software version 2.0 (Schneider et al., 2002).

3.1.2.3 *Design*

The design was a 3 x 3 mixed design approach with repetition as the within subjects factor (new, R1 and R2), and modality as the between subjects factor. Modality refers to the type of stimuli the participants were exposed to, i.e. visual, auditory and cross-modal (CM) (See **Figure 3-1** for further details). The visual condition consisted of only visual images, whereas the auditory condition required participants to listen to a spoken word presented with a gray background. In the cross-modal condition, participants were presented with a visual image, and an associated spoken word. The coloured images were presented in central vision on a black background, and the spoken words were presented through and were presented using headphones adjusted to a volume level that was comfortable to the participants.

There were three practice sessions consisting of 10 trials to ensure participants understood the instructions before proceeding to the experiment. There were two experimental blocks, each consisting of 135 trials (55 new, 50 R1, and 30 R2).

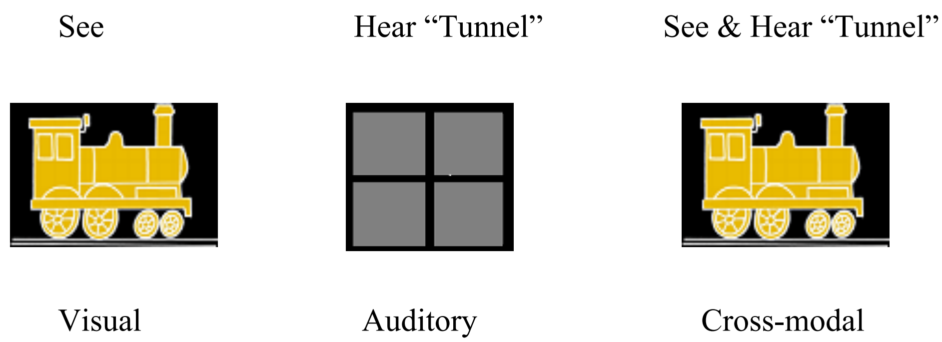

Figure 3-1: The conditions in experiment 3. The visual condition consisted of images only; the auditory modality consisted of spoken words paired with a fixation cross; whereas the cross-modal condition consisted of presentation of both images and an associated spoken word simultaneously.

3.1.2.4 *Procedure*

All participants were given written and verbal instructions describing the experimental procedures. After giving informed consent, participants were randomly assigned to either the visual, auditory or cross-modal condition and were seated at about 60 cm from the laptop screen and fixated at a cross at the center of the screen. The experiment began with 2 practice blocks, followed by 1 experimental block, 1 practice block and a final experimental block. There was an option to take a break between the blocks.

Before the start of the experiment, all participants were informed that stimuli from one block would not be repeated in another, and to respond as quickly and accurately as possible. Each block began 500 ms blank interval of a black background, followed by a text display with instructions. Once participants were ready, they were required to press the space bar to continue. For every trial, participants were presented with a blank screen for 500 ms, a fixation cross for 500 ms and a target stimulus that remained on the screen until a response was made. Depending on the condition they were assigned to, the target stimuli were an image (visual), a spoken word (auditory), or an image and a spoken word presented together (cross-modal). Participants were to indicate whether the target stimuli was new or a repeated presentation (R1 or R2), by either pressing the 'n' key (labeled new) or 'v' key (labeled old) on the keyboard. The target stimuli appeared until participants made an old/new decision. Please see **Figure 3-2** for the experimental flow of the three conditions in the experiment. Following the experiment, all participants completed the BDI.

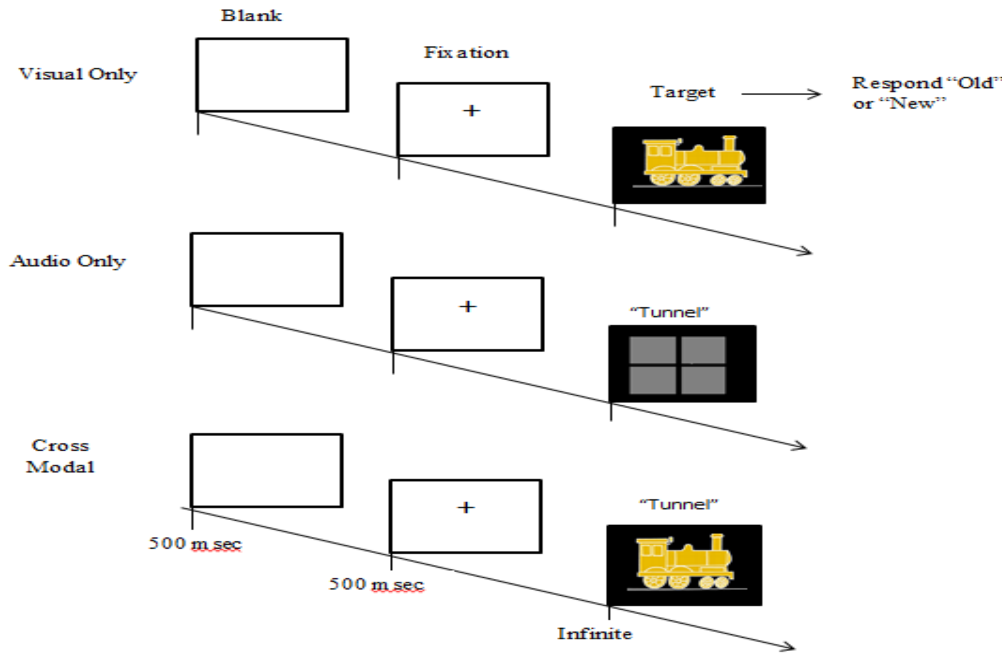

Figure 3-2: Flow diagram of the experimental procedure used in experiment 3. There were three conditions in the experiment: Top: Visual condition where the target stimuli were images; Middle: Auditory condition where the target stimuli were spoken words; Bottom: Cross-modal condition where the target stimuli were images presented with an associated spoken word.

3.1.3 Results

Participants' recognition performance was assessed in terms of mean percentage errors made, response time and *d'*. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses. In cases of violations of sphericity, degrees of freedom were corrected using Greenhouse-Geisser corrections.

3.1.3.1 *Effects of modality and repetition on percentage errors*

A mixed-design ANOVA with repetition (new vs. R1 vs. R2) as within-subjects factor; and modality (visual vs. auditory vs. cross-modal) as between subjects factor was conducted. There was a significant main effect repetition type, $F_{(2,84)}$=17.82, p< 0.001, η_p^2 = 0.30 with participants making significantly more percentage errors in the R1 trials (mean= 7.41%, SD = 3.23) compared to new (mean=3.97%, SD = 1.99) and R2 trials (mean=3.10 %, SD = 2.30), all at p< 0.001. There were no significant differences between new and R2 trial types, p>0.05

There was also a significant main effect of modality, $F_{(2,42)}$=4.15, p=0.02, η_p^2 = 0.17. Participants in the cross-modal condition (mean= 2.83 %, SD= 3.50) made significantly lower errors compared to participants in the auditory (mean=5.56 %, SD= 4.68) and visual conditions (mean=6.07 %, SD= 6.52). There were no significant differences in percentage errors made between auditory and visual condition, p>0.05.

There was also an interaction repetition x modality interaction, with $F_{(4,84)}$=8.14, p< 0.001, η_p^2 = 0.28. The interaction effect is explored below:

3.1.3.1.1 Effects of modality on percentage errors across new, R1 and R2 repetition trials

Three separate one-way ANOVAs were carried out to determine the effect of modality on new, R1 and R2 repetition type. There was an effect of modality on the R1 trials, $F_{(2,42)}$= 8.54, p< 0.001 and R2 trials, $F_{(2, 42)}$=4.20, p=0.02, but no effect of modality on the new trials, p> 0.05.

Pairwise comparisons (Bonferroni adjusted) showed that in the R1 trials, participants in the visual condition made significantly higher percentage errors (mean= 12.12%, SD= 7.46) compared to the auditory condition (mean= 6.11%, SD= 5.01), p=0.02 and the cross-modal condition (mean= 3.99%, SD= 3.58), p=0.001. In the R2 trials, participants in the auditory condition made significantly more errors (mean= 5.48%, SD= 5.79) compared to participants in the cross-modal condition (mean= 1.45%, SD= 2.26), p=0.03. There were no significant differences in errors made in the R1 trials between participants in the visual and cross-modal modality, or visual and auditory modality, p> 0.05.

3.1.3.1.2 Effects of repetition on percentage errors across visual, auditory and cross-modal modalities

Three separate repeated measures ANOVAs were carried out to determine the effect of repetition on visual, auditory and cross-modal condition.

There was an effect of repetition for cross-modal modality, $F_{(2,28)}$=6.28, p<0.001 and visual modality, $F_{(2,28)}$=18.48, p< 0.001. However, there was no effect of repetition in the auditory modality, p>0.05. Post-hoc paired samples t-tests (Bonferroni corrected p<0.0167) found that participants in the cross-modal condition reported significantly lower percentage error in the R2 trial type (mean=1.45, SD= 2.26) compared to the R1 trial type (mean=3.99, SD= 3.58), $t_{(14)}$= 3.15, p= 0.007. Participants did not differ significantly in the percentage of errors made in the new trial type (mean= 3.07, SD= 4.13) and the R1 trial type, or with the R2 trial type, p>0.0167

In addition, participants in the visual condition, made significantly more errors in responding to the R1 trials (mean=12.12%, SD= 7.46) compared to new trials (mean=3.72%, SD= 2.98), $t_{(14)}$= 4.05, p=0.001 and the R2 trials (mean=2.37%, SD= 3.03), $t_{(14)}$= 4.94, p<0.001. The percentage of errors made in the new trial type and the R2 trials did not differ significantly (p> 0.0167). However, there were no significant differences in percentage errors made for the 3 repetition types in the auditory condition (new: mean= 5.11%, SD= 3.12, R1: mean=6.11%, SD= 5.01, R2: mean=5.48%, SD=5.79, $p > 0.05$). See **Figure 3-3.**

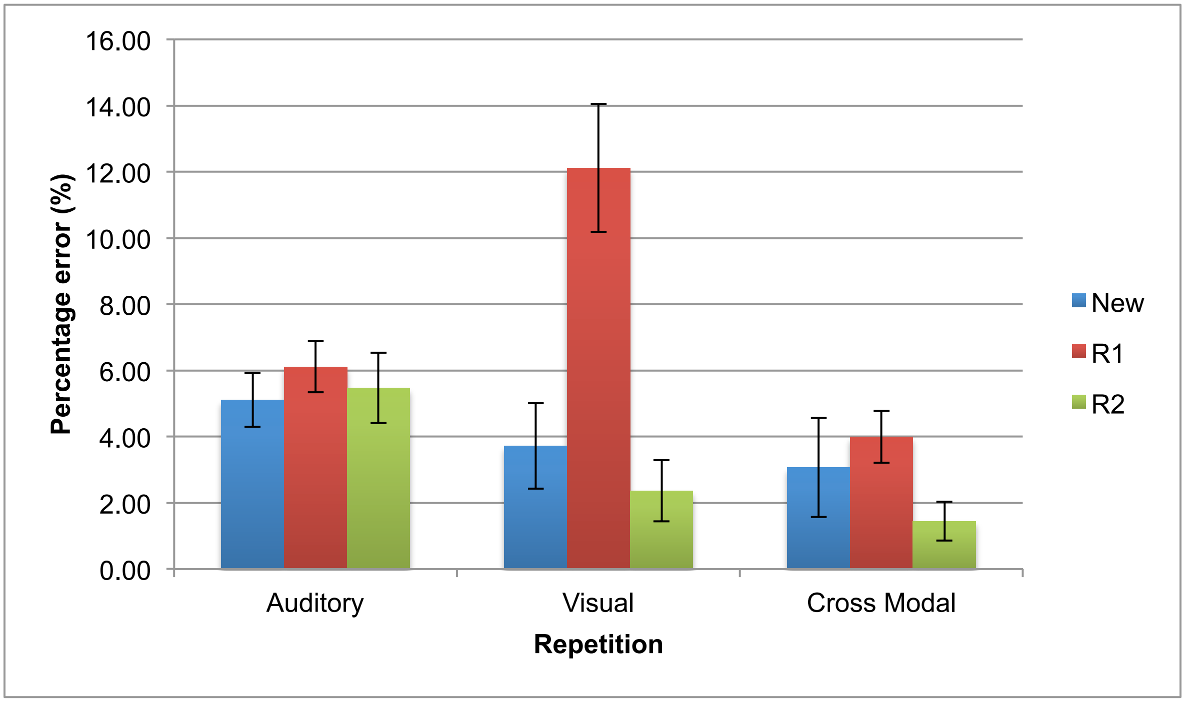

Figure 3-3: Graph of mean percentage errors made for new, R1 and R2 trials in each modality condition, showing the modality x repetition interaction effect. Errors bars represent standard error

3.1.3.2 *Effects of modality and repetition on response time*

A mixed-design ANOVA with repetition type (new vs. R1 vs. R2) as within-subjects factor; and modality (visual vs. auditory vs. cross-modal) as the between subjects factor was conducted. There was a significant main effect of repetition, with $F_{(2,84)}=34.45$, $p< 0.001$, $\eta_p^2=0.45$. Pairwise comparisons revealed faster response times to trials presented for the 2nd time after a long delay (R2) (mean= 846.17 ms, SD=168.69) compared to trials presented for the 1st time following a short delay (R1) (mean=904.29

ms, SD= 157.59) and new items (mean= 929.81 ms, SD= 190.03), all at $p< 0.05$. There was also a main effect of modality, $F_{(2,42)}=8.93$, $p< 0.001$, with participants showing faster response times in the visual (mean= 810.83 ms, SD= 135.56) and cross-modal conditions (mean= 850.55 ms, SD= 157.04) compared to the auditory condition (mean=1018. 89 ms, SD= 158.64), all at $p<0.05$). However, there were no significant differences between the visual and cross-modal conditions, $p>0.05$.

There was a repetition x modality interaction observed, $F_{(4,84)}=5.30$, $p< 0.001$, $\eta_p^2= 0.20$. The interaction effect is explored below:

3.1.3.2.1 Effects of modality on response time across new, R1 and R2 repetition types

Three separate one-way ANOVAs were carried out to determine the effect of modality on response time of new, R1 and R2 repetition type. There was an effect of modality on all repetition types (new: $F_{(2,42)}= 9.06$, $p<0.001$; R1: $F_{(2,42)}= 4.77$, $p=0.01$; R2: $F_{(2, 42)}=12.53$, $p< 0.001$).

Analyses of all trials (new, R1 and R2) showed the same trend. Participants in the auditory condition (new: mean= 1068.46 ms, SD= 161.83; R1: mean=998.96 ms, SD= 164.99; R2: mean= 989.26 ms, SD= 147.24) were significantly slower to respond to the trials compared to the visual condition (new: mean= 821.23 ms, SD= 150.16; R1: mean= 852.15 ms, SD= 132.52; R2: mean=759.09 ms, SD= 113.28); and the cross-modal condition (new: mean= 899.73 ms, SD= 174.81; R1: mean= 861.77 ms, SD= 137.18; R2: mean=790.15 ms, SD = 146.62). All p values<0.05.

3.1.3.2.2 Effects of repetition on response time across visual, auditory and cross-modal modalities

Three separate repeated measures ANOVA's were carried out to determine the effect of repetition on participants' response times in the visual, auditory and cross-modal condition.

There was an effect of repetition on all modality conditions (cross-modal: $F_{(2,28)}$= 14.35, p< 0.001; visual: $F(_{2,28})$= 17.54, p< 0.001; auditory: $F_{(2, 28)}$ =13.71, p< 0.001).

Post-hoc paired samples t-tests (Bonferroni corrected p<0.0167) found that participants in the cross-modal modality had significantly faster response times in the R2 trial type (mean=790.15 ms, SD = 146.62) compared to the new trial type (mean=899.73 ms, SD= 174.81), $t_{(14)}$=4.11, p=0.001) and the R1 trial types (mean=861.77 ms, SD= 137.18), $t_{(14)}$=6.87, p<0.001). There were no significant difference in response times between the new and R1 trial types, p>0.05.

Likewise, participants in the visual modality responded significantly faster to the R2 trials (mean=759.09 ms, SD= 113.28) compared to the new trial type (mean=821.23 ms, SD= 150.16), $t_{(14)}$=3.74, p=0.002) and the R1 trials (mean=852.16 ms, SD= 132.51), $t_{(14)}$=4.11, p=0.001), $t_{(14)}$= 6.75, p=0.001).

However, there were no significant differences in response times between the R1 (mean=998.96 ms, SD= 164.99) and R2 trials (mean=989.26 ms, SD= 147.24) for participants in the auditory modality, although they were significantly faster in both repetition types (R1 and R2), compared to new trial type (mean=1068.47 ms, SD=161.83; R1: $t_{(14)}$= 3.70, p=0.002; R2: $t_{(14)}$= 4.94, p<0.001) See **Figure 3-4**.

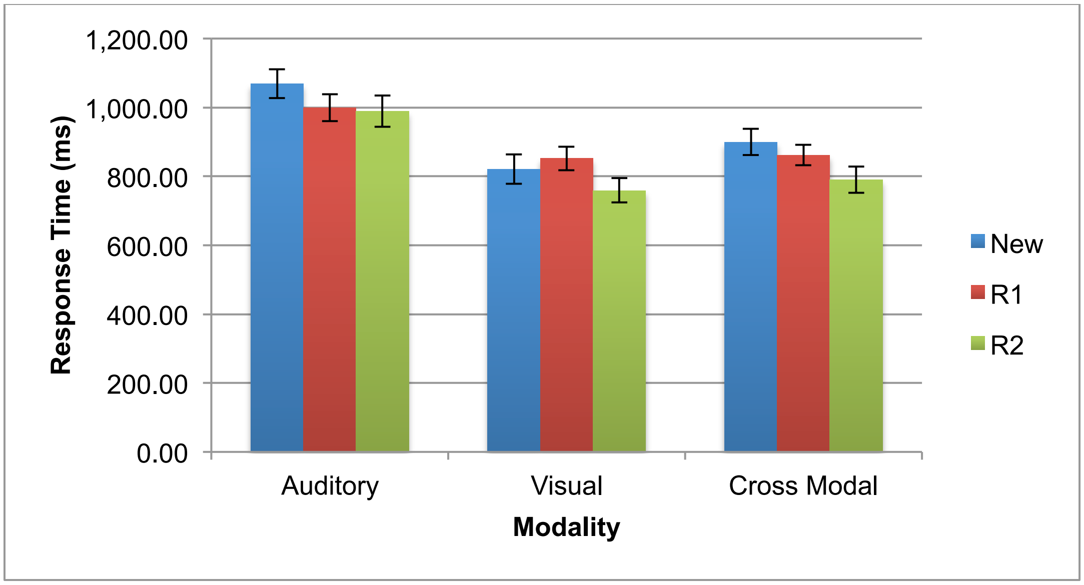

Figure 3-4: Graph of mean response time for new, R1 and R2 trials for participants in auditory, visual and cross-modal condition, showing the modality x repetition interaction effect. Errors bars represent standard error

3.1.3.3 *Effects of modality on d'*

Discriminability index (*d'*) between the three modalities, i.e. auditory, visual and cross-modal were compared via one-way between group ANOVA. The analyses revealed a significant effect of modality $F_{(2,42)} = 5.03$, p = 0.01. Pairwise comparisons (bonferonni adjusted) reveal that participants in the cross-modal condition (mean=4.12, SD= 0.86) recorded a significantly higher *d'* score compared to both participants in the visual (mean=3.44, SD= 0.62) and auditory condition (mean=3.40, SD=0.60), $p < 0.05$, with no significant differences in scores between the visual and auditory condition. See **Figure 3-5**.

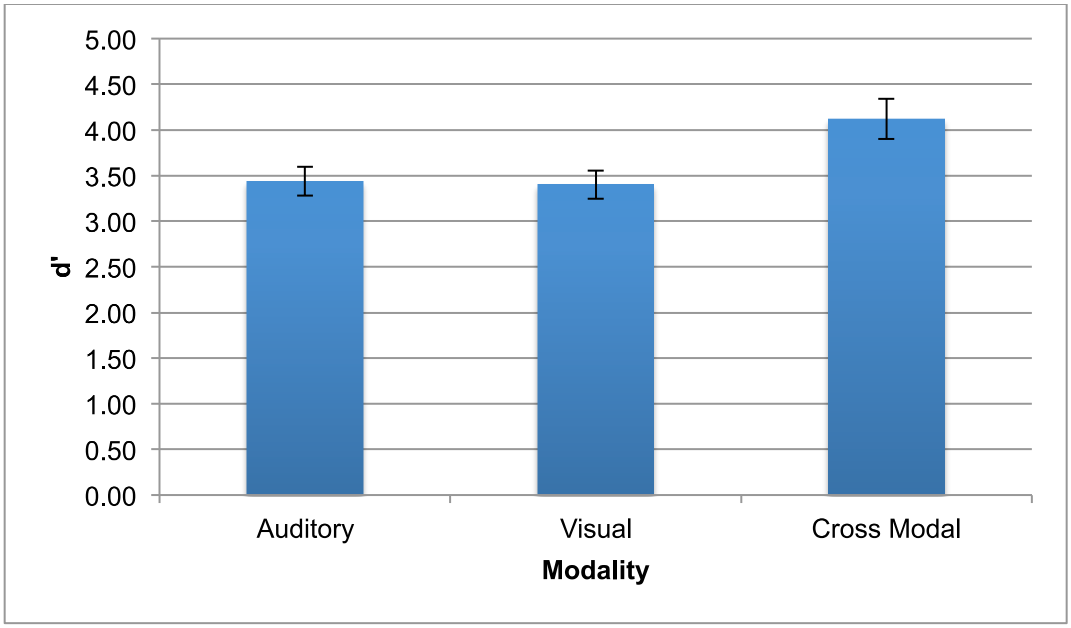

Figure 3-5: Graphs displaying *d'* scores for each condition. Errors bars represent standard error

3.1.4 Discussion

With respect to percentage errors made, in the first repetition, i.e. R1 trials, participants in the visual condition made more percentage errors compared to auditory and cross-modal condition, whereas more errors were made in the R2 trials for participants in the auditory condition. Looking at each modality, participants in both the cross-modal and visual conditions made significantly more errors for the R1 trial type compared to the R2 trial type, indicating that repetition improves recognition memory. However, this trend did not hold for auditory condition, where there were no significant differences in percentage errors made between new, R1 and R2 trials.

In terms of response times, participants in the auditory condition were significantly slower to respond to all trials (new, R1 and R2) compared to participants in the visual and cross-modal conditions, with no significant differences in response times between the latter two conditions. This indicates that the presence of visual images facilitated response times for participants. In addition, there was a similar pattern of response times for participants in the visual and cross-modal condition, where participants responded significantly faster to R2 trials compared to new and R1 trials. However, participants in the auditory condition showed a different pattern, whereby with repetition, there was no difference in response times on repeated trials, given by a significantly slower response times to new trials, compared to R1 and R2 trials but no significant differences between the latter two repetitions. This indicates that repetition seems to lead to faster processing if the stimuli were in visual and auditory modality; however, repetition did not facilitate faster recognition of spoken words alone.

Lastly, with respect to *d'*, participants in the cross-modal condition scored significantly higher, indicating better discriminability performance compared to visual and auditory condition. See section 3.2.5 in this chapter for a more comprehensive discussion of these results.

3.2 Experiment 4: Effects of age on cross-modal recognition memory

3.2.1 Introduction

There is increasing support in the literature that older adults show more benefits in multisensory integration compared to younger adults (Laurienti et al., 2006; Mahoney et al., 2011; Peiffer et al., 2007). This benefit in multisensory integration among older adults is demonstrated by faster reaction times to detect the presence of multi-modal sensory stimulation, such as pairs of auditory and somatosensory, visual and somatosensory, and auditory and visual stimuli; compared to uni-modal stimuli presented alone (Mahoney et al., 2011), or auditory, visual and pairings of auditory and visual stimuli (Peiffer et al. 2007), as mentioned in chapter 1.

There is evidence to show that older adults are relatively spared in tests of recognition memory (Balota et al., 2000; Danckert & Craik, 2013) due to their ability to rely on familiarity (Danckert & Craik, 2013). A recent finding (Kılıç et al., 2013) has shown that older adults do show increased benefits with space learning, where items that were difficult to be retrieved during the first repetition, were better remembered during third presentation. Findings from experiment 1 do indicate that with repetition, older adults can benefit and show increased performance in recognition memory.

Therefore, based on the premise that older adults show enhanced multisensory integration compared to their younger counterparts, it can be expected that their recognition memory using cross-modal stimuli during the first and second repetition should be comparable to that of younger adults. Hence, the objective of this study is to determine the effects of age on each repetition in a cross-modal associative recognition memory task.

Furthermore, as the English language is a second language among Malaysians, using English spoken words as the auditory stimuli may not maximize the recognition memory potential as using spoken words recorded in the native language amongst Malaysians. For this reason, in this experiment the auditory stimuli were recorded in the four languages, i.e. Bahasa Malaysia, Mandarin, Tamil and also English using Malaysian speakers.

3.2.2 Method

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus.

3.2.2.1 *Participants*

Fifty-three younger adults between the ages of 18- 30 and 39 older adults between the ages of 55-74 were recruited for this study. Data from 12 younger participants were excluded as they showed depressive symptoms, resulting in a final number of 41 younger adults whereas all 39 older adults were included in this study (See section 3.2.2.2.1 for further details on the screening criteria, and appendix A.9 for participant's mean scores). Further details of participant characteristics are given in **Table 3-1** below.

Table 3-1: Participant characteristics in experiment 4, including information regarding age, gender, preferred language, and years of education

	Younger Adults (n=41)	Older Adults (n=39)
Age (years)	21.56 (SD= 2.80)	65.15 (SD= 8.51)
Sex (n)		
Male	15	17
Female	26	22
Language of stimuli		
Bahasa Malaysia	12	11
Mandarin	9	10
Indian	11	9
English	9	9
Education (mean years)	13.73 (SD=1.45)	10.28 (SD= 4.52)

3.2.2.2 *Materials*

3.2.2.2.1 Questionnaires

As experiment 1, younger participants completed the BDI whereas older adults completed the GDS and MMSE scales to screen for depression (BDI and GDS) and cognitive impairment (MMSE). Older participants who were more comfortable in communicating in Malay completed the GDS-Malay and the MMSE-Malay form.

3.2.2.2.2 Stimuli

The stimuli of the experiment consisted of images and auditory clips of spoken words obtained from the ADEPT database (Kilborn et al., 2009). The visual stimuli were identical to that presented in experiment 1 and 2.

The auditory stimuli in experiment 3 (i.e. associated spoken words) were recorded again and translated into 3 languages, using 12 native speakers (2 male and 2 female for each language). There were 4 Bahasa Malaysia speaking Malay speakers that recorded the Bahasa Malaysia auditory stimuli, 4 Mandarin speaking Chinese speakers that recorded the mandarin auditory stimuli, and 4 Tamil speaking Indian speakers that recorded Tamil auditory stimuli. Although the English version of the auditory stimuli were available, they were recorded again as the accent in the original version was recorded using Scottish speakers, which may not be suitable in the Malaysian population. As such, 4 out of the 12 speakers (2 male and 2 female) recorded the English stimuli that were also used in experiment 3 (see appendix B.3 for sample cross-modal stimuli). The stimuli were then validated with 2 independent participants in their respective language to determine clarity and accuracy of pronunciation. After which modifications were made and stimuli re-recorded.

3.2.2.3 *Design*

The design of this study was a 2 x 3 x 4 mixed design approach with repetition (new vs R1 vs R2) as within subject factor and age (younger adults vs older adults) and language of auditory stimuli (English, Bahasa Malaysia, Mandarin and Tamil) as the between subjects factors.

The images (visual stimuli) were presented in central vision on a black background, and the spoken words (auditory stimuli) were presented using headphones adjusted to a volume level that was comfortable for the participants.

Identical to the previous experiments, there were 5 practice blocks consisting of 10 trials to ensure participants understood the instructions before proceeding to the experiment, and 2 experimental blocks each consisting of 135 trials (55 new, 50 R1, and 30 R2). Presentation of stimuli was controlled using E-Prime software version 2.0 (Schneider et al., 2002).

3.2.2.4 *Procedure*

The procedure for this study was identical to experiment 3 for participants in the cross-modal condition (please refer to **Figure 3-2** for flow diagram).

3.2.3 Results

Younger and older adults were compared in terms of their performance (percentage errors made on new, R1 and R2), response time (ms) and *d*'. Language of auditory stimuli spoken was also factored in to determine if there were any differences in performance with respect to language. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses. In cases of violations of sphericity for any variables used in the following ANOVAs, degrees of freedom were corrected using Greenhouse-Geisser corrections where applicable.

3.2.3.1 *Effect of age and repetition on percentage errors*

A 2 x 3 x 4 mixed-design ANOVA with repetition type (new vs. R1 vs. R2) as within-subjects factor; and age group (older adults vs. younger adults) and language (English vs Bahasa Malaysia vs Mandarin vs Tamil) as between subjects factor were conducted.

The main effect of language was not significant, $F_{(1, 72)}$=0.98, p = 0.41.

There was a significant main effect of age, $F_{(1, 72)}$=11.83, p< 0.001, η_p^2 = 0.14 with older adults making significantly more percentage errors (mean= 8.60%, SD= 12.42) compared to younger adults (mean= 3.20%, SD= 3.83) .

There was a also significant main effect of repetition, $F_{(1.36, 97.86)}$ = 21.14, p<0.001, η_p^2 = 0.27. Participants made significantly more errors in the R1 repetition type (mean= 9.40% SD=12.40) compared to the new trials (mean=4.13%, SD= 4.84), and the R2 repetition type (mean= 3.90%, SD= 8.61), all at p< 0.001. The percentage of errors committed in the new and R2 repetition type did not differ significantly, p>0.05.

There was a repetition x age interaction, $F_{(1.36, 92.24)}$= 9.54, p=0.01, η_p^2=0.08. See **Figure 3-6**. The interaction is explored below:

3.2.3.1.1 Effects of age on percentage errors across new, R1 and R2 repetition types

Independent samples *t*-tests were carried out to determine effects of age on new, R1 and R2 trials. Results found that older adults made significantly more errors compared to younger adults in the R1, $t_{(43.33)}$=3.87, p<0.001 (older adults: mean= 14.17%, SD= 15.72; younger adults: mean= 4.50%, SD= 4.27) and the R2 repetition type, $t_{(41.57)}$= 2.19, p=0.03 (older adults: mean= 6.06%, SD = 11.73, younger adults: mean=1.84%, SD= 2.61) There were no significant difference in percentage error rates among older and younger adults in the new trials p>0.05.

3.2.3.1.2 Effects of repetition on percentage errors made by older and younger participants

Follow up analyses was conducted using repeated measures analyses in each age group separately to compare the effects of repetition. A different pattern of errors was found for each age group. For younger adults, a significant effect of repetition was reported, $F_{(2, 80)}$=12.31, p< 0.001, η_p^2 = 0.24. Post-hoc paired samples *t*-test (Bonferroni corrected p<0.0167) found that younger adults made significantly less percentage errors in the R2 repetition type (mean=1.84%, SD = 2.61), compared to new repetition type (mean=3.27%, SD=4.01), $t_{(40)}$= 2.94, p=0.005, and R1 repetition type (mean=4.50%, SD= 4.27), $t_{(40)}$=4.42, p<0.001 There was no significant difference in percentage error reported for the new and R1 repetition type, p> 0.0167.

For older adults, a significant effect of repetition was also reported, $F_{(1.27, 48.37)}$= 15.36, p<0.001, $\eta_p^2 = 0.29$. Post-hoc paired samples t-test (Bonferroni corrected p<0.0167) found that older adults made significantly more percentage errors in the R1 repetition type (mean= 14.57%, SD= 15.72) compared to new (mean=5.04%, SD= 5.47), $t_{(38)}$= 3.87, p<0.001; and R2 repetition type (mean=6.06%, SD = 11.73), $t_{(38)}$= 7.12, p<0.001 However, there were no significant difference in percentage errors made between new and R2 repetition type, p> 0.0167. All other effects were not significant at p> 0.0167. See **Figure 3-6**.

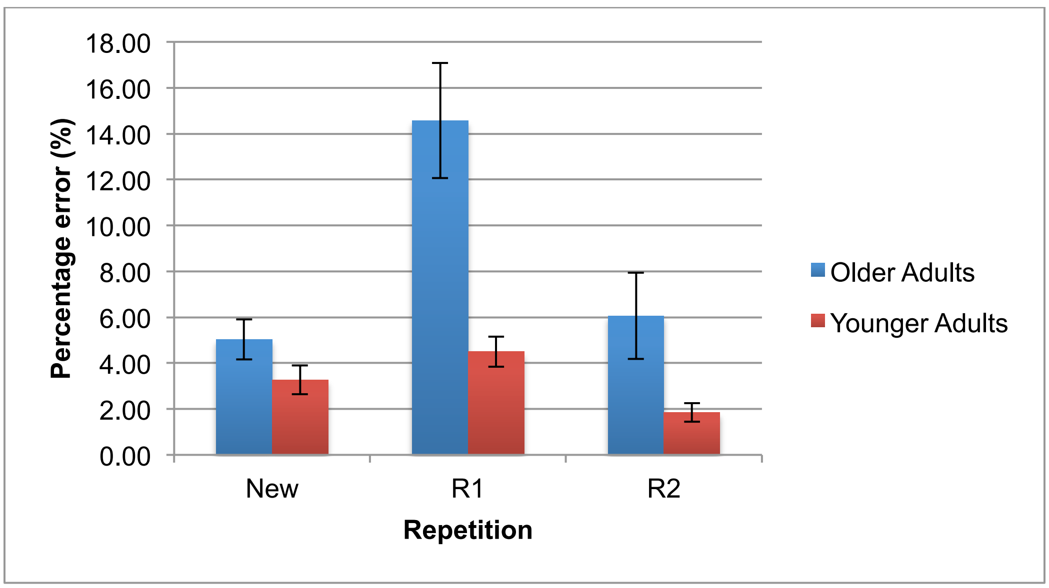

Figure 3-6: Graph of mean percentage errors made new, R1 and R2 trials for older and younger participants, showing the age x repetition interaction effect. Errors bars represent standard error.

3.2.3.2 *Effect of age and repetition on response times*

A 2 x 3 x 4 mixed-design ANCOVA with repetition (new vs. R1 vs. R2) as within-subjects factor; and age group (older adults vs. younger adults) and language of the auditory modality used in the cross-modal recognition memory test (English vs Bahasa Malaysia vs Mandarin vs Tamil) as the between subjects factor was conducted.

There was a significant main effect of age, $F_{(1, 71)}$=28.49, $p < 0\ .001$, $\eta_p^2 = 0.29$ with younger adults reporting significantly faster mean response times (mean= 918.76 ms, SD= 189.29) compared to older adults (mean= 1266.162 ms, SD= 264.05).

There was a significant main effect of repetition, $F_{(1.76,\ 125.12)}$=3.40, $p< 0.04$, η_p^2 = 0.05. Participants' response times in all three repetition types differed significantly from each other, all at p<0.001; participants were faster in the R2 repetition type (mean= 1000.74 ms, SD = 269.38), followed by R1 repetition type (mean= 1103.07 ms, SD= 269.51), and lastly in the new repetition type (mean= 1160.53 ms, SD=301.40). No other main effects or interaction effects were observed, p> 0.05. **Figure 3-7** below shows the main effect of age and repetition on response time.

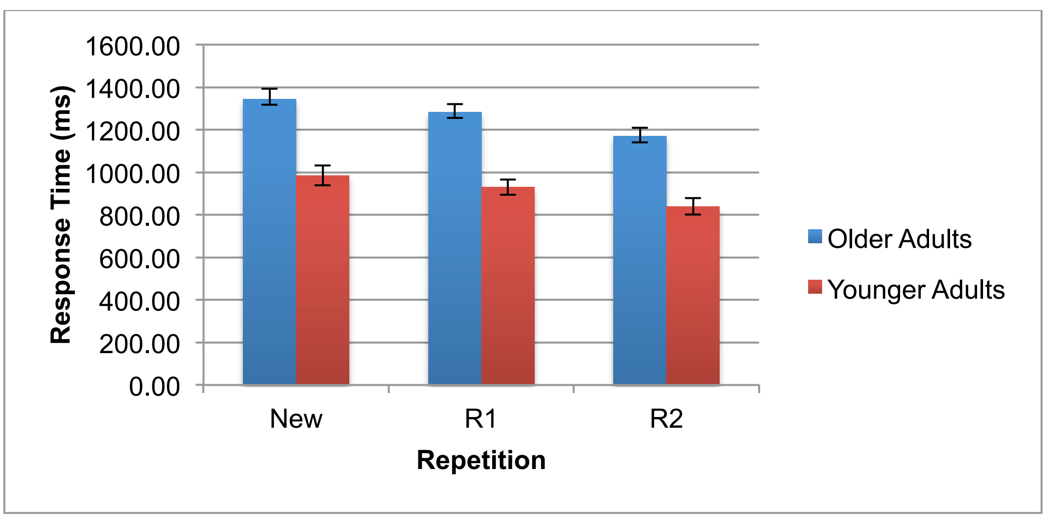

Figure 3-7: Graph of mean percentage errors made new, R1 and R2 trials for older and younger participants, showing the main effect of age and repetition. Errors bars represent standard error.

3.2.3.3 *Effects of Age on d'*

Independent samples *t*-test was computed to determine age effects in *d*'. *t*-tests analyses revealed a significant difference between the two groups, with the younger adults (mean=3.88, SD= 0.70) reporting significantly higher *d'* scores compared to older adults (mean=3.22, SD= 0.90), $t_{(78)}=3.64$, $p< 0.001$.

3.2.4 Discussion

The main objective of this study was to extend experiment 3 by exploring whether older adults will perform similar to younger adults in cross-modal recognition. Overall both age groups showed better recognition memory performance in the cross-modal modality. The only difference was the spoken word stimuli that were used in experiment 4 had been recorded by native/first language speakers and validated for suitability.

Although it was expected that older adults would show slower response times to younger adults, it was expected that they would show facilitation in terms of lower percentage errors in cross-modal recognition with repetition, compared to their younger counterparts.

It was also expected that participants would show facilitation in recognition in their respective native/first language compared to English, as English is a second language to Malaysian participants. However, there were no significant differences in response time or in percentage errors between the different languages. Like experiment 1 which did not find ethnic differences, experiment 4 did not find an effect of language. This further supports that this test would be suitable to be used in a diverse Malaysian population, and similar results can be expected among other diverse cultures.

Results show that older adults were significantly slower in responding to all repetition types compared to their younger counterparts. In addition, all participants were quickest to respond to the R2 trials types, followed by the R1 trial types and slowest in responding to the new trials. As for the percentage errors made, both older and younger adults made significantly more percentage errors in the R1 trials, compared to the R2 trials. The pattern was different for older and younger adults. Older adults made similar percentage errors in the R2 and new trials, whereas younger adults made similar number of errors in the R1 and new trials. It does appear that older adults showed significant improvement with repetition, with greater reduction of errors in R1 to R2 compared to younger adults. Lastly, the discriminability index shows that younger adults showed better discriminability compared to older adults.

3.2.5 General discussion

Looking at the results overall from experiment 3, it was not surprising that response times for the auditory condition was slower, which is attributable to the longer processing time needed for participants to continuously process auditory stimuli as opposed to visual stimuli, where complete information is available at target onset.

While it was reported in previous studies that auditory recognition memory was poorer than visual recognition memory (Bigelow & Poremba, 2014; Cohen et al., 2009), experiment 3 reported a surprising finding. It was shown that for first repetition, visual recognition memory caused participants to make more errors compared to auditory and cross-modal recognition memory while there were no significant differences between the latter two conditions during the first repetition (R1). It can be inferred since the R1 trials were repeated after a short delay of approximately 6 items, and as the results found significantly longer response times for auditory modality compared to visual modality, it is possible that although participants took a longer time, they may process it more deeply compared to visual stimuli, as they had to wait until the spoken word was presented before making a decision. As opposed to visual stimuli, where all the information is available upon target onset, participants may make quicker decisions, but not necessarily process it efficiently. Hence, this could have led to better recognition following the short delay. Hence, the significantly lower errors made by cross-modal stimuli in the R1 trials could be attributed to the presence of the auditory stimuli.

However, this effect was not seen in the R2 trials. While overall, participants made significantly less errors in the R2 trials, participants in the visual and cross-modal modality reported significantly lower error rates compared to the auditory modality. This is in line with past studies that reported poorer recognition for the auditory modality compared to visual modality (Bigelow & Poremba, 2014; Cohen et al., 2009). Hence, in reference to the visual modality, items that were difficult to be retrieved in the first repetition, was easily retrieved in the 2^{nd} repetition (R2), consistent with the results by Kılıç, Hoyer, Howard, & Howard, (2013). It should not be assumed that the significantly higher percentage errors made by participants in the visual modality indicate impoverished recognition memory. On the contrary, this indicates significantly better retention, compared to auditory modality.

The same pattern was also observed (but to a lesser extent) with the cross-modal modality as participants made significantly fewer errors in the R2 trials compared to R1 trials. An interesting finding revealed from this study is that this pattern was not seen in the auditory modality. There were no differences in percentage errors between all repetition types in the auditory modality. Hence, the effect of repetition was seen to improve recognition memory for participants in the visual and cross-modal modality, repetition did not improve participants' recognition memory performance in the auditory modality.

Finally the finding that the cross-modal modality led to better discriminability shows that participants scored a higher hit rate and were less likely to commit false alarms compared to the visual and auditory modality. Although participants appeared to record fewer percentage errors in the 2nd repetition for visual modality, overall its discriminability index was similar to the auditory modality. Hence, it can be inferred from the results that cross-modal modality led to better recognition memory overall, which is in line with prior studies (Lehmann & Murray, 2005; Moran et al., 2013; Murray et al., 2005; Murray et al., 2004; Nyberg et al., 2000; Thelen et al., 2012; Von Kriegstein & Giraud, 2006) that found presentation in cross-modal modality led to better uni-modal modality discrimination.

Overall, the findings suggests that the presentation of cross-modal stimuli leads to encoding of multi-sensory representation and will subsequently cause activations in larger networks of brain areas compared to encoding uni-modal stimuli. The activation of larger brain areas would facilitate better recognition memory with respect to accuracy and reaction time (Nyberg et al., 2001) In addition Shams and Seitz (2004) states that perceptual and cognitive mechanisms have evolved into processing multisensory stimuli, and not uni-sensory stimuli, which is deemed to be inadequate information to process as it does not use the perceptual mechanism to its fullest advantage.

One of the major limitations of Experiment 3 was that the auditory stimuli, i.e. associated spoken words were developed and validated in Scotland, hence the applicability in the Malaysian context is questionable. However, this was addressed in experiment 4, by recording auditory stimuli using Malaysian speakers. As there no effects of language it can be said that the same results can be found among Malaysians, with different languages and accents.

Experiment 4 extended the findings of experiment 3 by looking at age effects in cross-modal recognition memory across repetitions. As past findings have shown that older adults show benefits in multisensory integration compared to younger adults (Laurienti et al., 2006; Mahoney et al., 2011; Peiffer et al., 2007), it was expected that with repetition, although older adults may record slower response times, they will show comparable accuracy in recognition memory with cross-modal stimuli.

With respect to response times, as expected, older adults were significantly slower to respond compared to younger adults, in all repetition types. Overall participants' responses to the R2 trials were significantly faster compared to responses to the R1 trials, which was significantly faster than the new trials. The slower response times to new trials is expected as it reflects a longer time that is needed for memory evaluation and template matching (Kim et al., 2001). Participants were significantly faster in the R2 trials as it responds to higher confidence, as these items were presented for the 2nd time.

However, in terms of percentage errors made, results were contradictory to our expectations. Older adults made significantly more percentage errors compared to their younger counterparts in all repetitions. Older participants made significantly more percentage errors in the R1 trials, with no significant difference between the new and R2 trials. However, younger participants made significantly more errors in the R2 trials, with no significant difference in percentage errors made between the new and R1 trials. Although overall older adults made more errors compared to younger adults, they showed a significant reduction in errors with repetition. This implies that repetition facilitated older adults more than younger adults. This was in line with past findings reporting that older adults show more gains in multisensory integration compared to younger adults (Laurienti et al., 2006; Mahoney et al., 2011; Peiffer et al., 2007). However, this could be an indication of a ceiling effect for younger adults, which could be a reason why there are no significant difference between R1 and new trials.

Overall, younger participants also showed better discriminability compared to older participants. This could indicate that older participants were more prone to making false alarms compared to younger adults, or just an indication of poorer memory given by lower hit rates.

The finding that there were no language effects in participants' recognition memory performance was rather surprising. It would be expected that participants memory would perform better in their native/first language, compared to English. It would be expected that due to participants' fluency in the native language, their response times would be faster compared to their second language (English). However, this was not the case as this could be due to participant's education levels. For younger adults, the level of English proficiency was rather high, as they were college educated in the English medium. As for older adults, only participants who could converse efficiently in the English Language did the English version, and it was observed that all those who opted for the English Language memory test had at least a university level education. The fact that no differences was seen amongst the different languages is important as it highlights that cultural differences may not play a role in recognition memory performance, and similar results may be obtained across different cultures.

In summary, findings from experiment 3 showed that participants' recognition memory was significantly better for cross-modal stimuli compared to uni-modal stimuli. On the first repetition, participants' recognition memory in cross-modal and auditory modality was significantly better compared to their recognition memory in the visual modality. However, on the 2nd repetition, their recognition memory in the visual and cross-modal modality was significantly better than the auditory modality. An unexpected and new finding was that the auditory modality did not seem to show the effects of space learning or repetition, where participants in the auditory condition did not show improved recognition memory on the 2nd repetition. Experiment 4 looked at age effects of recognition memory on the cross-modal recognition test. Results showed that older adults showed significantly poorer recognition memory compared to younger adults. However, they showed greater facilitation with repetition and cross-modal stimuli as shown by a greater reduction in error from R1 to R2, compared to younger adults.

This study has shown the importance of cross-modal stimuli in enhancing recognition memory. Of much importance is that auditory and visual pair should also be semantically related in order to facilitate recognition.

However, to what extent does semantic congruency play a role, and will semantically incongruent information impair recognition memory upon subsequent repetition? This will be explored in the next experimental chapter.

CHAPTER 4

SEMANTIC CONGRUENCY ON RECOGNTION MEMORY

Past studies have shown that it not mere multisensory experiences that facilitates recognition memory by pairing tones with visual images (Lehmann & Murray, 2005; Murray et al., 2005; Murray et al., 2004) or pairing unique, or meaningless sounds with visual images (Thelen et al., 2012), but the pair of auditory and visual information must be semantically congruent to facilitate recognition memory. For example an image of a monkey paired with a spoken word “banana” would be semantically compatible (congruent) whereas an image of a monkey paired with a spoken word “tunnel” would be an incompatible pair (incongruent).

Further support for the effect of semantic congruency in facilitating memory comes from neuroimaging studies that have found that processing and integration of congruent and incongruent relied on distinct neural networks. When participants were exposed to congruent and incongruent pairs of objects and scenes, participants showed superior recognition to pairs that were higher in terms of congruency compared to incongruent pairs. This was also found to correlate with increasing encoding-related activity in the medial prefrontal cortex (mPFC). However, the processing of incongruent information was shown to rely on automatic processing in the medial temporal lobe (MTL) (van Kesteren et al., 2013). In addition, higher retrieval related activity was also found in the mPFC and the somatosensory cortex in response to successful retrieval of congruent visual tactile information, compared to incongruent information (van Kesteren et al., 2010).

The role of semantic congruency has been emphasized in many cognitive theories, which argue that semantically congruent information plays a crucial role in the formation of an elaborate memory trace, thereby facilitating the retrieval process. Experiment 5 will explore the effects of semantic congruency further by examining if the effects of semantic congruency are seen upon repetitions, and also investigate this effect across age groups. Lastly, experiment 6 is an ERP study examining how semantic congruency affects the ERP correlates of recognition memory, to understand the processes that support recognition memory when information is congruent and incongruent.

4.1 Experiment 5: Effects of semantic congruency and repetition on cross-modal recognition memory across age groups

4.1.1 Introduction

The aim of this study was to determine if the effects of semantic congruency on performance of recognition memory vary as a function of age. While past research has shown that semantic congruency of information can facilitate recognition memory, it has not examined the effects of semantic congruency across multiple repetitions. As shown from experiment 2-4, subsequent repetition (R2) significantly facilitated recognition memory. Hence, it is expected that semantic congruency will only facilitate recognition memory for the first repetition (R1).

In the present study, the same type of stimuli from experiment 3 will used, i.e. visual images presented alone, cross-modal pairs consisting of an image paired with a congruent or incongruent spoken word or a meaningless tone, as carried out in Lehmann and Murray's (2005) study. As experiment 4 showed no significant effect of language, the English version of the cross-modal test will be used in this study with English speaking participants. Recognition memory performance will be compared across four conditions, i.e. congruent (visual and auditory stimuli are semantically congruent), incongruent (visual and auditory stimuli are not semantically congruent), visual (visual stimuli presented alone), and tones (visual stimuli presented with a brief meaningless tone). The tones condition was included in the experiment as a control to show that it is not meaningless multisensory stimulation that enhances recognition memory but the pairs of visual and auditory stimuli should be semantically related. As for visual condition, it is expected that participants will do better when stimuli is presented in the cross-modal modality compared to in a single modality. Overall, it expected that it is participants will perform significantly better in the congruent condition compared to all other conditions for all presentation types for the first repetition (R1). However, it is expected that this effect will be non significant upon the second repetition (R2).

4.1.2 Methods

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus

4.1.2.1 *Participants*

Twenty-two younger adults between the ages of 19-24, and 22 older adults between the ages of 55-73 were recruited for this study. However, data from 2 younger participants and 3 older participants was excluded as they showed depressive symptoms

(See section 3.2.2.2.1 for further details on the screening criteria, and appendix A.9 for participants' mean scores). This resulted in a final number of 20 younger participants (mean age= 21.8, SD= 1.40) and 19 older participants (mean age= 65.21, SD= 5.28). The younger participants comprised of 6 males and 14 females, with mean years of education of 13.65 (SD= 1.14), whereas the older participants comprised of 4 males and 15 females, with mean years of education of 12.47 (SD= 2.78). Younger participants were compensated with RM 5; whereas older participants were compensated for RM 10 for their participation. None of the participants took part in experiments 1-4.

4.1.2.2 *Materials*

4.1.2.2.1 Questionnaires

As experiments 1 - 4, younger participants completed the BDI whereas older adults completed the GDS and MMSE scales to screen for depression (BDI and GDS) and cognitive impairment (MMSE). Older participants who were more comfortable in communicating in Malay were given the GDS-Malay and the MMSE-Malay form.

Additionally, participants were also given the LexTale questionnaire to assess for English proficiency, details given below:

LexTALE: The LexTALE (see appendix A.8 for questionnaire, Lemhöfer & Broersma, 2012) is a short 5 minutes yes/no vocabulary test consisting of 60 items (40 words, 20 nonwords) Participants are to indicate whether item is a word or a non-word. This test has been shown to be a good indication of English vocabulary knowledge and a valid indicator of general English proficiency (Lemhöfer & Broersma, 2012). Participants were given the LexTALE task to control for English proficiency levels as the experiment included English spoken words, and were included in the study if their scores were at least 60%.

4.1.2.2.2 Stimuli

The same stimuli that were used in Experiment 4 (i.e. the visual images and auditory spoken words) were used in this study. The auditory spoken words consisted of only the English stimuli.

The visual and auditory stimuli were rated for semantic congruency by ten independent raters who did not participate in the actual experiment. For each visual and auditory pair in the congruent and incongruent condition, they were to rate how semantically related a given pair was on a scale of 1 (lowest degree of semantic congruency) to 7 (highest degree of semantic congruency). A paired samples *t*-test was then conducted on the ratings between the congruent (mean= 5.48, SD= 0.41) and incongruent (mean= 1.84, SD=0.47) conditions, and were found to be significantly different in ratings, $t_{(9)}=19.37$, $p<0.001$. Presentation of stimuli was controlled using E-Prime software version 2.0 (Schneider et al., 2002).

Please refer to appendix B.4 and B.5 for a sample of visual images paired with congruent and incongruent spoken word respectively.

4.1.2.3 *Design*

The study design was a 2 x 4 mixed design approach with age group (younger adults vs older adults) as the between subjects factor and condition (Congruent vs Incongruent vs Tones vs Visual) as the within subjects factor.

The congruent condition consisted of auditory and visual stimuli that were semantically congruent (e.g. a visual image of a monkey presented with the spoken word "banana"). The incongruent condition consisted of auditory and visual stimuli that were semantically incongruent (e.g. a visual image of a monkey presented with the spoken word "tunnel"). The tones condition consisted of visual stimuli presented with a meaningless tone, i.e. a brief 1000Hz tone created using *Audacity* software. Lastly, the visual condition consisted of visual images presented alone. The stimuli in each of the conditions were not repeated again in other conditions. Each condition consisted of 55 new stimuli, 50 R1 stimuli and 30 R2 stimuli presented in one block of trials, with a total of 4 blocks. The blocks randomized for counterbalancing.

4.1.2.4 *Procedure*

The procedure for this experiment was identical to experiment 1, 3 and 4.

4.1.3 Results

Younger and older adults were compared in terms of their performance (percentage errors made in each of the conditions and in repetition types of new, R1 and R2; response time (ms) and *d*'). Years of education did not differ significantly between older and younger groups, $t_{(23.62)}=1.715$, $p>0.05$. However, standard of English proficiency, measured by the LexTale test differed significantly between older (mean= 91.77, SD= 6.93) and younger adults (mean= 75.62, SD= 13.39), $t_{(28.80)}= 4.691$, $p<0.001$ and was entered as a covariate but will only be reported if the covariate was found to be significant. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses. In cases of violations of sphericity for any variables used in the following ANOVAs, degrees of freedom were corrected using Greenhouse-Geisser corrections where applicable.

4.1.3.1 *Effect of semantic congruency and repetition on percentage errors*

2 x 3 x 4 mixed-design ANOVA with age group (older adults vs. younger adults) as between subject factor and trial type (new vs. R1 vs. R2) and condition (congruent vs. incongruent vs. tones vs. visual) as within-subjects factor were conducted.

There was a significant main effect of condition, $F_{(2.80,\ 103.71)}$=8.95, p<0.01, η_p^2= 0.20. Pairwise comparisons (Bonferroni adjusted) revealed that participants made significantly mean lower percentage errors in the congruent condition (mean=4.55, SD= 7.73) compared to incongruent (mean=7.15, SD= 9.64), tones (mean=8.39, SD= 9.46) and visual (mean=8.01, SD= 10.59) conditions, all at p<0.05. Participants mean percentage error in all other conditions did not differ significantly, p> 0.05.

There was a main effect of age, $F_{(1,\ 37)}$=5.75, p=0.02, η_p^2 = 0.14. Older adults made more percentage errors (mean=8.92%, SD= 4.81) compared to younger adults (mean= 5.22%, SD = 4.81).

There was a main effect of repetition, $F_{(1.21,\ 44.73)}$=32.81, p<0.01, η_p^2 = 0.47. Pairwise comparisons (Bonferroni adjusted) showed that participants made more percentage errors in the R1 repetition type (mean= 12.71%, SD= 9.50) compared to both new (mean= 4.06% , SD= 3.72) and R2 repetition type (mean= 4.45%, SD= 4.69).

There was a significant age x repetition interaction, $F_{(2,44.73)}$=5.89, p< 0.001, η_p^2 = 0.47, and a significant condition x repetition interaction, $F_{(4.50,\ 166.44)}$=5.66, p<0.001 η_p^2 = 0.13, please see **Figure 4-1**; The interactions are explored below:

4.1.3.1.1 Effect of age on percentage errors across new, R1 and R2 repetition types

A series of independent samples t-tests was carried out to determine how younger and older adults differed on the mean percentage errors for new, R1 and R2 repetition types.

There were no significant difference in percentage errors made between older and younger adults for the new trials, p=0.79. However, older adults made significantly more errors (mean=16.68%, SD= 11.61) compared to younger adults (mean=8.73%, SD=6.94) in the R1 trials, $t_{(29.12)}$= 2.58, p<0.05. Older adults also made significantly more errors (mean= 6.18%, SD=6.19) compared to younger adults (mean= 2.72%, SD= 2.58) in the R2 trials, $t_{(2.3.80)}$= 2.30, p< 0.05. Please see **Figure 4-1**.

4.1.3.1.2 Effect of repetition on percentage errors made by older and younger adults

Follow up analyses were conducted using repeated measures analyses in each age group separately to compare the effects of repetition. The same pattern of errors was found for each age group. A significant effect of repetition was reported (younger adults: $F_{(1.20, 22.84)}$=12.10, p=0.091, η_p^2=0.39; older adults: $F_{(1.20, 22.84)}$=21.81, p=0.001, η_p^2 = 0.54).

Post-hoc paired samples t-tests (Bonferroni corrected p< 0.0167) found that in both age groups, participants made significantly more percentage errors in the R1 repetition type (younger adults: mean =8.73%, SD = 6.94, older adults: mean=16.68%, SD= 11.61) compared to new repetition type (younger adults: mean= 4.22%, SD=3.83; $t_{(19)}$=2.68, p=0.015; older adults: mean= 3.90%, SD = 3.61, $t_{(18)}$ = 4.63, p< 0.001), and R2 repetition type (younger adults: mean=2.72%, SD= 2.58, $t_{(19)}$=4.95, p< 0.001; older adults: mean= 6.18%, SD= 6.19, $t_{(18)}$=5.43, p< 0.001. There was no significant difference in percentage error reported for the new and R2 repetition types for both age groups, p>0.0167. Please see **Figure 4-1**.

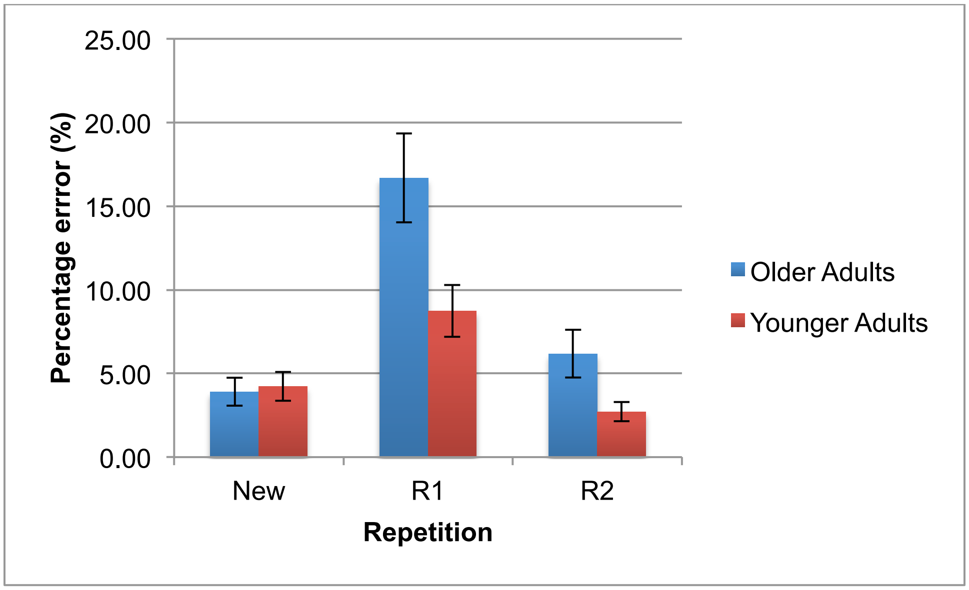

Figure 4-1: Graph displaying mean percentage error of old and young participants in each repetition type; showing an age x repetition interaction effect. Error bars represent standard error.

4.1.3.1.3 Effect of condition on percentage errors across new, R1 and R2 repetition types

A series of repeated measures ANOVA was carried out to determine how participants differed in mean percentage errors among the four conditions in each repetition.

There was a significant effect of condition on the new trials, $F_{(2.27, 86.25)}$=5.33, p<0.001, η_p^2 = 0.12. Post-hoc paired samples t-tests (Bonferroni corrected p< 0.008) revealed that participants made fewer errors in the congruent condition (mean= 2.31%, SD=3.45) compared to all other conditions (incongruent: mean= 4.66%, SD= 5.08, $t_{(38)}$ = 3.21, p=0.003; tones: mean= 4.55%, SD= 4.21, $t_{(38)}$=4.14, p<0.001; visual: mean= 4.75%, SD= 5.37, $t_{(38)}$ = 3.76, p = 0.001). There were no significant difference in percentage errors made between incongruent, tones and visual condition p>0.008.

There was also a significant effect of condition on the R1 trials, $F_{(3, 114)}$=12.29, p<0.001, η_p^2 =0.24. Participants made significantly less mean percentage errors in the R1 trials for congruent (mean=7.25%, SD= 7.31) condition compared to all other conditions (incongruent: mean=12.03%, SD=13.29, $t_{(38)}$=2.90, p= 0.006; tones: mean=16.35%, SD=11.19, $t_{(38)}$=6.07, p< 0.001; visual: mean=14.78% SD= 14.58, $t_{(38)}$= 4.38, p< 0.001).

However, there were no differences in mean percentage errors made between all other conditions, p>0.008.

4.1.3.1.4 Effect of repetition on percentage errors across congruent, incongruent, tones and visual conditions

A series of repeated measures ANOVA was carried out to determine how participants differed in mean percentage errors among the three repetition types in the congruent, incongruent, tones and visual conditions. There was a significant effect of repetition in all four conditions (congruent: $F_{(1.71, 65.0)}$=6.59, p=0.002, η_p^2=0.15; incongruent: $F_{(1.30, 49.47)}$=11.98, p< 0.001, η_p^2= 0.24; tones: $F_{(1.40, 53.37)}$=39.24, p<0.001, η_p^2 = 0.51; visual: $F_{(1.28, 48.5)}$=17.94, p< 0.001, η_p^2=0.32). However, participants showed a different pattern of errors in the repetition types of the congruent condition, compared to the incongruent, tones and visual condition.

In the congruent condition, post-hoc paired samples t-tests (Bonferroni corrected p< 0.0167) analyses revealed that participants made more percentage errors in the R1 repetition type (mean= 7.25%, SD= 7.31) compared to the new repetition types (mean=

2.31%, SD= 3.45), $t_{(38)}$=4.43, p<0.001. There was no significant difference in the new and R2 repetition type (mean=4.08%, SD=10.20), or the R1 and R2 repetition types, p<0.016.

In the incongruent, tones and visual conditions, post-hoc paired samples *t*-tests (Bonferroni corrected p < 0.0167) revealed that participants made more errors in the R1 repetition type (incongruent: mean= 12.04%, SD=13.29; tones: mean= 16.35%, SD=11.18; visual: mean= 14.77%, SD=14.58) compared to both the new (incongruent: 4.66%, SD= 5.08, $t_{(38)}$=3.24, p=0.002; tones: mean= 4.55%, SD= 4.21, $t_{(38)}$=6.05, p< 0.001; visual: mean= 4.75%, SD= 5.37, $t_{(38)}$=4.02, p<0.001) and R2 repetition types (incongruent: mean= 4.74%, SD= 6.65, $t_{(38)}$=5.15, p<0.001; tones: mean= 4.27%, SD= 5.70; $t_{(38)}$=7.78, p< 0.001; visual: mean= 4.52%, SD= 5.54, $t_{(38)}$=5.13, p<0.001).

In incongruent, tones and visual conditions, there were no significant difference in the new and R2 repetition types, p>0.0167. See **Figure 4-2**.

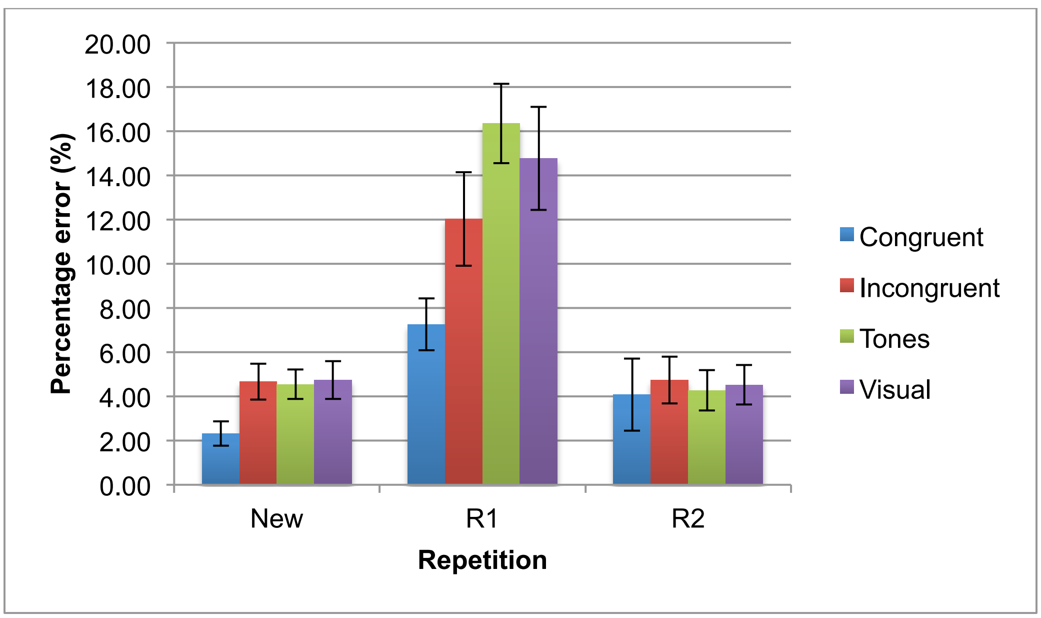

Figure 4-2: Graph displaying mean percentage error of participants for each repetition type in all conditions. There is a condition x repetition interaction effect. Error bars represent standard error.

4.1.3.2 *Effect of semantic congruency and repetition on response time*

A 2 x 3 x 4 mixed-design ANCOVA with age group (old vs. young) as between subjects factor and trial type (new vs. R1 vs. R2) and condition (congruent vs. incongruent vs. tones vs. visual) as within-subjects factors was conducted. Scores on the LexTale English test was entered as a covariate, and it was found to be significant, $F_{(1,36)}$=4.37, p=0.04, η_p^2 =.11.

There was a significant main effect of age, $F_{(1, 36)}$= 35.17, p<0 .001, η_p^2 = .49, with younger adults reporting significantly faster mean response times (mean= 907.21 ms, SD= 188.83) compared to older adults (mean= 1256.39 ms, SD= 207.08), after controlling for effects of English proficiency (LexTale).

There was a trend towards significance for the interaction effect of age x condition, $F_{(3, 108)}$=2.57, p=0.06, η_p^2 = .07. This interaction effect is explored below:

4.1.3.2.1 Effect of age on congruent, incongruent, tones and visual conditions

A series of independent samples *t*-tests was carried out to determine how younger and older adults differed on the mean response times for congruent, incongruent, tones and visual condition.

Younger participants (congruent: mean= 940.06 ms, SD= 132.41; incongruent: mean= 989.29 ms, SD= 175.37; tones: mean= 852.43 ms, SD= 113.37; visual: mean= 847.08 ms, SD= 92.55) recorded faster response times compared to older participants (congruent: mean= 1286.25 ms, SD= 185.31; incongruent: mean= 1303.59 ms, SD= 190.85; tones: mean= 1201.18 ms, SD= 137.62; visual: mean= 1234.54 ms, SD= 161.84) on all conditions, p< 0.001.

4.1.3.2.2 Effect of condition on younger and older adults

Separate repeated measures analyses for younger adults and older adults revealed different patterns in response times for the four conditions.

There was a main effect of condition for younger adults, $F_{(1.73, 32.80)} = 8.73$, $p < 0.001$, $\eta_p^2 = 0.32$. Post-hoc paired samples t-test ($p < 0.008$) indicated that younger adults recorded significantly slower response times in congruent (mean=940.06 ms, SD= 164.00) and incongruent conditions (mean=989.29 ms, SD= 251.91), compared to tones (mean=852.43 ms, SD= 144.50, congruent: $t_{(19)}=3.69$, $p=0.002$, incongruent: $t_{(19)}=3.06$, $p=0.006$ and visual condition (mean=847.08, SD= 134.88, congruent: $t_{(19)}=4.17$, $p=0.001$, incongruent: $t_{(19)}=4.12$, $p=0.001$). Participants' response times to trials in the congruent and incongruent conditions did not differ significantly; and this pattern was the same in the tones and visual conditions, all at $p>0.08$

There was a main effect of condition for older adults, $F_{(3,54)} = 4.87$, $p=0.01$, $\eta_p^2 = 0.21$. Post-hoc paired samples *t*-tests revealed that older adults were significantly faster in the tones condition (mean=1201.19 ms, SD= 171.36) compared to incongruent condition (mean= 1303.59 ms, SD= 233.73), $t_{(18)}=3.40$, $p=0.003$. Older adults' response times in the rest of the conditions did not significantly differ, $p>0.05$.

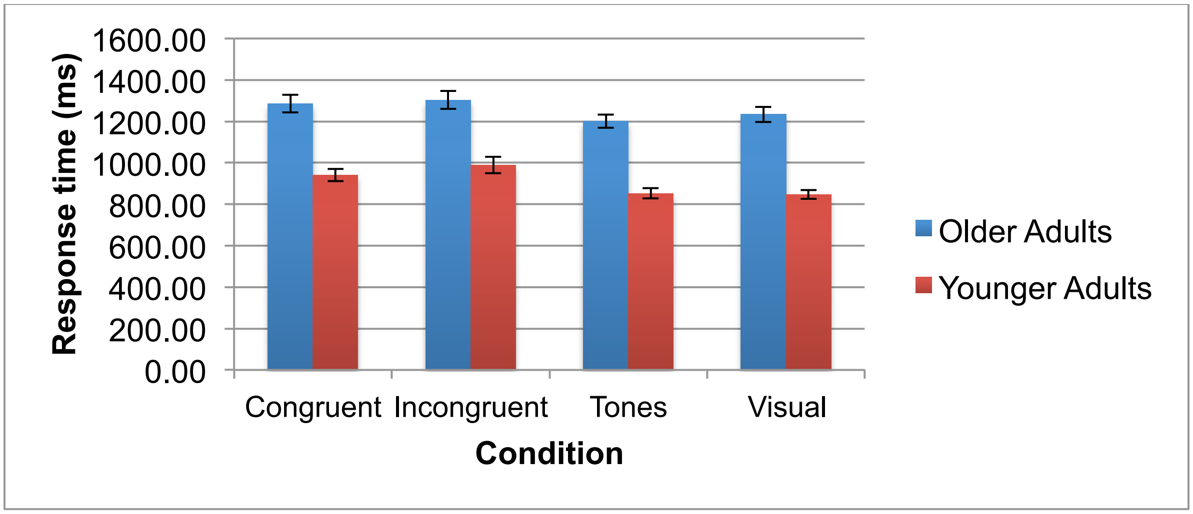

Figure 4-3: Graph displaying mean response times of old and young participants for each condition. There is an age x condition interaction effect nearing significance. Error bars represent standard error

4.1.3.3 *Effect of semantic congruency and age on d'*

A 2 x 4 mixed design ANOVA with age (older adults vs younger adults) as between subject factors and condition (congruent vs. incongruent vs. tones vs. visual) as within-subjects factor were conducted to determine age effects in *d'* across the 4 conditions.

There was a main effect of age, $F_{(1,37)}$=5.63, p=0.02, η_p^2=0.13. Younger adults reported significantly higher *d'* scores (mean= 3.64, SD= 0.72) compared to older adults (mean= 3.19, SD= 0.76).

There was a main effect of condition, $F_{(3, 111)}$=16.08, p< 0.001. Pairwise comparisons indicated that participants recorded significantly higher *d'* in the congruent condition (mean=3.83, SD= 0.70) compared to incongruent (mean=3.40, SD= 0.75), tones (mean=3.18, SD=0.70), and visual conditions (mean=3.26, SD= 0.78), all at p<0.001. Participants' *d'* score in the incongruent, tones and the visual conditions did not differ significantly, $p > 0.05$. The age x condition interaction effect was found to be non-significant, $p>0.05$. See **Figure 4-4**.

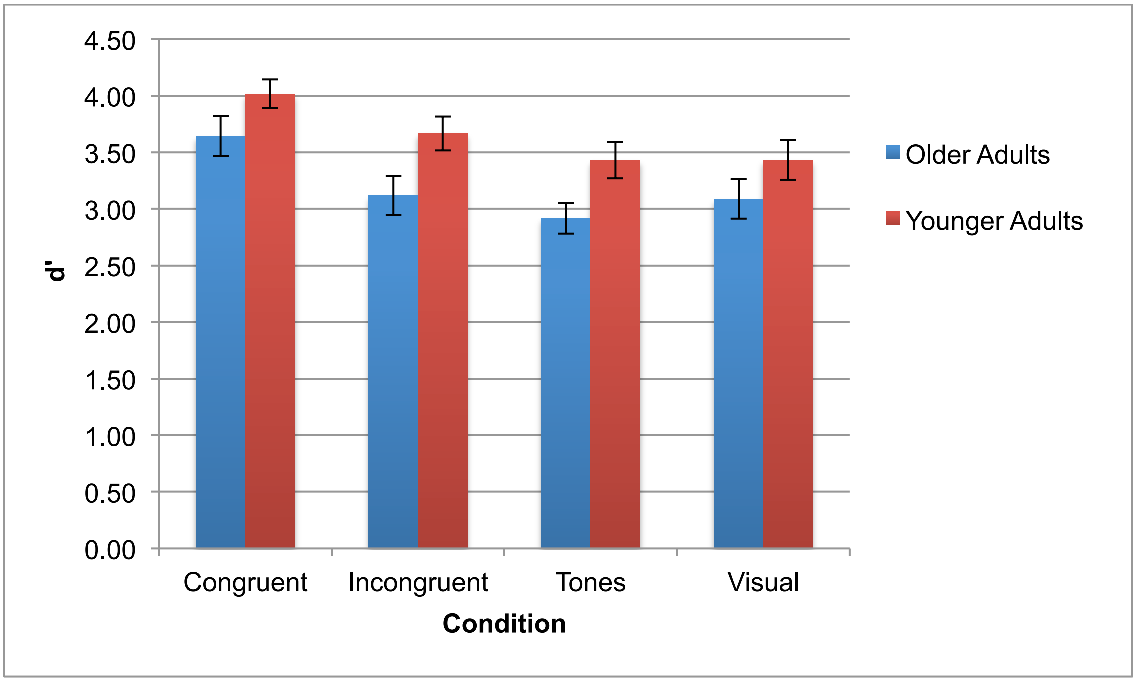

Figure 4-4: Graph displaying mean *d'* for participants for all participants. There is a main effect of age group, and a main effect of condition. Error bars represent standard error.

4.2 Discussion

Experiment 3 has shown that cross-modal stimuli facilitate recognition memory compared to uni-modal stimuli. However, it is not just multisensory experiences that facilitate recognition memory, but rather, the stimuli pair must be semantically meaningful to facilitate recognition memory. Thus the objective of this study was to compare recognition memory performance across four conditions, i.e. congruent (cross-modal pairs were semantically congruent), incongruent (cross-modal pairs were not semantically congruent), tones (visual image paired with a brief tone) and visual stimuli presented alone. While past studies have found that congruent stimuli facilitated recognition memory compared to incongruent stimuli, this congruency effect has not been tested beyond 1st repetition. Hence, it was expected that with repetition, participants would perform equally on all four conditions.

With respect to percentage errors made, as expected, older adults made significantly more percentage errors compared to younger adults. In addition, participants made significantly less percentage errors in the congruent condition for the new and the R1 repetition types, but not the R2 repetition types, where there was no difference in percentage errors made across the conditions. In addition, while there were no difference in older and younger participants in percentage errors made for the new trials, older participants made significantly more errors in the R1 and R2 trials compared to their younger counterparts.

In terms of response times, as expected, older adults' response times were significantly slower compared to younger adults in all conditions. Older and younger adults showed a different pattern in response times across the conditions. Older adults responded significantly faster in the tones condition compared to the incongruent condition, with no differences between the rest of the conditions. However, younger adults showed significantly longer response times to the congruent and incongruent conditions compared to both the tones and visual condition.

Lastly, younger adults showed better discriminability compared to older adults, as given by higher *d'* scores. Participants also recorded highest *d*' scores in the congruent condition compared to all other conditions, supporting previous studies showing the importance of semantic congruency in facilitating memory performance. See section 4.5 for further discussion

4.3 Experiment 6: Effects of semantic congruency and repetition on the ERP correlates of recognition memory

4.3.1 Introduction

The main objective of this study was to investigate the effects of semantic congruency across repetitions on the ERP components of recognition memory, namely the FN400 old/new effect associated with recollection, the LPC old/new effect associated with recollection and the LFE old/new effect associated with post retrieval monitoring and evaluation (Ally & Budson, 2007; Curran, 2000; Rugg & Curran, 2007).

With respect to semantic processing, ERP studies have investigated congruency within sentences and statements; and incongruent words or semantic violations within sentences elicits N400, indicating this waveform to be associated with reprocessing of semantically incongruent information (Besson, Kutas, & Petten, 1992; Kutas & Hillyard, 1980; Mitchell, Andrews, & Ward, 1993; Neville, Kutas, Chesney, & Schmidt, 1986). While the ERP component associated with familiarity has been labeled the FN400, it has been argued that there are no morphological differences between FN400 and the N400 apart from its distribution. The FN400 has been found to be more frontal compared to the N400 in studies of language processing (Voss & Federmeier, 2012). Support for this comes from research that showed the FN400 to be affected by semantic priming, rather than familiarity (Voss & Federmeier, 2012). In a recent study, the FN400 was unaffected when pseudowords were repeated, unlike the LPC component, indicating that this FN400 component to be sensitive to semantic processing (Bermúdez-Margaretto, Beltrán, Domínguez, & Cuetos, 2015)

There has been a lack of research in understanding the role of semantic congruency and how it affects these recognition components, i.e familiarity and recollection. While information that is semantically congruent has been shown to lead to a more elaborate memory trace during encoding, and this facilitates retrieval processes during recognition memory (van Kesteren et al., 2013, 2010) little is known about the processes of familiarity and recollection, particularly in light of information that is incongruent. It is expected that semantically incongruent information affect encoding processes, which then would lead to enhanced familiarity processes as a compensatory mechanism to support recognition memory. In contrast, congruent information should lead to a better encoding process, leading to a more elaborate memory trace, which should be reflected in the LPC. Lastly, as experiment 5 has shown retrieval difficulties in incongruent condition, compared to congruent condition, it is expected that the LFE should be enhanced for the incongruent condition. Although behavioral results showed no significant difference in percentage errors made for the R2 trials, ERP data would be more informative in the processes supporting recognition memory in both conditions during R2 trials.

4.3.2 Methods

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus

4.3.2.1 *Participants*

Thirty participants were recruited for the study. All the participants were Malaysian students at University of Nottingham Malaysia Campus with normal or corrected-to-normal vision and no auditory impairments, or suffer from any neurological disorders. Data from 5 participants were excluded as they showed depressive symptoms (See section 4.3.2.2.1 for further details on the screening criteria, and appendix A.9 for participant's mean scores). This resulted in a final number of 25 participants (mean age= 21.48, SD= 3.33), comprising of 13 males and 12 females. For the behavioral study, the responses of 25 participants were tabulated. However, following EEG pre-processing, only data from 19 participants were suitable, as data from 6 participants were excluded due to technical difficulties in ERP recording, causing difficulties in data analyses. Participants in this study did not participate in any of the previous experiments.

4.3.2.2 *Materials*

4.3.2.2.1 Questionnaires

As experiments 1-5, younger participants completed the BDI to screen for depressive symptoms.

4.3.2.2.2 Stimuli

The stimuli used in the experiment were identical to the stimuli used in the congruent and incongruent conditions of Experiment 5. Stimulus presentation was controlled using *Psychopy* software version 2.0 (Peirce, 2008) and a desktop computer was used to run the experiment.

4.3.2.3 *Design*

The design was a 2 x 3 repeated measures design with condition (congruent vs incongruent) and repetition (new vs R1 vs R2) as the within subjects factors.

There was one practice session consisting of one block with 12 trials of stimuli from both conditions varied to represent the new and R1 trial types. Of the 12 trials, 6 were new and 6 were R1 trials. There was a total of four experimental blocks with 2 blocks for each condition, randomized for counterbalancing. Each block consisted of 55 new stimuli, 50 R1 stimuli and 30 R2 stimuli, with a total of 135 trials in each block, making up 270 trials for each condition.

4.3.2.4 *Procedure*

4.3.2.4.1 Behavioral task

The procedure for this experiment was identical to experiment 2. See **Figure 2-2** for the flow diagram of the experimental procedure. However, there were some differences where the fixation cross was presented for 1000 ms, and the target stimuli (image and spoken word) was presented for 2500 ms. The auditory stimuli was presented via Sony earphones where participants adjusted the volume to a comfortable level. Participants responded '*new* or '*old'* within the time frame using the keyboard. An absence of responding during the time frame would cause the next trial to start, with 'no response' being recorded.

4.3.2.4.2 Electroencephalogram (EEG) Recording and pre-processing

The EEG acquisition procedure was identical to that of experiment 2, except for a few differences. In this experiment, participants provided their response via a keyboard instead of a button box, and following acquisition; EEG data were segmented off-line into single-trial epochs of 2700 ms (200 ms pre-stimulus), and into six categories, namely correct responses for new, R1 and R2 repetition trials for congruent and incongruent conditions.

4.3.3 Results

4.3.3.1 *Behavioral results*

Participants' recognition performance was assessed in terms of mean percentage errors made and response time. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses. In cases of violations of sphericity, degrees of freedom were corrected using Greenhouse-Geisser corrections.

4.3.3.1.1 Effects of condition and repetition on percentage errors

A repeated measure ANOVA with condition (congruent vs incongruent) and repetition (new vs. R1 vs. R2) as within-subjects factors was conducted. There were no main effects observed, $p < 0.05$.

However, there was a condition x repetition interaction effect, $F_{(2,48)}=8.56$, $p< 0.001$, $\eta_p^2 = 0.20$. Please see **Figure 4-5**. The interaction is explored below:

4.3.3.1.1.1 Effects of condition on percentage errors made in new, R1 and R2 repetition types

Three paired samples *t*-tests were conducted on each repetition to determine if there was an effect of condition on the new, R1 and R2 repetition types. There was a difference in condition for the new trials, $t_{(24)}$=3.49, p= 0.002 Participants made significantly less percentage errors in the new trials in the congruent condition (mean= 1.82%, SD= 1.41) compared to the incongruent condition (mean= 3.13%, SD= 2.00). However, there were no significant differences in mean errors made between the two conditions in the R1 and R2 trials, p>0.05.

4.3.3.1.1.2 Effects of repetition on percentage errors made in congruent and incongruent condition.

Separate repeated measures analyses were conducted on both the congruent and incongruent conditions to determine if there was an effect of repetition in percentage errors made in both the conditions.

There were no effects of repetition in the congruent condition, p=0.24. However, there was a significant effect of repetition in the incongruent condition, $F_{(2,48)}$=10.91, p<0.001, η_p^2= 0.31. Post-hoc paired samples *t*-tests (Bonferroni corrected p< 0.0167) revealed that revealed that participants made significantly lower percentage errors in the R2 trials (mean=0.93%, SD=2.00) compared to new trials (mean= 3.12%, SD= 2.31), $t_{(24)}$=4.76, p<0.001 and R1 trials (mean= 2.60%, SD= 2.31), $t_{(24)}$=3.57, p=0.002.

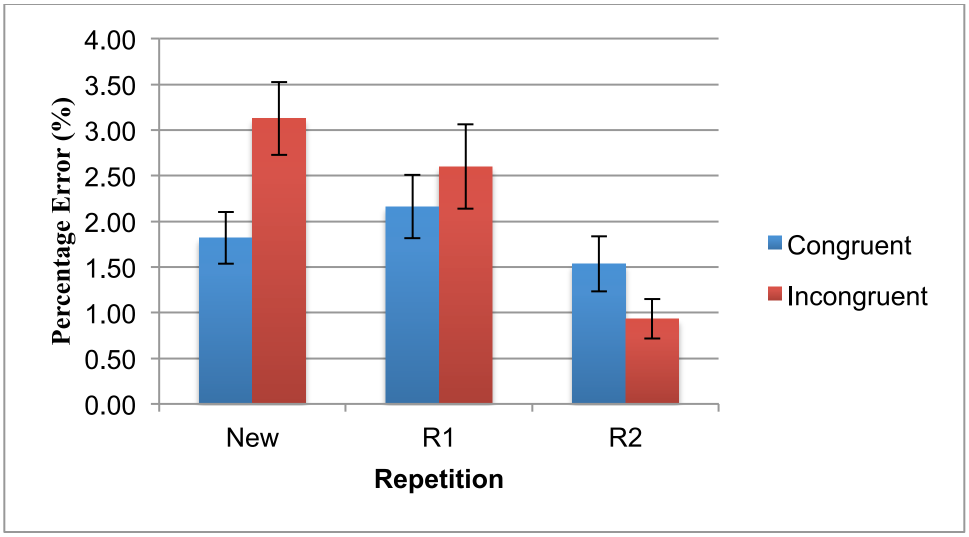

Figure 4-5: Graph depicting mean percentage error for each repetition in congruent and incongruent conditions, showing the condition x repetition interaction effect. Error bars represent standard error

4.3.3.1.2 Effects of condition and repetition on response times

A repeated measure ANOVA with condition (congruent vs incongruent) and repetition (new vs. R1 vs. R2) as within-subjects factors was conducted. There was a significant effect of repetition, $F_{(1.32, 31.72)}$=27.10, p<0.01, η_p^2=0.53. Pairwise comparisons found that participants response times to the new trials (mean=1083.42, SD= 173.42) were significantly slower than the R1 trials (mean=1028.60 ms, SD= 151.91), which was significantly slower than the R2 trials (mean= 985.17 ms, SD= 140.74), all p values < 0.001. No other main effects of interaction effects were significant, p>0.05. Please refer to **Figure 4-6** below:

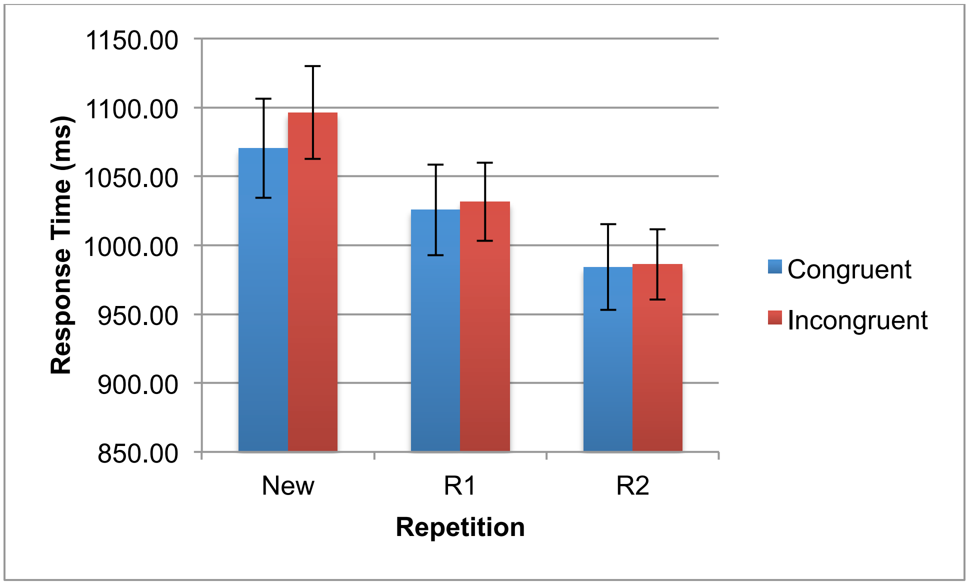

Figure 4-6: Graph depicting mean reaction time for each repetition in both conditions, showing the main effect of repetition. Error bars represent standard error.

4.3.3.2 *Effects of condition on d'*

Paired samples *t*-test conducted revealed a significant effect of condition, with congruent condition (mean= 4.27, SD= 0.41) reporting higher *d'* scores compared to incongruent condition (mean= 4.05, SD=0.48), $t_{(24)}$= 2.20, p<0.05.

4.3.3.3 *ERP results*

Mean amplitude results pertaining to the three time windows representing the FN400, the LPC and the LFE are presented below.

4.3.3.3.1 FN400

A 2x3x4 repeated measures ANOVA was conducted with condition (congruent vs incongruent), repetition (new vs R1 vs R2) and region (RAI vs RAS vs LAI vs LAS) as the within subjects factor on mean amplitudes within the time window of 300-500 ms post stimulus onset.

There was a main effect of region, $F_{(3,54)}$=6.14, p< 0.001, $\eta_p^2 = 0.26$. Pairwise comparisons found that the LAI region recorded more negative mean amplitude (mean=-1.50, SD= 3.12) compared to the RAS (mean= 0.92, SD= 3.71) and the LAS region (mean=0.76, SD= 3.33), p<0.001

There was a region x repetition interaction effect, F (3.46, 62.22) =3.46, p=0.02, $\eta_p^2 = 0.16$. Please refer to **Figure 4-7**.

To analyze this interaction effect, a series of one factor repeated measures ANOVAs were conducted on each region to determine if there was a difference in mean amplitude for the three repetition types. There was a trend towards significance of repetition on the RAI region, $F_{(2,36)}$=3.09, p=0.06, η_p^2=0.15; and LAS region, $F_{(2,36)}$= 3.09, p=0.06, $\eta_p^2 = 0.15$. There were no effects of repetitions in the RAS, and LAI region, p>0.05.

Post-hoc paired samples t-tests (Bonferroni corrected p< 0.0167) found that in the RAI region, the mean amplitude recorded by the new trials were more positive (mean= 0.51μv, SD= 1.97) compared to the R1 trials (reverse old/new effect), which were more negative (mean=-0.50 μv, SD= 1.90), $t_{(18)} = 2.94$, p=0.009. There were no significant differences between the new trials and the R2 trials, or the R1 and the R2 trials p>0.0167. Please see **Figure 4-8** and **Figure 4-9** for grand averaged waveform for congruent and incongruent condition respectively at the RAI region.

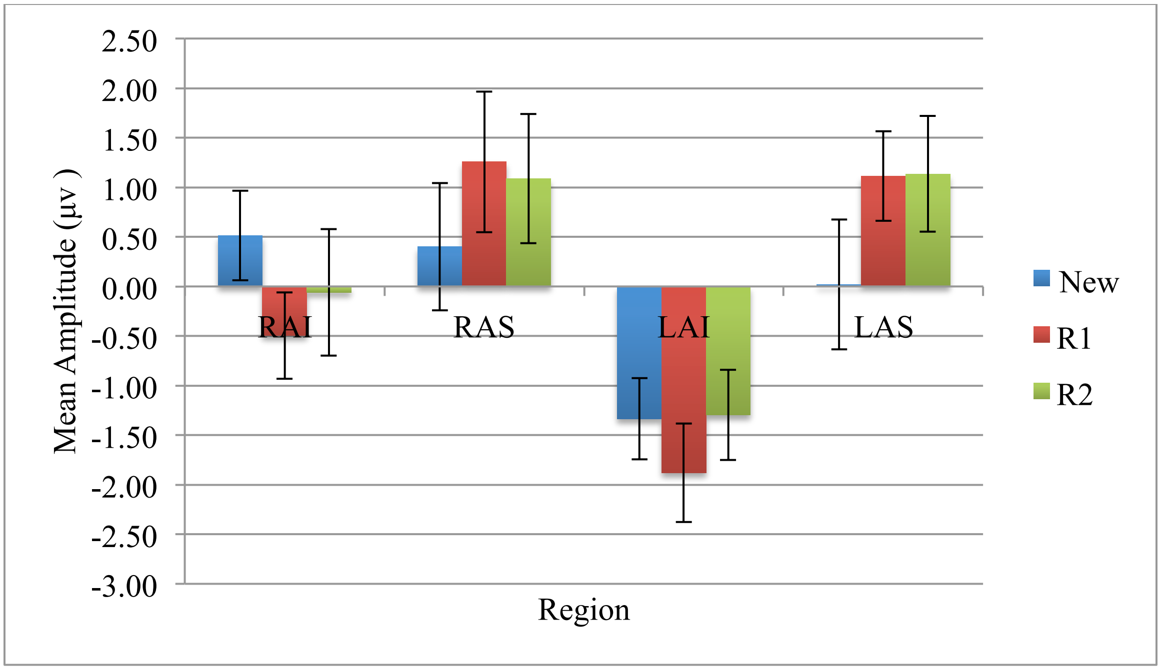

Figure 4-7: Graph depicting the interaction effect of region x repetition. Error bars represent standard error

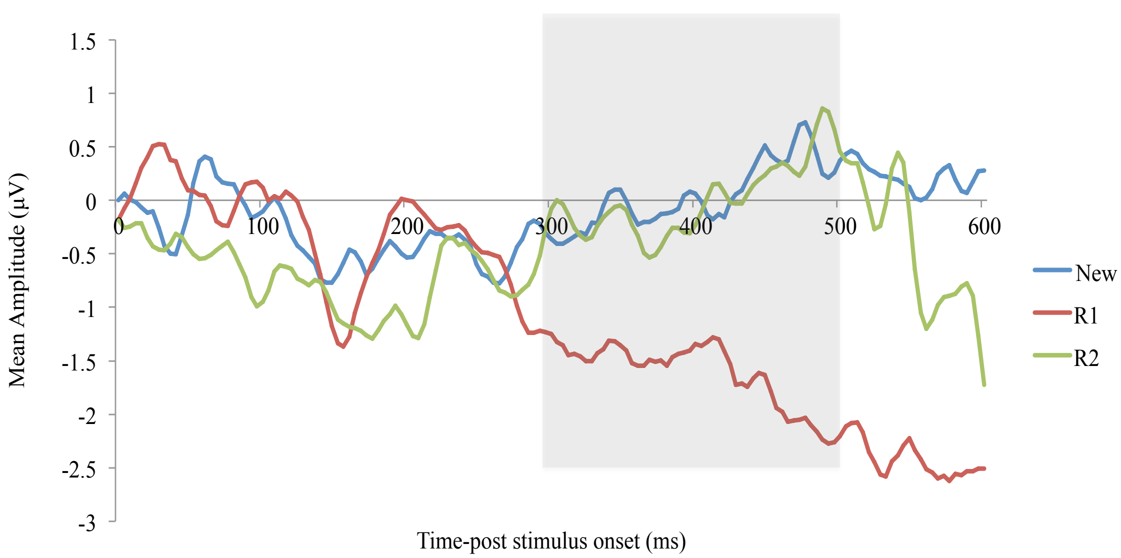

Figure 4-8: Grand averaged waveform for congruent Condition in the RAI region. Time window reflecting the FN400 old/new effect highlighted.

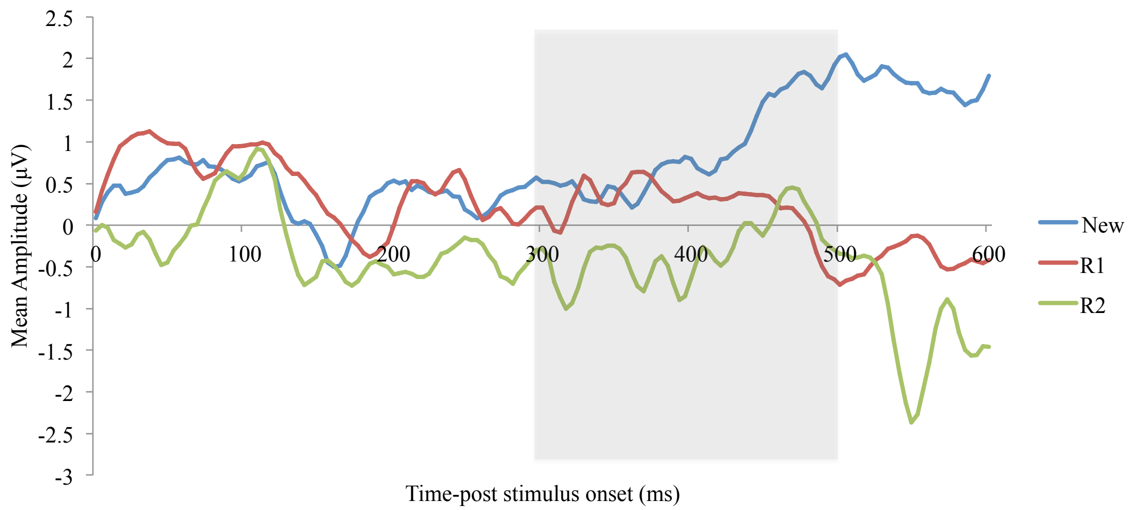

Figure 4-9: Grand averaged waveform for incongruent condition in the RAI region. Time window reflecting the FN400 old/new effect highlighted

In the LAS region, Bonferroni corrected paired samples *t*-tests ($p < 0.0167$) found the R2 trials recorded a significantly higher mean amplitude (mean= 1.14 µv, SD= 2.55) compared to the new trials (mean=0.02 µv, SD= 2.85), $t_{(18)}=2.86$, $p=0.01$. Please refer to **Figure 4-10** and **Figure 4-11** the grand averaged waveforms for congruent and incongruent conditions respectively, in the LAS region.

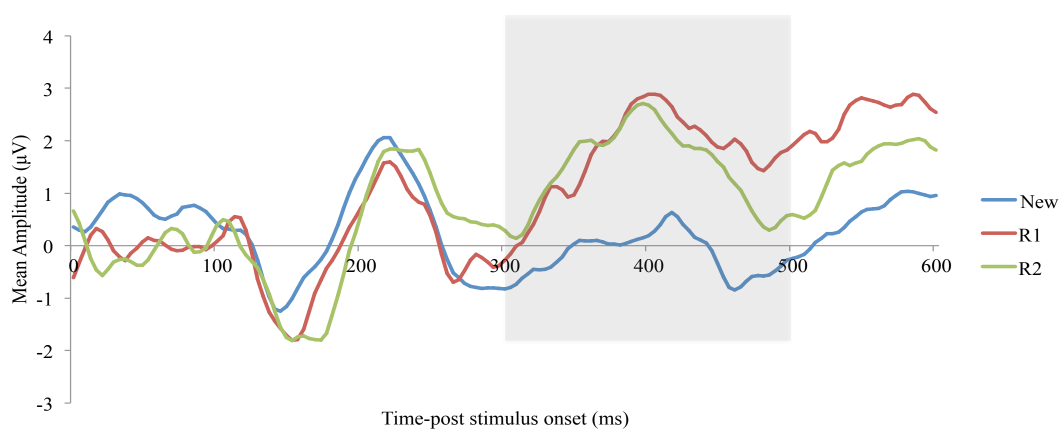

Figure 4-10: Grand averaged waveform for congruent condition in the LAS region. Time window reflecting the FN400 old/new effect highlighted `

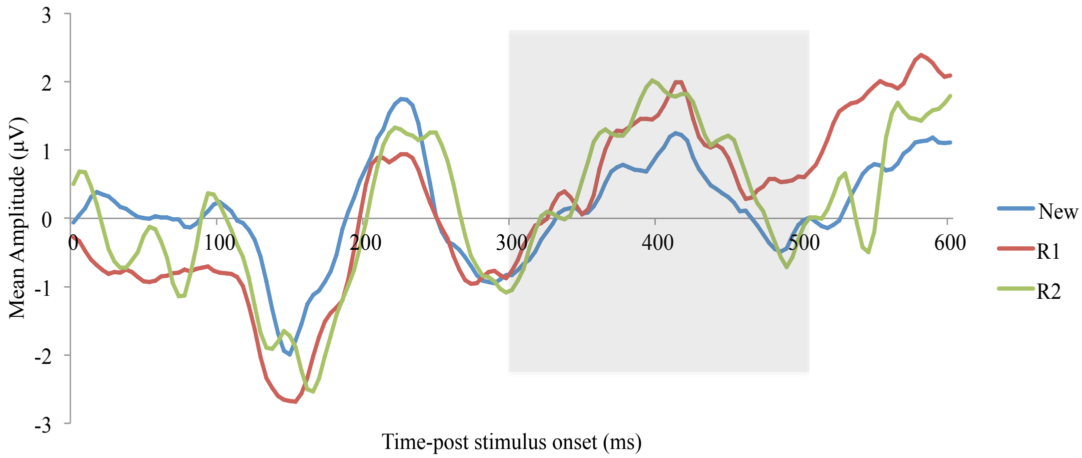

Figure 4-11: Grand averaged waveform for incongruent condition in the LAS region. Time window reflecting the FN400 old/new effect highlighted.

4.3.3.3.2 LPC

A 2 x 3 x 4 repeated measures ANOVA was conducted with condition (congruent vs incongruent), repetition (new vs R1 vs R2) and region (RPI vs RPS vs LPI vs LPS) as the within subjects factors on mean amplitudes within the time window of 500-800 ms post stimulus onset. There was a main effect of region, $F_{(3,54)}$=32.60, p<0.001, η_p^2=0.64. Pairwise comparisons showed the mean amplitude to be significantly different in the inferior regions compared to the superior regions. The RPI (mean=0.34µv, SD= 3.62), and LPI region (mean= -1.12 µv, SD= 4.69) recorded lower mean amplitude compared to the RPS (mean= mean= 3.99 µv, SD= 4.05) and LPS region (mean= 4.42µv, SD= 3.67), p<0.001.

All other main effects and interaction effects were not significant, p>0.05.

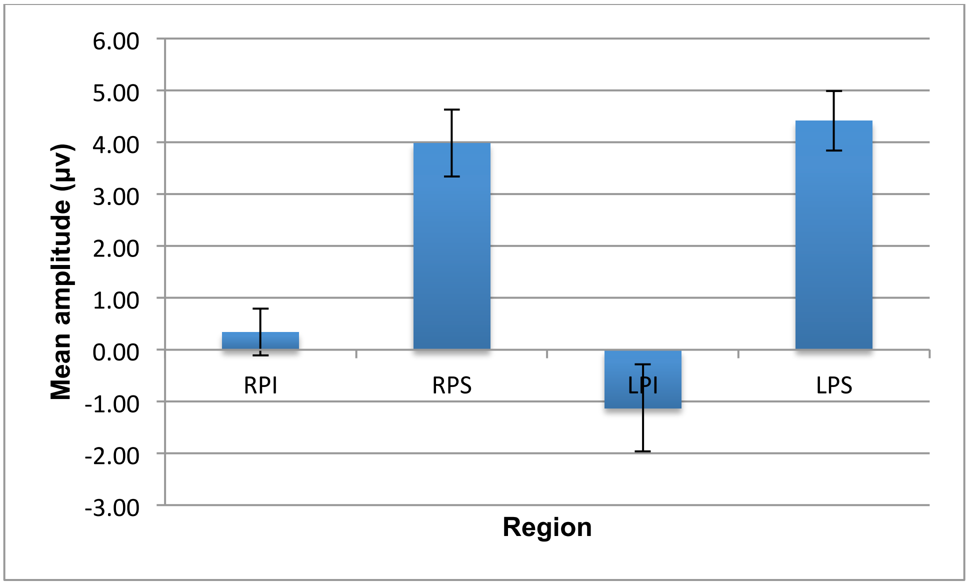

Figure 4-12: Graph depicting the mean amplitudes across the four regions during the time window of 500-800 ms. Error bars represent standard error.

4.3.3.3.3 LFE

A 2x3x4 repeated measures ANOVA was conducted with condition (congruent vs incongruent), repetition (new vs R1 vs R2) and region (RAI vs RAS vs LAI vs LAS) as the within subjects factor on mean amplitudes within the time window of 1000-1800 ms post stimulus onset. There was a main effect of region, $F_{(3, 54)}$=4.54, p=0.01, η_p^2 = 0.20. Pairwise analyses found that the LAS region (mean=2.86, SD= 5.41) recorded a significantly higher mean amplitude compared to the LAI region (mean=-0.26, SD= 4.43), p=0.03. Please refer to **Figure 4-13**.

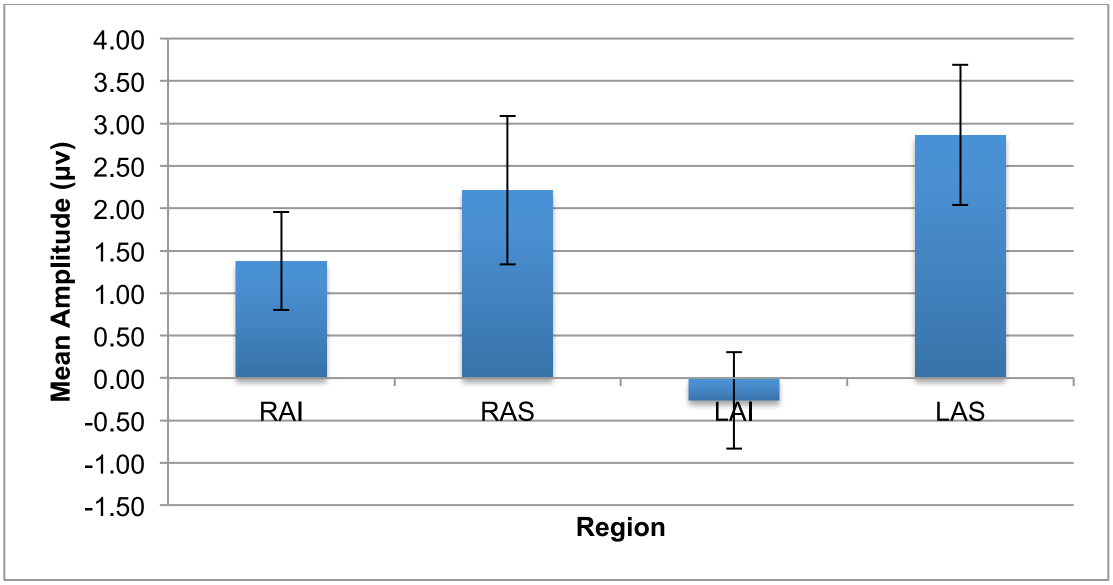

Figure 4-13: Graph depicting mean amplitude across the four regions for time window (1000-1800 ms). Error bars represent standard error.

4.4 Discussion

4.4.1 Behavioral results

Consistent with our previous experiments, response times for the R2 trials were significantly faster than the R1 trials, which were significantly faster than the new trials. However, there were no significant differences between the congruent and incongruent conditions with respect to response times. Participants made fewer errors in the congruent condition compared to incongruent condition for the new trials. There were no significant differences in errors made between the two conditions for the R1 and R2 trials. Lastly, participants showed better discriminability, shown by higher *d'* scores in the congruent condition compared to incongruent condition.

4.4.2 ERP results

The ERP results were analyzed via assessing mean amplitudes averaged across a cluster of electrodes in specific regions of interest, in specific time windows, split between whether the stimuli was congruent or incongruent.

4.4.2.1 *FN400*

Looking at the difference in mean amplitudes, for the 300-500 ms time window associated with familiarity, there was a significant repetition x region interaction in the RAI and LAS region only, with no significant differences in repetition in the RAS and LAI region. In the RAI region, new trials recorded a significantly larger and more positive mean amplitude voltage compared to R1 trials. This was an inverse from the typical pattern normally reported in the literature, where new trials would record significantly more negative voltage compared to repeated trials. Furthermore, the pattern was not seen with R2 trials where no significant differences in mean amplitude voltage was seen between new or R1 trials.

In the LAS region, an old/new effect was seen where the R2 trials recorded a significantly larger and more positive mean voltage compared to the new trials, with no significant differences in mean voltage for the R1 trials.

4.4.2.2 *LPC*

In contrast to the 300-500 ms, the 500-800 ms time window (LPC component associated with recollection) found only an effect of region. For the LPC component, the differences lay in the inferior regions, compared to the superior regions. The RPI and LPI recorded significantly smaller mean amplitude compared to the RPS and the LPS.

4.4.2.3 *LFE*

Unlike the FN400 component, no old/new effects were seen in this time window. However, there was an effect of region. Similar to the LPC results, the differences in the LPE region also lay in the left inferior and superior regions, and significantly smaller mean amplitude was recorded in the LAI compared to the LAS region.

4.5 General Discussion

The objective of experiment 5 and 6 was to determine the effect of semantic congruency on recognition memory using cross-modal stimuli. The results from experiment 5 found that older adults recorded slower response times than younger adults in all conditions. However across conditions, older adults were significantly faster in the tones condition compared to the incongruent condition, while younger adults were significantly faster in the tones and visual condition compared to both incongruent and congruent conditions. Moreover, there was an effect of age on percentage errors with older adults making more errors compared to younger adults in R1 and R2 trials, but not in new trials. Overall, participants made significantly fewer errors in congruent compared to all other conditions, and the congruent condition recorded a significantly higher *d'* score compared to all other conditions.

With respect to response times, the results are consistent with our previous experiments (experiment 3 and 4) where response times for R2 was significantly faster than R1, which was faster than new. The significantly longer response times for new is consistent with the time taken for memory evaluation and template matching (Kim et al., 2001). Another reason could be due to higher confidence for R2 items as they had been repeated for the 2nd time, which also translates to participants making fewer percentage errors.

Furthermore, with respect to the longer response times recorded for the incongruent, congruent conditions, compared to the visual and tones conditions. Consistent to our findings from experiment 3, it can be inferred the presence of the spoken word stimuli had caused slower response times, as the auditory stimuli in the form of spoken words would need to be processed continuously from target onset, which would take several milliseconds. This is as opposed to visual stimuli, in which the entire information is available for processing upon target onset. The use of tones did not add on to any further information to make the old/new discrimination, as the tones did not have to be processed continuously as using spoken words. In addition, older participants responded significantly faster in the tones condition, compared to the incongruent condition. This could be due to the tones serving as an alerting signal to prompt older participants to answer quickly. Furthermore, the finding that there was an effect of condition on recognition (repeated items) is contradictory to prior research (Lehmann & Murray, 2005; Thelen et al., 2012) that found no effect of condition (audio-visual pairs vs visual images) on recognition of repeated items. However, in the previous studies mentioned, repeated items were only presented in the visual modality, and hence all repeated items were in the visual modality, with no significant differences in response times. Hence, this further strengthens the idea that the longer response times were due to the longer processing time needed to continuously process the spoken word before a discrimination could be made, rather than longer processing time to recognize the stimuli.

With respect to percentage errors made, there was an interesting effect of age. While older adults made more errors compared to younger adults only in both the recognition (R1 and R2) trials, they were equally able to discriminate a new trial as being presented for the first time, as well as younger adults, consistent with the results found in experiment 4, in the cross-modal recognition test.

Another interesting result revealed was that there was only an effect of condition on both new trials and R1 trials, but not R2 trials. Participants made fewer errors in responding to new trials and R1 trials when the auditory and visual stimuli were congruent, compared to trials in the incongruent, tones and visual condition. This contradicts Lehmann and Murray (2005), who found no significant differences in discrimination of new trials of visual images paired with tones, and visual images presented together. However, discrimination of visual images that had been initially paired with tones were significantly poorer compared to visual images presented alone. Similarly in the study by Thelen et al., (2012), instead of meaningless tones, visual images paired with meaningless sounds (that were different across the new images) found that pairing of visual images with these sounds also impaired uni-sensory visual recognition. However, a major difference between that study and the current study was that in their design, initial presentation was in the cross-modal modality, while repeated presentations was in the uni-sensory modality. Hence, it was found that initial pairing of visual images with meaningless tones/sounds impaired uni-sensory discrimination when the image was repeated. In contrast, in our present study, the initial presentation and repeated presentations were all in the cross-modal modality. While their studies indicated that tones impaired recognition of uni-sensory visual recognition, in this study, as items were presented in the same condition (modality) as initial presentation, there were no significant differences seen in visual and tones condition for all repetitions.

An interesting finding was seen with the R2 trials where, upon second repetition, these effects (of condition) disappeared where all participants made fewer errors in R2 trials. This findings extends all prior multisensory research that found an effect of congruent multisensory pair in recognition memory (Lehmann & Murray, 2005; Murray et al., 2005; Murray et al., 2004; Thelen & Murray, 2013). These studies have shown the effects of semantic congruency only upon first repetition. However, the current study revealed that upon subsequent repetition, these effects disappear, and it is possible that the effects of repetition are stronger than the effects of congruent multi-sensory pairings. While older adults made significantly higher percentage errors compared to younger adults in all conditions, the result indicate that older adults show a similar trend, i.e. with repetition, recognition memory improves. In line with experiment 1, retrieval difficulties do not indicate impoverished memory, as items that were difficult to recognize in the 2nd repetition, was recognized in the 3rd repetition (see related findings by Kılıç et al., 2013; Zhao et al., 2014). From the results of this experiment, it can be inferred that while participants made significantly more errors during 1st repetition compared to both new and 2nd repetition, this is more likely due to error in retrieval rather than encoding. This is because if the higher errors made for the incongruent, tones and visual conditions (compared to the incongruent conditions) were due to encoding failure, then this effect of condition should have appeared in the R2 trials. Instead, because of repetition, participants' error rates reduced across all conditions, and they performed equally among all conditions. Therefore, in line with Kılıç et al. (2013) and Zhao et al. (2014), retrieval difficulties in the R2 trials for the visual, tones and incongruent condition is not a sign of impoverished memory, or encoding difficulties, as these items were easily retrieved in the final repetition (R2).

Lastly, *d'* scores gives a measure of how well a participant was able to discriminate repeated items from items presented for the first time (new), taking into consideration the rate a participant commits false alarms (responding an item as 'old' when it is 'new'). In line with experiment 4 results, it was found that younger adults had significantly better discriminability scores than older adults in all conditions. Furthermore, participants' discriminability in congruent condition was significantly better compared to the incongruent, visual and tones condition, with no significant differences between the latter three conditions. This was consistent with experiment 3 that found the cross-modal condition to have significantly better discriminability than the visual and auditory condition.

Overall, the three main interesting findings that came from experiment 5 was 1) the effects of congruency was only seen in first repetition, and disappeared with subsequent repetition; 2) This pattern was seen with older adults. Thus, repetition could serve as a compensatory mechanism in ageing to improve recognition memory; and 3) it is likely that the higher errors made were due to retrieval difficulties rather than encoding failure.

The objective of experiment 6 was to explore the effects of semantic congruency on the EEG correlates recognition memory, to better understand the processes supporting recognition memory when information is congruent, and when it is incongruent.

While there were no significant differences in response times between the two conditions (congruent vs incongruent), this was in line with experiment 5 as well as Lehmann and Murray (2005) that found no significant differences in response times between congruent and incongruent conditions, when participants made old/new discriminations of visual images that had initially been presented with a congruent sound or an incongruent sound. Hence it can be said that semantic congruency of item pairs does not affect the processing speed of making old/new discriminations. So far results have shown that the presence of having a spoken word as the auditory stimuli leads to longer response times compared to presentation of visual images alone as this is likely due to the longer time needed for the spoken word to be presented fully.

Experiment 6 found no effect of semantic congruency on R1 and R2 trials, but only for new trials. This indicates that semantic congruency had an effect in discriminating between new items but not in recognizing repeated items, which contradicted past studies that found an effect of semantic congruency in discrimination of repeated items memory (Lehmann & Murray, 2005; Murray et al., 2005; Murray et al., 2004; Thelen & Murray, 2013). On the other hand, experiment 5 found semantic congruency to have an effect in new trials and R1 trials but not R2 trials. Consistent to experiment 5, these results show that when taking false alarm rates into consideration, participants were able to discriminate congruent information significantly better compared to incongruent information. Therefore, despite showing no difference in percentage errors made between the conditions, results of experiment 6 still show support that semantic congruency increases recognition memory accuracy when false alarm rates are taken into consideration.

Past research have shown that old/new effect, i.e. a more negative going wave for new items compared to old items to be associated to familiarity, in the right and left frontal superior regions (Curran & Cleary, 2003; Curran & Doyle, 2011; Curran & Friedman, 2004; Nyhus & Curran, 2009; Rugg & Curran, 2007), i.e. the RAS and LAS, while in addition to this others have also reported to test this effect in the inferior regions, i.e. RAS, LAS, RAI and LAI, while manipulating pictures and words during study and test (Ally & Budson, 2007; Ally et al., 2008). While the old/new effect has been reported in the superior regions, comparison of the regions found a larger effect at the superior regions (RAS, LAS) compared to the inferior regions, i.e. the RAI and LAI (Ally et al., 2008), while the RAI region was found to be sensitive to test format (significantly more positive for pictures rather than words). In the current study, we analyzed the repetition effects in all four regions, i.e. RAS, LAS, RAI and LAI in order to determine if the effects of semantic congruency and its differences on superior and inferior regions.

In the 300-500 ms time window, results showed the mean amplitude was only significantly more positive for the R2 trials compared to the new trials (old/new effect) in the LAS region, but it was not significant in the RAS region. While no effect was seen in the RAS, the significant old/new effect in the LAS region was partly in line with prior findings (Curran & Cleary, 2003; Curran & Doyle, 2011; Curran & Friedman, 2004; Nyhus & Curran, 2009; Rugg & Curran, 2007) that only tested familiarity effects in these regions where they stated it to be more maximal in the superior regions. In addition, in comparison to both superior and inferior regions, Ally et al. (2008) have found larger effects in the superior compared to inferior regions, particularly when pictures were used.

A surprising effect was seen in the RAI region where mean amplitude for the new trials were more positive compared to the R1 trials. This is an inverse of the old/new effect that is typically reported in studies where the new trials would record a negative going wave compared to the repeated trials. However, this inverse effect was seen in the inferior regions where the old/new effect is typically not observed and hence, should be investigated further.

As for the 500-800 ms time window is known to be associated with recollection (Curran & Cleary, 2003; Curran & Friedman, 2004; Rugg & Curran, 2007 etc). Results show that the differences in mean amplitude between the repeated and new waveforms at all regions were not significantly different. The differences in overall mean amplitudes where the superior sites showed significantly larger mean amplitudes (RPS and LPS) compared to the inferior regions (RPI and LPI). Contradicting past studies that had found repetition effects, i.e. the old/new effect associated with recollection at the superior sites (Curran & Cleary, 2003; Curran & Doyle, 2011; Curran & Friedman, 2004; Nyhus & Curran, 2009; Rugg & Curran, 2007), the current study did not find any old/new effects associated with recollection. However, in line with previous past studies mentioned, it did find that a higher mean voltage in the superior sites compared to inferior sites in this time window.

Lastly, the only effects seen in the 1000-1800 ms time window were a significant increase in voltage in the superior regions (RAS and LAS), compared to the inferior regions (RAI and LAI), which was similar to the LPC old/new effect. As no old/new effects were apparent, the current findings stood in stark contrast to past findings (Allan, Wilding, & Rugg, 1998; Ally & Budson, 2007; Rugg & Wilding, 2000; Wilding & Rugg,

1996) that reported the late frontal old/new effect associated with post retrieval monitoring of contents, more dominant at the right frontal regions.

One possibility for the lack of an old/new effect observed in the LPC and the LFE time window could be the large standard error associated and small sample size.

In summary, while experiment 5 and 6 showed that repetition plays a bigger role in recognition memory compared to semantic congruency, and that semantically congruent or incongruent affects these neural processes in a qualitatively different way. Old/new effects related to familiarity were found for items repeated for the 2nd time in the LAS region, which could infer that items repeated for the 2nd time may invoke familiarity rather than recollection, as familiarity acts fast, compared to recollection (Rugg & Curran, 2007), without requiring any information from the source. While no old/new effects related to recollection or post-retrieval monitoring were significant, the superior regions recorded a significantly higher voltage compared to the inferior regions for both these time windows tested, which could indicate processing related to memory retrieval to be dominant in the superior regions, rather than the inferior regions.

So far, the results have shown that recognition memory performance improves if the information is presented cross-modally, is semantically congruent and repeated. However, what if the repeated presentation is presented in a different modality compared to initial presentation? For instance, we may be presented with information in a different modality at repeated encounters (study material being presented in auditory format, and having to recognize it during a subsequent test in the visual (written) format). This is known as modality-mismatch (Mulligan & Osborn, 2009) and its effects on recognition memory will be explored in the next chapter.

CHAPTER 5

MODALITY MISMATCH AND ITS EFFECTS ON RECOGNITION MEMORY

Previous research has shown that participants show better recognition memory performance when stimuli are identical at study and at test (perceptual match), compared to when there are some changes in perceptual format during study and test (Ecker, Zimmer, & Groh-Bordin, 2007a, 2007b; Gardiner et al., 2001; Groh-Bordin et al., 2005; Nyhus & Curran, 2009; Reder et al., 2002). One form of perceptual match is a match in modality, where previous research has shown that when the modality of study and test items match, participants show an increase in processing speed due to perceptual fluency (Gallo, Weiss, & Schacter, 2004; Miller et al., 2008; Thapar & Westerman, 2009; Westerman et al., 2002, 2003).

In addition, when study items and test items match in modality (auditory and visual), participants show better recognition memory compared to when they are not (Leynes, et al., 2003; Mulligan & Hirshman, 1995). For instance, Mulligan, Besken, & Peterson, 2010) intermixed visual text and auditory spoken words during study and test and participants had to make recognition judgments. They found that there was no modality-match effect when participants were required to make standard old/new discriminations. However, recognition accuracy was higher when modality was matched, and participants were required to make remember/know decision or retrieve the source it was presented in initially. These procedures indicate a greater perceptual sensitivity than the standard old/new recognition test may detect. The findings also indicate that a modality-match may create a stronger memory trace during consolidation. Therefore, when participants were required to retrieve information related to source memory, or make a remember/know judgment, they would be tapping into recollection. However, in a standard old/new judgment, responding on the basis of familiarity would suffice.

In addition, even when there was a modality and perceptual match, pictures are better remembered compared to words (Schloerscheidt & Rugg, 2004). In this study, when perceptual format was not consistent across study and test, items presented as pictures during study were better recognized as words, compared to vice versa. However, items studied and tested as words were recognized as equally as items presented as pictures and tested as words.

In this chapter, we investigate the modality mismatch using combinations of uni-modal stimuli (pictures and spoken words) and cross-modal stimuli (picture and spoken word presented together) on recognition memory.

5.1 Experiment 7: Effects of modality mismatch on recognition memory

5.1.1 Introduction

This experiment aims to explore the effect of modality mismatch with the more common modalities, i.e. visual, auditory and cross-modal modalities, and to determine if the this effect is consistent across repetitions. In this experimental design, participants faced a modality mismatch at both R1 and R2 repetitions. Hence the objective of this study is to determine how visual, auditory and cross-modal modalities affect recognition memory when modality is mismatched on R1 and R2 trials.

5.1.2 Methods

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus

5.1.2.1 *Participants*

Thirty-eight students participated in this study. All the participants were students at University of Nottingham Malaysia Campus with normal or corrected-to-normal vision. Data from 4 participants that showed depressive symptoms were discarded (See section 5.1.2.2.1 for further details on the screening criteria, and appendix A.9 for participant's mean scores) and 8 students were excluded due incomplete data. This resulted a final number of 26 participants (6 males and 20 females) aged between 18-24 years of age (Mean age= 20.69, SD= 1.29). Participants were compensated with RM5 for their participation. Participants who participated in this experiment had not participated in previous experiments.

5.1.2.2 *Materials*

5.1.2.2.1 Questionnaires

As all previous experiments, younger participants completed the BDI to screen for depressive symptoms, and were only included in the study if their scores were below 17.

5.1.2.2.2 Stimuli

The same visual and auditory stimuli from Experiment 1 were used. See **Figure 3-1** for an example of the visual, auditory and cross-modal stimuli. Presentation of stimuli was controlled using E-Prime software version 2.0 (Schneider et al., 2002).

5.1.2.3 *Design*

The design of the study was a 3x4 repeated measures design with condition and repetition as the within subjects factors. There were 4 conditions in this experiment, i.e.: 'Auditory – Cross-modal – Visual (A|C-M|V)', and 'Visual – Cross-modal – Auditory (V|C-M|A)' 'Cross-modal – Auditory – Visual (C-M|A|V) and 'Cross-modal – Visual – Auditory' (C-M|V|A). In each condition, the first, second and third item represent the type of modality the stimuli was presented in. For example, in the A|C-M|V condition, the first presentation of stimuli was in the auditory modality. The stimuli would then be repeated (with a new associated visual image) in the cross-modal modality after a short delay of 4-6 intervening items at R1. See **Table 5-1** for an outline of each condition.

There was one practice block consisting of 14 trials. 6 were new, 5 were R1 and 3 were R2. The practice block consisted of stimuli from all the four conditions that were varied to represent the new, R1 and R2 in the different modalities. There were 2 experimental blocks, the orders of which were randomized for each participant. Each block consisted of 55 new stimuli, 50 R1 stimuli and 30 R2 stimuli, with a total of 135 trials in each block.

Table 5-1: Outline of each condition in the experiment

Condition	1st Presentation (new)	2nd Presentation (R1)	2nd Presentation (R2)
A|C-M|V	Auditory	Cross-modal	Visual
V|C-M|A	Visual	Cross-modal	Auditory
C-M|V|A	Cross-modal	Visual	Auditory
V|C-M|A	Visual	Cross-modal	Auditory

5.1.2.4 *Procedure*

The procedure of the study was identical to experiment 1, 3, 4 and 5.

5.1.3 Results

5.1.3.1 *Effects of modality mismatch on percentage errors of R1 repetition type*

A one-way within subjects ANOVA with condition as the independent variable (A|C-M|V vs C-M|A|V vs C-M|V|A vs V|C-M|A) and participants' percentage error on R1 trials as the dependent variable was carried out. There was a significant main effect condition, $F_{(2.28, 57.09)}$= 18.92, p<0.001, η_p^2=0.43. Post-hoc paired samples t-tests (Bonferroni corrected p< 0.0083) found participants made significantly more percentage errors in the |A|C-M|V condition (mean= 13.54, SD= 6.72) compared to all other conditions, i.e. V|C-M|A condition (mean=5.46%, SD= 4.22), $t_{(25)}$=5.48, p<0.001; C-M|A|V condition (mean= 7.54%, SD= 5.19), $t_{(25)}$= 4.01, p< 0.001 and the C-M|V|A condition (mean=4.85%, SD= 3.84), t(25)= 6.03, p< 0.001. Participants also made significantly more percentage errors in the C-M|A|V condition compared to the C-M|V|A condition (mean=4.85%, SD= 3.84), t(25)= 6.03, p< 0.001. Participants also made significantly more percentage errors in the C-M|A|V condition compared to the C-M|V|A condition, $t_{(25)}$=3.40, p= 0.002. See **Figure 5-1**.

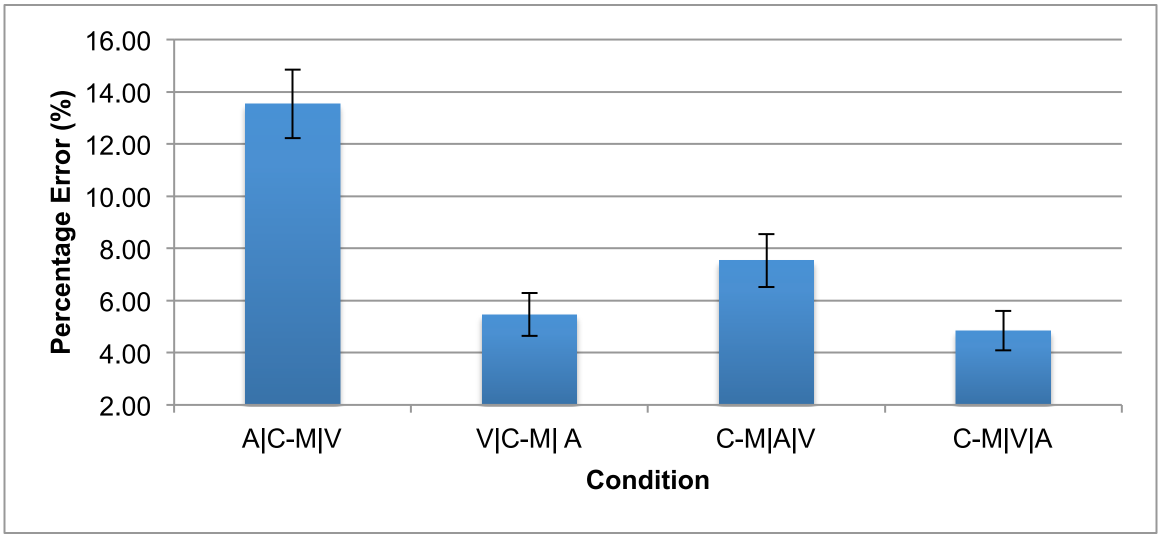

Figure 5-1: Graph showing percentage error in R1 repetition type for the 4 conditions, showing the effect of condition on recognition in R1. Error bars represent standard error.

5.1.3.2 *Effects of modality mismatch on percentage errors of R2 repetition type*

A one-way within subjects ANOVA with condition (|A|C-M|V vs C-M|A|V vs C-M|V|A vs V|C-M|A) and participants' percentage error on R2 trials as the dependent variable was carried out.

There was a significant main effect of condition, $F_{(3, 75)}$=3.50, p=0.02, η_p^2=0.12 . However, Bonferroni corrected paired samples t-tests (p< 0.0083) found that there were no significant differences in percentage errors made in all conditions for the R2 repetition type, all p values > 0.0083. See **Figure 5-2**.

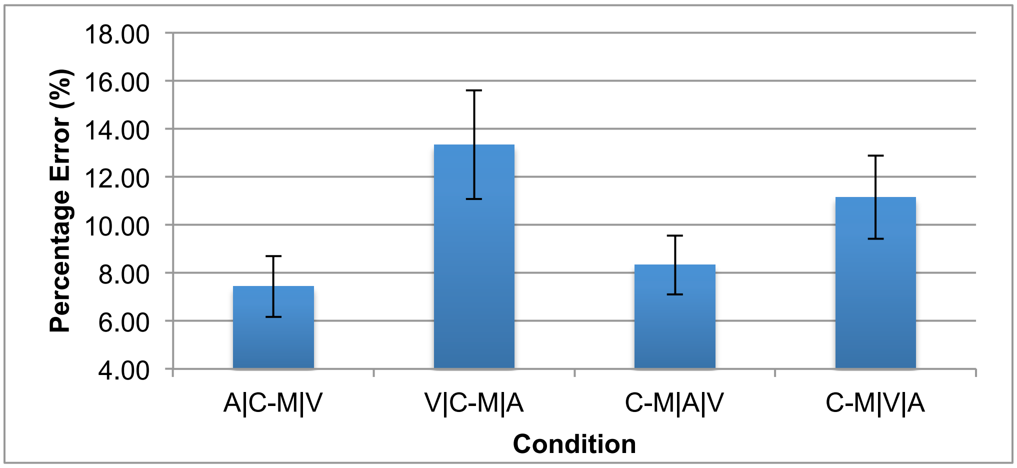

Figure 5-2: Percentage errors made on final repetition trials (R2) for the 4 conditions. There were no significant differences in percentage errors made between all conditions. Error bars represent standard error.

5.1.3.3 *Effects of modality mismatch on d'*

A one-way within subjects ANOVA with condition (A|C-M|V vs C-M|A|V vs C-M|V|A vs V|C-M|A) and participants' *d'* as the dependent variable was carried out to determine the differences in overall sensitivity of all the conditions in participants' discrimination.

There was a main effect of condition, $F_{(3, 75)}= 6.03$, $p=0.001$, $\eta_p^2=0.19$. Post-hoc paired samples *t*-tests (Bonferroni corrected $p<0.0083$) found that participants reported significantly lower discriminability (*d')* in the A|C-M|V condition (mean= 2.33, SD= 0.64) compared to all other conditions, i.e. V|C-M|A condition (mean= 3.28, SD= 1.20), $t_{(25)}=4.08$, $p<0.001$; C-M|A|V condition (mean= 3.45, SD= 1.73), $t_{(25)}= 3.59$, $p<0.001$ and the C-M|V|A condition (mean=3.73, SD= 2.19), $t_{(25)}=3.55$, $p=0.002$. There were no significant difference in *d'* between all other conditions, $p>0.008$. Please see **Figure 5-3**.

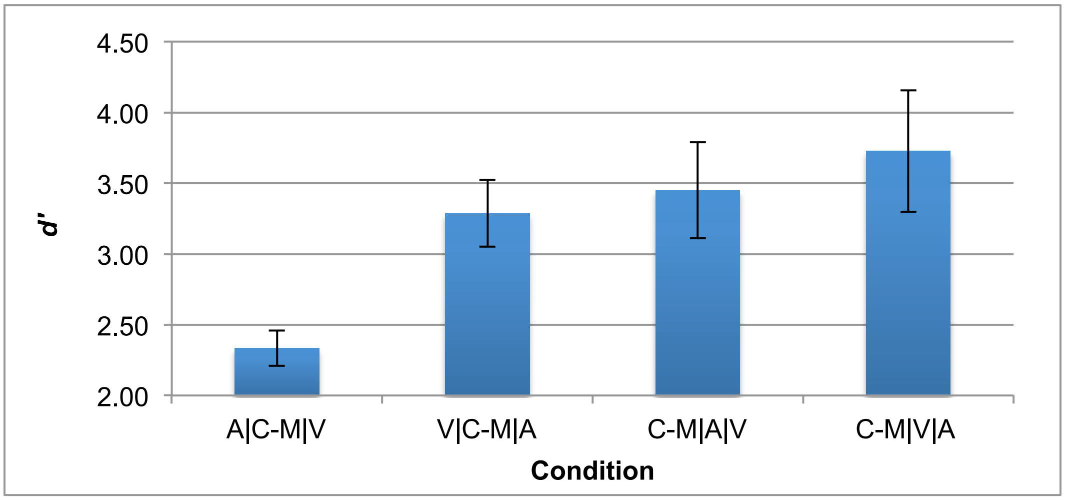

Figure 5-3: *d'* scores of all conditions in the experiment. Participants recorded lowest d' score in the A|C-M|V compared to all other conditions. Error bars represent standard error.

5.1.4 Discussion

The objective of experiment 7 was to determine the effect of modality mismatch using auditory, visual and cross-modal modalities on two levels of repetition, i.e. R1 and R2 to determine the effects of modality mismatch across repetitions. Performance was measured using percentage error rates. *d'* scores were also analyzed to take into consideration participants' discriminability across the four conditions of modality mismatch. Unlike previous experiments within this thesis, this experiment did not look at performance on new repetition trials as the effects of modality (auditory, visual and cross-modal) on new trials have already been examined in section 3.1.3.1.1 and it was found that modality had no effect on percentage errors made in new trials.

In terms of participants' recognition memory performance on the R1 trials, i.e. recognition following a short delay, modality mismatch had significant effect on percentage errors made. It is clear that when initial modality was in the auditory modality, participants made significantly more errors when recognition (R1) was in the cross-modal (A|C-M|V) modality compared to when initial modality was in the visual (V|C-M|A) or cross-modal modality (CM|V|A and CM|A|V). Interestingly, when the stimuli was initially presented in the auditory domain this led to significantly more errors at R1 when the item was in the cross-modal modality (A|C-M|V), compared to the reverse, i.e. initial presentation in the cross-modal modality and recognition in the auditory domain (C-M|A|V). Additionally, when comparing between (C-M|V|A) and (C-M|A|V), although participants were presented with cross-modal stimuli in the new trials, they made more errors when R1 trials were in the auditory modality (C-M|A|V) compared to when R1 trials was in the visual modality (C-M|V|A). Overall, it is clear that initial modality in the auditory format leads to significantly more errors in all other modality formats. Additionally, when participants are exposed to initial modality in the cross-modal format, recognition in the auditory modality also impaired recognition compared to recognition in the visual modality.

Participants' recognition memory performance in R2 was analyzed to determine the effect of modality mismatch across repetitions. Although participants faced a modality mismatch in all levels of presentation, the stimuli in R2 were actually presented for the second time. For instance, in A|C-M|V, the visual stimuli was presented once in the R1 trial, and for the second time in the R2 trials. Similarly, the auditory stimuli in the R2 trials for V|C-M|A was also presented once at the R1 trial and for the second time in the R2 trials after a long delay. For C-M|A|V and C-M|V|A, the visual and auditory stimuli in R2 trials were initially presented as new trials. The second time, it is presented again after a long delay (R2). It is expected that participants will perform significantly better after repetitions because although the information was not presented in an identical form or modality, the information that was repeated was semantically associated.

Results found that modality mismatch had a significant effect on recognition on the R2 trials. However, post-hoc analyses found no reliable significant differences between the four conditions.

The final analyses on discriminability performance was carried out comparing *d'* scores for all four conditions, i.e. A|C-M|V, V|C-M|A, C-M|A|V, C-M|V|A. Results show participants *d'* is significantly lower in A|C-M|V compared to all other conditions. This clearly shows that when initial modality is in the auditory format, participants are more likely to have lower discriminability compared to when initial modality is in the visual or cross-modal format, although final repetition is in the auditory format (eg. V|C-M|A). Further discussion of the results of this experiment will be given later in section 5.3.

Out of the 4 conditions in experiment 7, results show that participants had the lowest discriminability in the A|C-M|V condition, despite scoring a significantly lower percentage error rate in the R2 trials compared to the V|C-M|A condition. In both conditions (A|C-M|V and V|C-M|A), R1 trials are presented in the C-M modality.

Thus, it would be interesting to extend experiment 7 and directly compare the visual and the auditory modality during initial and final repetition (R2) to determine the effects on the neural indices of recognition memory. Therefore, only two conditions will be employed in the next study, i.e. the A|C-M|V and the V|C-M|A.

5.2 Experiment 8: Effects of modality mismatch on the ERP correlates of recognition memory

5.2.1 Introduction

Research has shown that perceptual change of items from study to test can affect the ERP components of recognition memory. For example, Schloerscheidt and Rugg (2004) manipulated the presentational format during study and test (picture to name, or vice versa). They found that the early frontal effect consistent with familiarity when the format was consistent between study and test, but not when the format had changed. Consistent to Groh-Bordin et al. (2005) when pictures and mirror reversals were used, and in the study by Ecker et al. (2007b) where they changed the colour of the object at study and test and found that a change in this feature diminished the FN400 effect. Hence, the frontal effect is sensitive to perceptual changes, and is consistent to the argument that the frontal effect is a neural correlate of familiarity-driven recognition, based on processing of items perceptual characteristics.

An interesting manipulation to this perceptual change was not only to change some aspect of the item, but also to add in an additional novel element to the stimuli. Tsivilis, Otten & Rugg (2001) manipulated objects and context pairs such that at test, some of the object-context pairs were identical or items re-arranged in the same context, or items paired with unseen context or vice versa. This familiarity based neural correlate was found in identical item-context pairs, and rearranged item-context pairs. However, it was absent for items in a new unstudied context or vice versa. If this neural correlate was really driven by familiarity, then the studied item, or the studied context should elicit this component, regardless of its unstudied additional item or context. Therefore, its absence led Tsivilis et al. (2001) to argue this familiarity based component of recognition, is not actually a reflection of stimulus familiarity, however it is a component reflective of stimulus novelty, such that stimulus novelty leads to a negative modulation.

However in a related study by Ecker, Zimmer, Groh-Bordin, & Mecklinger, (2007) using cues to direct attention to stimuli, argued that FN400 is due to the capture of attention of highly salient background (context) that it is treated as an object. And the two highly salient object together triggered the familiarity signal, and if one was absent, and replaced by an new object it would be treated as a novel object, and a novelty signal would be produced.

There have also been inconsistencies regarding the effect of perceptual match on the parietal (LPC) component associated with recollection. For instance, when colors of pictures were manipulated from study to test, the parietal effect was found to be sensitive to this perceptual match (Ecker, Zimmer, & Groh-Bordin, 2007a; Groh-Bordin et al., 2006). However this LPC component was not found to be affected when the presentation format was manipulated from word/picture format. Rather, this effect was found largest when pictures were studied compared to words, which indicates that this effect was sensitive to the type of stimulus encoded rather than the change in stimulus format (Ally & Budson, 2007; Curran & Doyle, 2011; Schloerscheidt & Rugg, 2004). Furthermore, In the study by Ally & Budson (2007), words and pictures were varied during study and test, and it was found that while using pictures enhanced recollection effects (LPC) compared to using words, the LFE was largest when recollection was not enhanced, such as when words were used during study, or in test, which indicates that the LFE is an indication of additional processing.

The results of experiment 7 showed that manipulating modality affects participants' recognition memory performance. However, it is not clear how this manipulation affects the underlying neural indices of recognition memory (FN400, LPC and LFE), which can give more insight into the processes supporting recognition memory when modality is mismatched across repetitions.

The objective of experiment 8 is to determine the effect of modality manipulations across repetitions on the ERP correlates of recognition memory, namely the FN400, the LPC and the LFE. Hence, there are two aims. First, to examine how initial presentation format (auditory vs visual modality) affects the neural correlates of recognition of R1 trials in the cross-modal format, when there is a modality mismatch. Second, to determine how final presentation format, i.e. R2 (auditory vs visual modality) affects the neural correlates of recognition memory when there is modality mismatch.

5.2.2 Method

This research was approved by the Science and Engineering Research Ethics Committee, University of Nottingham Malaysia Campus

5.2.2.1 *Participants*

Twenty-six participants aged between 18-24 years of age were recruited for this study. All the participants were students at University of Nottingham Malaysia Campus with normal or corrected-to-normal vision. Data from 1 participant was excluded as the participant showed depressive symptoms (See section 5.2.2.2.1 for further details on the screening criteria, and appendix A.9 for participant's mean scores). This led to a total of 25 participants (mean age= 20.96, SD= 2.32), comprising of 9 males and 16 females who participated in the study. For the behavioral study, the responses of 25 participants were tabulated. However, following EEG pre-processing, only data from 12 participants data were suitable, as data from 13 participants did not have sufficient good trials in all conditions to form a reliable averages for data analyses.

5.2.2.2 *Materials*

5.2.2.2.1 Questionnaires

As experiments 1-7, younger participants completed the BDI to screen for depressive symptoms, and were only included in the study if their scores were below 17.

5.2.2.2.2 Stimuli

The stimuli used in the experiment were identical to the visual and auditory stimuli used in the A|C-M|V and V|C-M|A conditions in experiment 7. Stimulus presentation was controlled using *Psychopy* software version 2.0 (Peirce, 2008) and a desktop computer was used to run the experiment.

5.2.2.3 *Design*

The design was a 2 x 3 within subjects study with condition (A|C-M|V vs V|C-M|A) and repetition type (new, R1 and R1) as the factors. In the A|C-M|V condition, participants were first presented (new trials) with spoken word (auditory), repeated after a short delay of 5-7 intervening items with a paired visual image (R1 in C-M modality). The visual image will then be repeated after 37-39 intervening items (R2 repetition in visual modality). In the V|C-M|A condition, participants were first presented (new trials) with an image (visual), repeated after a short delay of 5-7 intervening items with a paired spoken word (R1 in auditory modality). The spoken word will then be repeated after 37-39 intervening items (R2 repetition in auditory modality).

There was one practice block for each of the conditions with 14 trials, of which 5 were new, 5 were R1 trials and 4 were R2 trials. There was a total of four experimental blocks with 2 blocks for each condition, randomized for counterbalancing. Each block consisted of 55 new stimuli, 50 R1 stimuli and 30 R2 stimuli, with a total of 135 trials in each block, making up 270 trials for each condition.

5.2.2.4 *Procedure*

The behavioral task and the EEG acquisition procedure was identical to experiment 6.

5.2.3 Results

5.2.3.1 *Behavioral results*

Participants' recognition performance was assessed in terms of mean percentage errors made. Trials with response times quicker than 80 ms and slower than 2500 ms were excluded from the analyses. In cases of violations of sphericity, degrees of freedom were corrected using Greenhouse-Geisser corrections.

5.2.3.1.1 Effect of modality mismatch (condition) on percentage errors made on repetition

A 2 x 3 repeated measures ANOVA was conducted with Condition (A|C-M|V vs V|C-M|A) and repetition (new vs R1vs R2) and the within subjects factors. There was no main effects of condition or repetition, p>0.05. However, there was condition x repetition interaction, $F_{(1.51, 36.14)}$ =7.20, $p< 0.001$, $\eta_p^2= 0.23$. See **Figure 5-4**. The interaction effect was explored below:

5.2.3.1.1.1 Effect of repetition on percentage errors made in A|C-M|V and V|C-M|A conditions

Two repeated measures analyses were conducted to determine the effects of repetition in percentage errors made in A|C-M|V and V |C-M|A conditions.

There was no effect of repetition on the percentage errors made in the A|C-M|V condition, p> 0.05. However, there was an effect of repetition on the percentage errors made in V|C-M|A condition, $F_{(1.12, 26.84)}= 33.20$, $p< 0.001$, $\eta_p^2= 0.58$.

Post-hoc paired samples *t*-tests (Bonferroni corrected p< 0.0167) found that participants made significantly more errors in the R2 repetition type (i.e. auditory modality) (mean= 19.13, SD= 11.46) compared to both new trials (i.e. visual modality) (mean= 5.06, SD= 4.96), $t_{(24)}$=1.54, p<0.001; and R1 trials (i.e. cross-modal modality) (mean= 6.08, SD= 5.42), $t_{(24)}$=5.90, p<0.001.

5.2.3.1.1.2 Effect of modality mismatch (condition) on percentage errors made in new, R1 and R2 trials.

Subsequent analyses using paired samples *t*-test showed that participants made significantly higher percentage error when items were presented for the first time (new) in the auditory modality (A|C-M|V) (mean=10.11%, SD=5.89) compared to in the visual modality (V|C-M|A), (mean=5.06%, SD= 4.96), $t_{(24)}$= 4.07, p<0.001. Subsequently, participants made more errors in recognition for the R1 trials in the A|C-M|V condition (mean=13.48 %, SD= 11.19) compared to the V|C-M|A condition (mean=6.08%, SD= 6.08), $t_{(24)}$=3.47, p<0.001. However, there were no significant differences in percentage error in recognition between the visual and auditory R2 trials between both the conditions, (A|C-M|V: mean=15.20, SD= 13.41; V|C-M|A: mean= 19.13, SD= 11.46), p> 0.05.

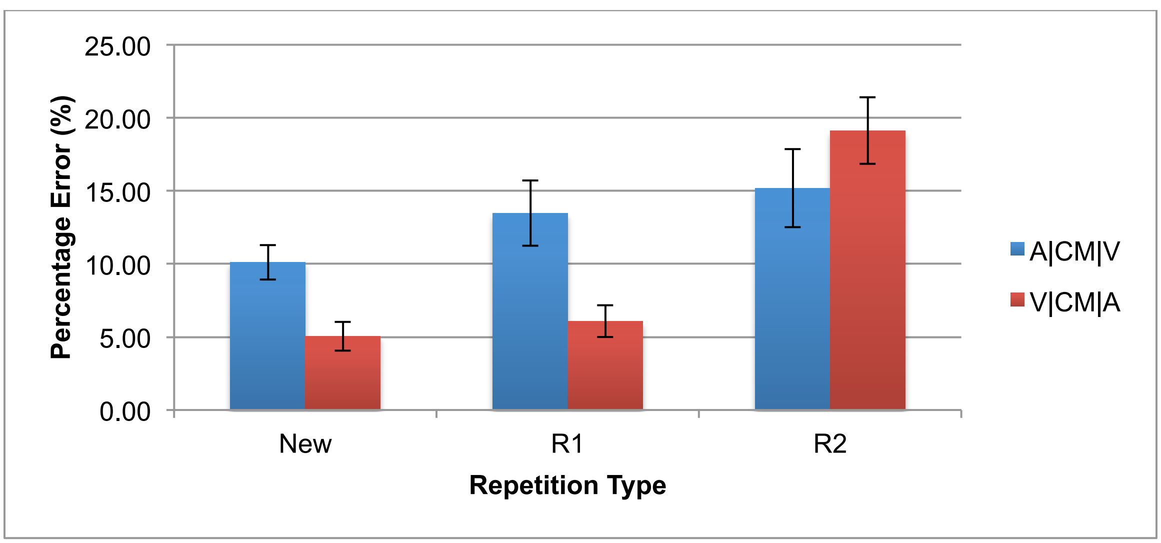

Figure 5-4: Graphical representation of participants' percentage error across the three repetitions for A|C-M|V and V|C-M|A conditions, showing the condition x repetition interaction effect. Error bars represent standard error.

5.2.4 ERP results

The ERP analysis was identical to experiment 6. Only relevant grand-averaged waveforms are presented in this chapter.

5.2.4.1 *FN400*

A 2x3x4 repeated measures ANOVA was conducted with condition (A|C-M|V and V|C-M|A), repetition (new vs R1 vs R2) and region (RAI vs RAS vs LAI vs LAS) as the within subjects factor on mean amplitudes within the time window of 300-500 ms post stimulus onset. There were no main effects of condition, repetition or region, or any interaction effects, $p > 0.05$

5.2.4.2 *LPC*

A 2x3x4 repeated measures ANOVA was conducted with condition (A|C-M|V and V|C-M|A), repetition (new vs R1 vs R2) and region (RPI vs RPS vs LPI vs LPS) as the within subjects factor on mean amplitudes within the time window of 500-800 ms post stimulus onset. There was a condition x repetition x region interaction, $F_{(3.50,\ 38.45)} = 14.46$, $p<0.001$, $\eta_p^2 = 0.57$. See **Figure 5-8**. The interaction effect is explored below.

5.2.4.2.1 Old/new effects of A|C-M|V and V|C-M|A conditions in RPI, RPS, LPI, and LPS regions.

One way repeated measures ANOVA was conducted separately for each condition (A|C-M|V and V|C-M|A) in each region (RPI, RPS, LPI, LPS).

5.2.4.2.1.1 RPI

There was no effect of repetition in the A|C-M|V condition, $p>0.05$. However, there was an effect of repetition for the V|C-M|A condition, $F_{(1.32,\ 14.48)}= 6.50$, $p=0.01$, $\eta_p^2= 0.57$. Post-hoc paired samples *t*-tests (Bonferroni corrected $p< 0.0167$) found new trials (mean= -2.56 µV, SD= 4.35) recorded a more negative and smaller mean amplitude compared to the R2 trials, (mean=1.09 µV, SD= 5.32), $t_{(11)}= 2.89$, $p< 0.015$. R1 trials did not differ significantly from other trials, $p>0.0167$. See **Figure 5-5**.

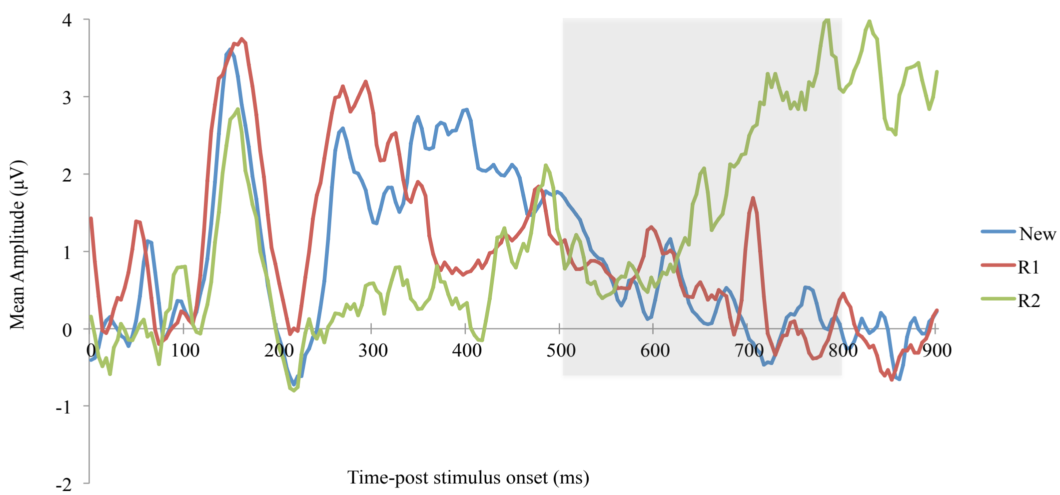

Figure 5-5: grand averaged waveform for V|C-M|A condition, at RPI region. Time window 500-800 ms highlighted

5.2.4.2.1.2 RPS

There was a main effect of repetition in the A|C-M|V condition, $F_{(2,22)}= 4.04$, $p=0.03$, $\eta_p^2= 0.27$, and a main effect of repetition in the V|C-M|A condition, $F_{(2,\ 22)}= 6.73$, $p< 0.01$, $\eta_p^2= 0.38$. However, in both conditions, post-hoc paired samples *t*-tests (Bonferroni corrected p< 0.0167) found no significant differences between the three repetition trials, $p> 0.0167$.

5.2.4.2.1.3 LPI

There was no significant effect of repetition in both the A|C-M|V and V|C-M|A condition, p> 0.05.

5.2.4.2.1.4 LPS

There was a significant effect of repetition in both the conditions, i.e. A|C-M|V: $F_{(2,22)}$= 13.83, p<0.001, η_p^2= 0.56; V|C-M|A, $F_{(2,22)}$=14.16, p< 0.001, η_p^2= 0.56. Bonferonni corrected paired samples *t*-tests (p< 0.0167) found that in the A|C-M|V condition, both the R1 (mean= 3.98 μV, SD= 3.95) and R2 (mean= μV, SD= 2.69) repetition types recorded significantly more positive mean amplitudes compared to new items. There was no significant difference in mean amplitude between the repeated trials, p>0.0167. See **Figure 5-6**. In the V|C-M|A condition, R2 trials recorded significantly smaller mean amplitude (mean=1.19 μV, SD = 3.28) compared to new (mean=6.08 μV, SD= 2.95) and R1 trials (mean= 5.76 μV, SD= 3.34). This is a reverse of the typical old/new effect. There was no significant difference between new and R1 trials, p>0.0167. See **Figure 5-7**.

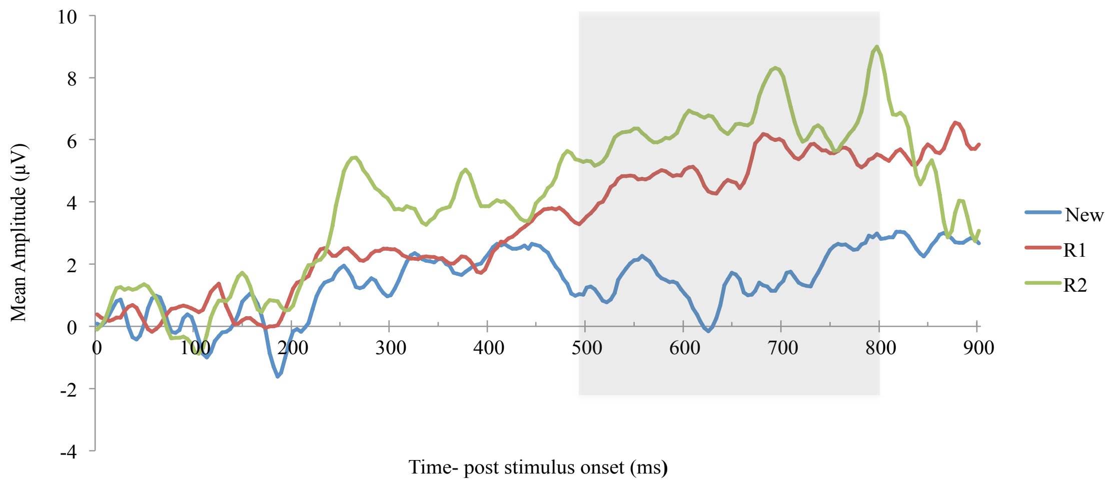

Figure 5-6: Grand averaged waveform for A|C-M|V at the LPS region. Time window 500-800 highlighted

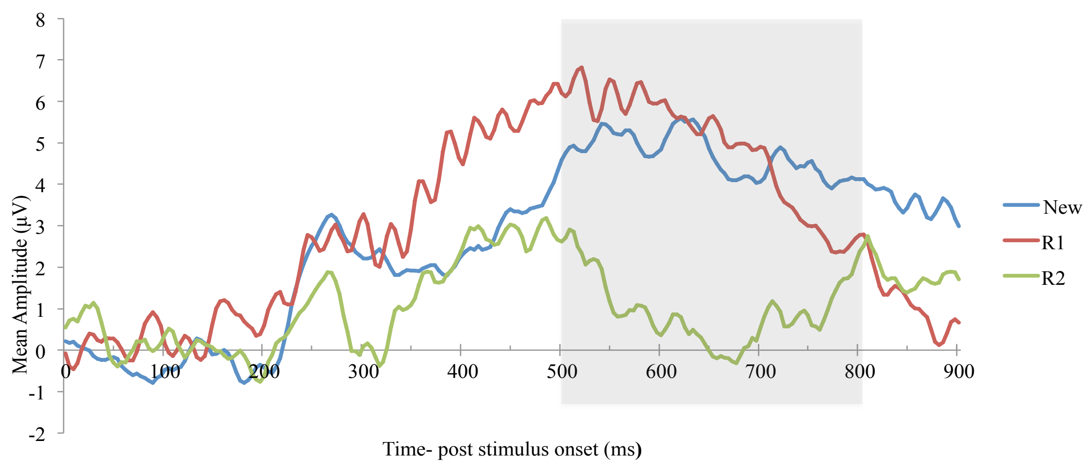

Figure 5-7: Grand averaged waveform for V|C-M|A condition at the LPS region. Time window 500-800 highlighted

5.2.4.2.2 Effect of condition (modality) on new, R1, and R2 repetition in the RPI, RPS, LPI, and LPS regions.

2x3 repeated measures analyses with condition (A|C-M|V vs V|C-M|A) and repetition (new, R1 and R2) as the within subjects factors was conducted in each region (RPI, RPS, LPI and LPS).

5.2.4.2.2.1 RPI

There were no main effects, $p< 0.05$. However, there was a significant repetition x condition interaction effect in the RPI region, $F_{(2,22)}=6.89$, $p=0.01$, $\eta_p^2= 0.39$. See **Figure 5-8**. Post-hoc paired samples *t*-test was conducted to determine the difference in mean amplitudes between the conditions (A|C-M|V vs V|C-M|A) for each repetition (new, R1 and R2) in the RPI region. There was no difference in mean amplitude between the conditions for the new repetition type. However, there were significant differences in mean amplitude between the 2 conditions for the R1 repetition type, $t_{(11)}= 4.56$, $p<0.001$, and the R2 trial type $t_{(11)}= 2.39$, $p=0.04$. The R1 trials for the A|C-M|V recorded significantly smaller negative mean amplitude (mean= -0.87 µV, SD=5.89) compared to the R1 trials V|C-M|A condition (mean=-3.18 µV, SD= 4.81). The R2 trials for the A|C-M|V was larger but more negative in mean amplitude (mean= -2.58 µV, SD= 4.36) compared to the R2 trials in the V|C-M|A condition (mean=1.09 µV, SD= 5.32).

5.2.4.2.2.2 RPS

There were no main effects, $p>0.05$. However, there was a significant repetition x condition interaction, $F_{(2,22)}=7.86$, $p<0.001$, $\eta_p^2= 0.42$. See **Figure 5-8**. Post-hoc paired samples *t*-test comparing the difference in mean amplitudes between the conditions for each repetition in the RPS region found that there was a significant difference in conditions in mean amplitude for the new, $t_{(11)}$= 2.24, p=0.05, and R2 repetition, $t_{(11)}$=2. 65, p=0.02. The new trials for the V|C-M|A condition recorded a higher mean amplitude (mean=5.22 µV, SD=2.59) compared to the new trials of the A|C-M|V condition (mean=1.23 µV, SD= 6.40). The R2 trials for the A|C-M|V condition recorded a higher mean amplitude (mean=5.49 µV, SD=2.71) compared to the R2 trials of the V|C-M|A condition (mean=1.55 µV, SD= 4.40).

5.2.4.2.2.3 LPI

There was no main effects or interaction effects observed in the LPI region, p> 0.05.

5.2.4.2.2.4 LPS

There were no main effects. However, there was a condition x repetition effect observed in the LPS region, $F_{(2,22)}$=24.88, p<0.001, η_p^2= 0.69. See **Figure 5-8**. Post-hoc paired samples *t*-tests found that there was a significant difference between conditions in mean amplitude for the new $t_{(11)}$= 3.36, p<0.001, and also the R2 trial type, $t_{(11)}$= 4.82, p< 0.001, but no difference between conditions in the mean amplitude of the R1 trial, p<0.05. In the new trials in the V|C-M|A showed a significantly more positive mean amplitude (mean= 6.08 µV, SD= 2.95) compared to the new trials in the A|C-M|V condition (mean= -0.78 µV, SD= 6.18). For the R2 trial type there was significantly higher mean amplitude for the A|C-M|V condition (mean=5.60 µV, SD= 2.69) compared to the V|C-M|A condition (mean =1.19 µV, SD= 3.28).

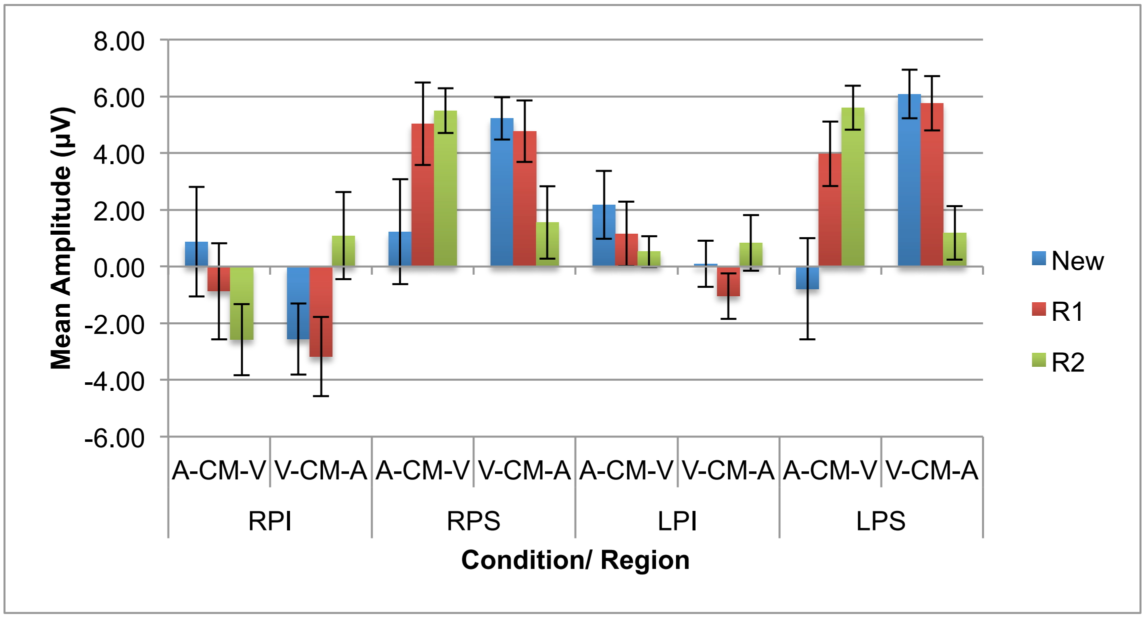

Figure 5-8: Graphical representation of the condition x repetition x region interaction effect for the 500-800 ms time window. There was a condition x repetition effect in all regions except for the LPI. Error bars represent standard error

5.2.4.3 *LFE*

A 2x3x4 repeated measures ANOVA was conducted with condition (A|C-M|V vs V|C-M|A), repetition (new vs R1 vs R2) and region (RAI vs RAS vs LAI vs LAS) as the within subjects factor on mean amplitudes.

There was a repetition x region interaction effect, $F_{(6,66)}=2.25$, $p<0.05$. See **Figure 5-13**. As there was no effect of condition on mean amplitude, condition was collapsed across the repetition and region and separate one-way ANOVAs were conducted on each region to determine the effect of repetition on each region, i.e. RAI, RAS, LAI and LAS.

5.2.4.3.1 RAI

There was no effect of repetition seen in the RAI region, $p>0.05$.

5.2.4.3.2 RAS

There was a significant effect of repetition on the RAS region, $F_{(2,22)}$=5.59, p=0.01, η_p^2= 0.34. Post-hoc paired samples t-tests (p< 0.0167) found that the mean amplitudes were significantly higher in the new trial (mean=3.96 µV, SD= 3.34, compared to the R2 trials (mean=1.29 µV, SD= 3.97), $t_{(11)}$=3.56, p=0.005. There were no significant difference in mean amplitudes between the new and R1 repetition type, or the R1 and R2 trials, p>0.0167. See **Figure 5-9** and **Figure 5-10**.

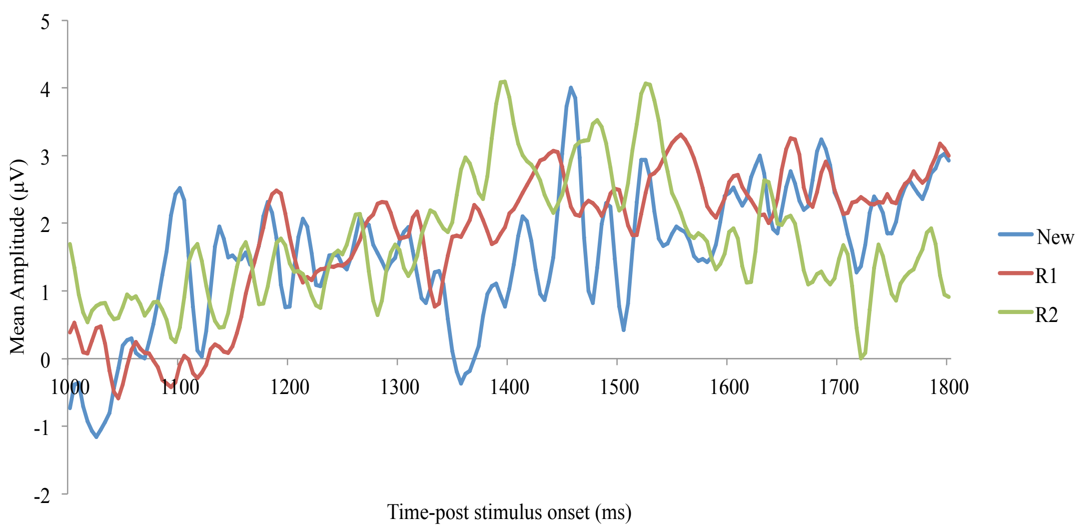

Figure 5-9: Grand-averaged waveform for time window spanning 1000-1800 ms for A|C-M|V condition in the RAS region

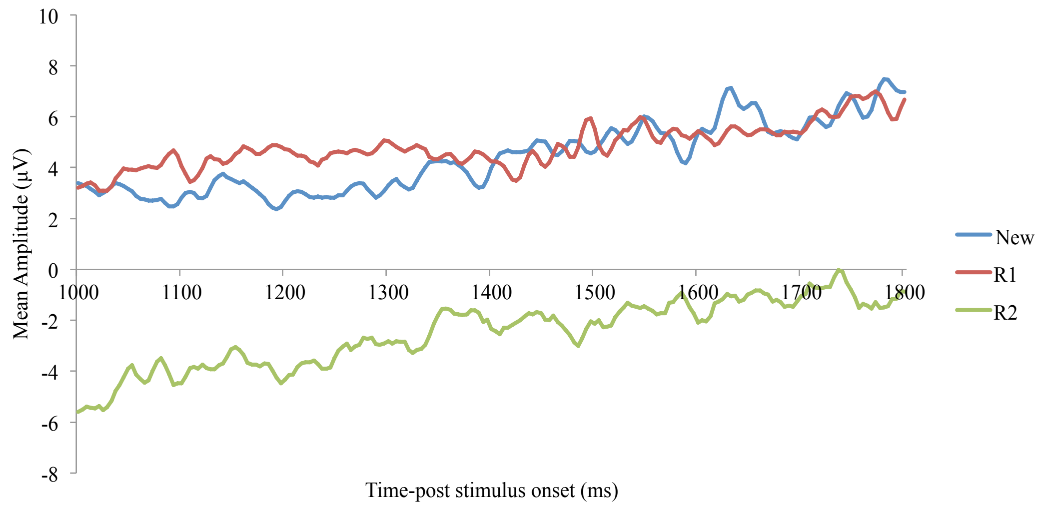

Figure 5-10: Grand-averaged waveform for time window spanning 1000-1800 ms for V|C-M|A condition in the RAS region

5.2.4.3.3 LAI

There was no effect of repetition seen in the LAI region, $p > 0.05$.

5.2.4.3.4 LAS

There was a significant effect of repetition on the LAS region, $F_{(2,22)}$=9.20, p< 0.001, η_p^2= 0.46. Post-hoc paired samples *t*-tests (p<0.0167) found that R2 trials recorded significantly lower mean amplitude (mean=-0.78 µV, SD= 2.20) compared to the R1 trials (mean= 3.60 µV, SD= 3.58, $t_{(11)}$= 5.03, p>0.001). There were no significant difference in mean amplitude between the new trials (mean= 3.44 µV, SD=3.88), and the R1 trials, or the R2 trials, p> 0.0167. See **Figure 5-11** and **Figure 5-12**.

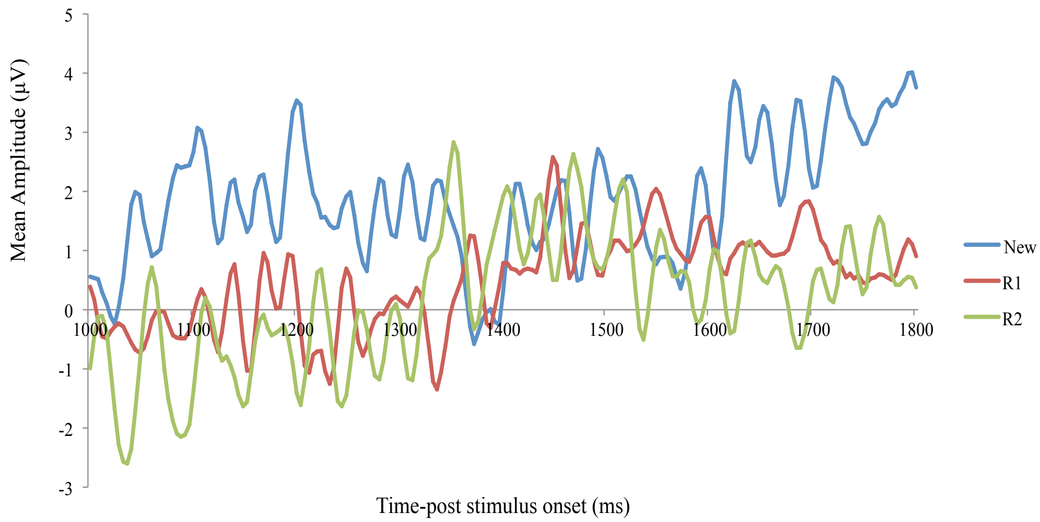

Figure 5-11: Grand averaged waveform for time window spanning 1000-1800 ms for A|C-M|V condition at the LAS region

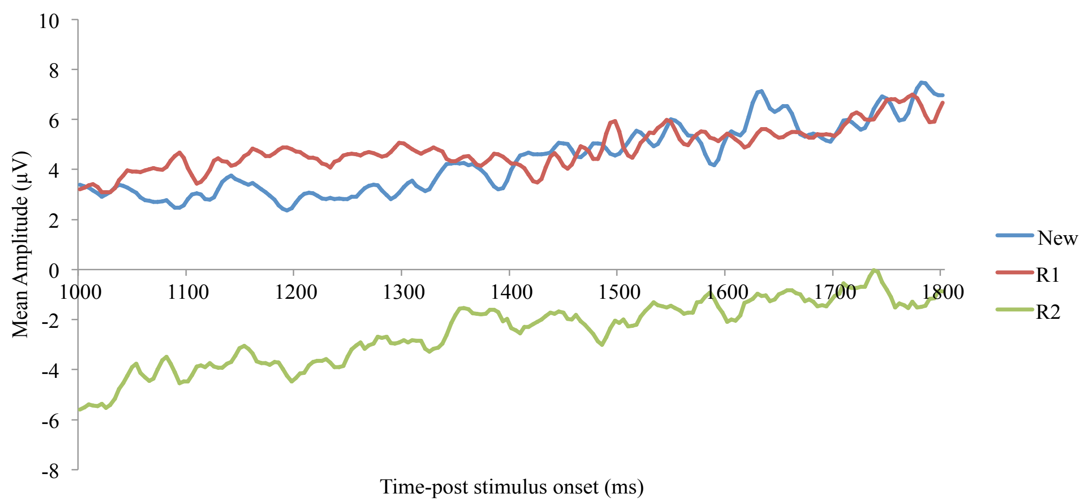

Figure 5-12: Grand averaged waveform for time window spanning 1000-1800 ms for V|C-M|A condition at the LAS region

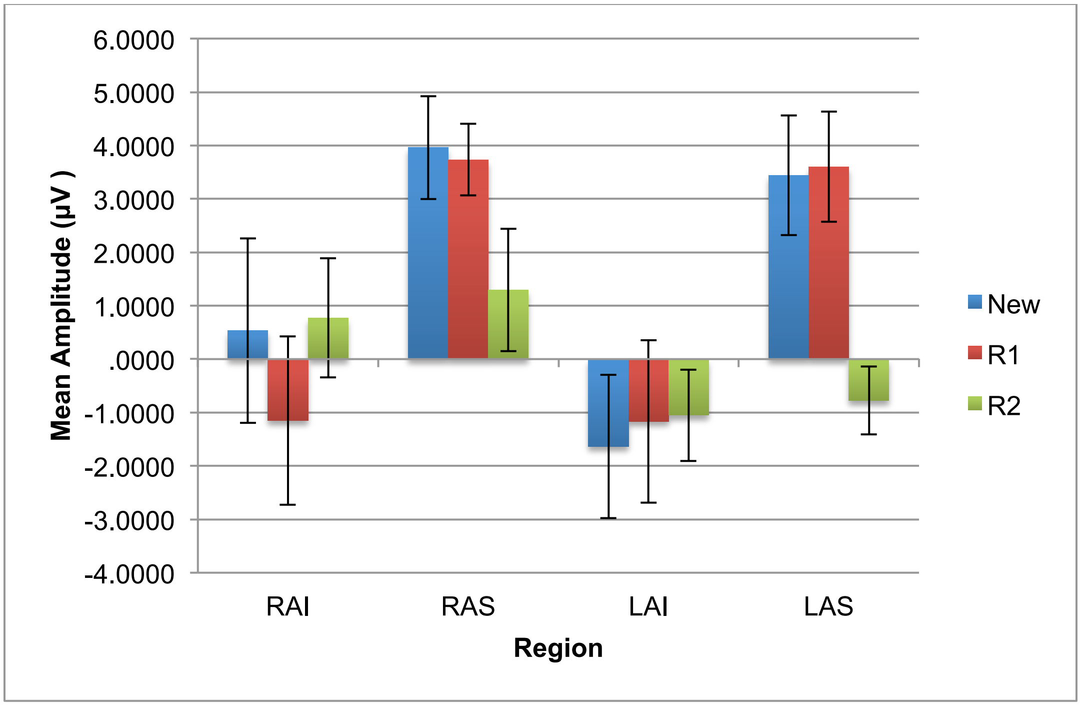

Figure 5-13: Graphical representation of the condition x region interaction effect for the 1000-1800 ms time window. Error bars represent standard error. There was a significant effect of repetition on the RAS and LAS region

5.2.5 Discussion

5.8.1 Behavioral results

Consistent to experiment 7, initial presentation in auditory modality led to significantly more errors in recognition (R1) in the cross-modal modality (A|C-M|V), compared to when initial presentation was in the visual modality. In addition, there were no significant differences between conditions on the R2 repetition type. Looking separately at the effects of repetition between the conditions, results show that there is a significant effect of repetition in the V|C-M|A condition, but not the A|C-M|V. This effect is largely due to participants making significantly more errors in the R2 repetition trials in the V|C-M|A, as R2 trials were presented in the auditory modality. In the A|C-M|V condition, there was no significant effect of repetition; together with the findings of V|C-M|A, it can be inferred that regardless of whether participants were presented with auditory modality at the initial presentation (new) or final recognition (R2), recognition in R2 is significantly poorer.

5.8.2 ERP results

Analyses of mean amplitudes in the 300-500 ms associated with familiarity found no main effects or interaction effects. As for the 500-800 ms time window, associated with recollection, in the RPI region, there was an old/new effect of R2 trials for the V|C-M|A condition but not for A|C-M|V condition. Comparing between conditions, the R1 trials for the V|C-M|A were significantly larger and negative compared to the R1 trials for the A|C-M|V trials. In addition, the R2 trials for the V|C-M|A condition was significantly more positive compared to the R2 trials for the A|C-M|V condition.

At the RPS region, the old/new effect for both conditions was absent. There was a significant difference between conditions for new and R2 repetitions. With respect to new trials, where V|C-M|A condition recorded higher mean amplitude in this region compared to the A|C-M|V condition. However, the R2 trials for A|C-M|V recorded higher mean amplitude compared to V|C-M|A.

There was no effect at the LPI region, but at the LPS there was an old/new effect seen for both R1 and R2 trials for the A|C-M|V condition, where the R1 and R2 trials were significantly more larger in mean amplitude compared to the new trials. However, for the V|C-M|A condition, there was a reverse old/new effect seen in this time window where the R2 trials recorded significantly small mean amplitude compared to the new and

R1 trials. Comparing between conditions, new trials recorded higher and more positive mean amplitude in the V|C-M|A condition compared to the A|C-M|V condition, whereas the R2 trials were much larger in mean amplitude in the V|C-M|A condition compared to the R2 trials of A|C-M|V condition.

In the 1000 -1800 ms time window thought to be associated with post-retrieval monitoring and memory evaluation (LFE), there was no main effect of condition, hence the mean amplitudes of condition was collapsed across the repetitions in the 4 regions of interest, ie. the RAI, RAS, LAI and LAS. Repetition effects were only seen in the right and left superior regions, i.e. the RAS and the LAS, in these regions there was a reverse old/new effect seen with R2 trials recording significantly lower mean amplitude compared to new trials (RAS), and the R1 trials (LAS).

5.3 General discussion

Experiment 7 compared recognition performance when there was a modality mismatch in 1st repetition (R1) and 2nd repetition (R2). Experiment 8 was an ERP study to see the effects of modality mismatch in recognition and its effects on the underlying neural correlates of recognition memory.

In experiment 7, four conditions were compared namely A|C-M|V, V|C-M|A, C-M|A|V and C-M|V|A. The results suggests that visual and cross-modal modality had no significant difference in recognition at R1 if initial presentation was in the visual modality while recognition was in the cross-modal modality and vice versa conditions V|C-M|A or C-M|V|A. However, initial exposure in the auditory modality impaired recognition at R1 in the cross-modal modality (A|C-M|V). This led to poorer recognition compared to when initial exposure was in the cross-modal/ visual modality. The findings that initial presentation in the auditory modality impairs recognition performance at R1 trials compared to initial presentation in the visual or cross-modal modalities is consistent to results of experiment 3; which shows poorer performance in the auditory modality compared to items in the visual or cross-modal modality, where even with repetition, participants' performance in auditory modality showed no improvement. This is consistent to Bigelow and Poremba (2014) and Cohen et al. (2009) that found recognition in the auditory modality to be inferior to other modalities.

In terms of percentage errors made in R2, results found that there were no significant differences among the 4 conditions. This result was not expected because unlike previous experiments, R2 trials were repeated for the first time due to modality mismatch. For instance in the A|C-M|V condition, the R2 trials were stimuli repeated for the first time, where the first time it appeared was at R1 trials paired with a repeated auditory stimuli. In this case, R2 recognition trials were stimuli that had been associated with previously presented stimuli at either new presentation (C-M|A|V and C-M|V|A) or at R1 presentations (A|C-M|V or V|C-M|A). Hence, encountering its pair may have consequently led to retrieving the stimuli again in memory during R1 presentation although the stimuli itself is absent (C-M|A|V / C-M|A|V). Additionally, in A|C-M|V and V|C-M|A conditions, R1 repetitions are repeated stimuli presented with a new paired associate. Hence this could have led to better consolidation of memory, consequently leading to better recognition at R2 for all conditions. This refers to a classical idea known as *redintegration* where a part of the stimulus encountered again can be sufficient to evoke the memory of the whole context. This was shown in a study where participant's were given visual words and auditory sound during encoding; and during recognition phase of visual words alone, although no auditory information was required to be retrieved, auditory brain regions were seen to be activated upon recognition (Nyberg et al., 2000).

Results also show that discriminability is significantly lower when initial presentation is in the auditory modality (A|C-M|V), compared to all other conditions. As our findings from experiment 3 shows that there are no significant differences in percentage errors made in auditory, cross-modal and visual new stimuli, it could be possible that the lower discriminability is due to an overall low hit rates on both R1 and R2 when initial modality is in A|C-M|V, rather than a high false alarm rate for the condition.

In experiment 8, two conditions were compared, A|C-M|V and V|C-M|A. The ERP analyses show that there was no effect on familiarity component. This is consistent to previous studies (Curran & Doyle, 2011; Ecker et al., 2007b; Groh-Bordin et al., 2005; Schloerscheidt & Rugg, 2004; Tsivilis et al., 2001 etc) that found the FN400 to be sensitive to perceptual match between study and test, where they found that when the perceptual format was altered, this effect was diminished.

In line with previous research, due to the mismatch in modality or a change in perceptual format, recognition may be supported by recollection, and not familiarity. In addition, this absence of familiarity supports the argument by Tsivilis et al. (2001) that FN400 may be a negative modulation of stimulus novelty, such that novelty of stimuli shows an absence of an effect, and stimulus that is perceptually familiar would trigger this effect. From that perspective, all stimuli from new, R1 and R2 were novel stimuli, as it had either an addition of a novel stimuli (R1) or an absence of a familiar stimuli, hence perceptually the stimuli would be novel at the time (R2).

The results are in line with Ecker et al. (2007c) who reported the role of attention and saliency of objects in the study where both objects presented together would trigger the familiarity signal, and an absence of one, or presentation of a new object, would render the new combination or stimuli as a novel stimuli. These two types of stimuli in the study are visual, auditory or visual and auditory presented together (cross-modal). Visual stimuli alone, or auditory stimuli alone should be salient to capture attention. For instance, as the visual stimuli was presented with an auditory stimuli which is in a different modality (cross-modal), this combination should be salient compared to presentation of two stimuli in the same modality. Hence, if the novelty signal indicates an absence of the FN400, or renders the item to be novel and not familiar, it is not surprising that the FN400 was not seen.

Looking at the LPC component, the results are more interesting. Firstly, there was an effect in all regions except the LPI region. This is in line with past research that found the LPC component to be less affected by perceptual change compared to the FN400 (Ally & Budson, 2007; Curran & Cleary, 2003; Curran & Doyle, 2011; Schloerscheidt & Rugg, 2004). Although this component is less affected by perceptual change, the type of stimulus encoded affects it, whereby large differences were found at test when pictures were presented at study compared to words (Ally & Budson, 2007; Curran & Doyle, 2011).

Looking at the results in the study, the differences in magnitude in each repetition type and region are not as clear-cut. With respect to old/new effects, there appeared to be an old/new effect in the RPI and the LPS. In the RPI, the V|C-M|A condition reported an old/new effect with R2 trials being significantly larger in mean amplitude compared to new trials. In the LPS, the A|C-M|V reported an old/new effect for both R1 and R2 trials, whereas the V|C-M|A observed a reverse old/new effect for R2 trials.

It is quite clear that modality of recognition has an effect on mean amplitudes, which then affects the old/new effect. Looking at the LPS, the V|C-M|A condition reports the reverse old/new effect, whereas the A|C-M|V reports the typical old/new effect. The only difference was that the R2 trials in the A|C-M|V condition was presented in the visual modality, with new trials being presented in the auditory modality; whereas in the V|C-M|A condition, the R2 trials were in the auditory modality, with new trials in visual modality. R1 trials reporting an old/new effect was only seen in LPS for the A|C-M|V format. It appears to be apparent that visual stimuli have an effect on mean amplitudes by increasing the mean amplitudes in the superior regions. On the other hand, auditory stimuli appear to cause a decrease in mean amplitudes of the ERP component. This could explain the reverse old/new effect seen for the V|C-M|A condition as repeated items were presented in the auditory modality, with new items presented in the visual modality.

When comparing the repetition from both conditions separately, it appears that only the RPI region showed that the mean amplitude for R1 and R2 differed between the conditions. For R1 trials, the V|C-M|A condition was larger than the A|C-M|V condition (although both were negative). The R2 trials for the V|C-M|A region were more positive than the R2 trials for the A|C-M|V.

In the superior regions (RPS and LPS), there were no differences between the conditions for the R1 trials. However, the mean amplitude for the new and R2 trials were always larger when presented in the visual modality compared to the auditory modality. Results seem to strongly suggest that the mean amplitude is affected by the stimulus presented at retrieval rather than at encoding.

The ERP data seems to show that the mean amplitudes in the superior region do not differ for R1 trials (cross-modal stimuli) between the conditions. Taking behavioral studies together, it is clear that auditory stimuli leads to poorer recognition performance compared to visual stimuli. Additionally, looking at the ERP data, mean amplitudes are smaller with auditory stimuli compared to visual stimuli, at R2 which seems to strongly support past research that argues this effect is an index of the amount of information retrieved (Fjell, Walhovd, & Reinvang, 2005; Vilberg, Moosavi, & Rugg, 2006). Results suggest that modality affects ERP components of recollection, by modulating the amount of information to be retrieved.

The LFE results found that there was no significant effect of modality, which indicates that regardless of modality of repetition, this waveform indicates further processing after recollection has taken place (see Allan & Rugg, 1997; Allan et al., 1998; Ally & Budson, 2007; Ally et al., 2008 for similar pattern of results). There was a significant effect of repetition in the superior regions, i.e. RAS and LAS region, but not the inferior regions, i.e. RAI and LAI region. In the RAS and LAS region, the R2 trials recorded significantly lower mean amplitude compared to the new trials and the R1 trials (only for RAS region). This lower mean amplitude could be due to retrieval being in uni-modal modality (visual/auditory) where further post-retrieval processing could reflect participants trying recalling the stimuli it was paired with in the R1 condition. In the R1 condition, the type of stimuli was cross-modal and participants did not need to engage further processing, or further recollection as they did for the R2 trials, as both modalities were present.

When modalities are mismatched during initial presentation, participants make more errors in the auditory modality; and make more errors during recognition in the cross-modal modality if prior presentation was in the auditory modality. However, following repetition in the cross-modal modality (R1), there are no differences in errors between auditory or visual modality.

The results show that when there is a modality mismatch condition, there is an absence of the familiarity component (FN400), and this is consistent with the idea that it is sensitive to perceptual match and is an indication of negative modulation of stimulus novelty (see Tsivilis et al., 2001). In addition, it also indicates that where there is no perceptual match, or there is a modality mismatch, participants may rely more on recollection rather than familiarity to guide their discrimination. Furthermore, findings from the recollection component (i.e. the LPC) suggests that the difference is likely due to the effects of modality, which could affects the amount of information to be retrieved. Lastly, while condition or modality had no effect on the LFE component, it was sensitive to the type of repetition, whereby R2 showed a much bigger difference in mean amplitude to new compared to the R1 trials. This suggest that regardless of the type of modality, the uni-modal modality in R2 trials may have caused participants to retrieve additional information associated with the stimuli as it was presented in the R1 trial. This could be reflective of memory evaluation processes.

CHAPTER 6

GENERAL DISCUSSION

6.1 Aims of thesis

The main aim of this thesis was to investigate the factors that affect recognition memory among older and younger adults, and its effects on the processes supporting recognition memory (i.e. familiarity and recollection) using both behavioural and EEG methods. Using a continuous recognition memory paradigm, participants made old/new discriminations to stimuli presented for the first time, repeated after a short interval (R1) of 5-7 intervening items, and repeated again after a longer interval (R2) of 37-39 intervening items. This design was used from experiment 2 onwards because it was shown that this was a design that was found to lead to the lowest recognition accuracy in experiment 1 when spacing between initial and 2nd presentation; and between the 2nd and 3rd presentation was varied.

In chapter 3, the main aim was to investigate the effects of modality across repetitions, comparing three types of modality, i.e. visual, auditory and cross-modal (visual and auditory presented together) (Experiment 3). Recognition memory performance was compared amongst the initial presentation (new) and two repetitions (R1 and R2). As the spoken word stimuli used in the cross-modal presentations in Experiment 3 were developed in UK, it serves as a potential cultural barrier in the administration of Malaysian participants. Hence, this was addressed in Experiment 4 by recording spoken word stimuli using Malaysian participants in 4 languages, i.e Bahasa Malaysia, English, Mandarin and Tamil; and subsequently age effects were compared to determine if there was an effect of age on the cross-modal recognition memory across repetitions.

Apart from cross-modal stimuli leading to better recognition memory, research has shown that cross-modal pairs should be semantically related (semantic congruency) in order to facilitate memory. However, the effects of semantic congruency on recognition memory across repetitions are not clear. Hence, this was explored in chapter 4, where the objective was to determine the effects of semantic congruency on recognition memory across repetitions, for both older and younger participants (Experiment 5). This was then extended in Experiment 6 by investigating the effects of semantic congruency on the processes of familiarity and recollection to gain insight into how these processes contribute to recognition memory using ERPs (Experiment 6).

Lastly, past research has shown that encountering information in a different modality than how it was presented (modality mismatch) leads to poorer memory. The aim of this chapter 5 was to investigate modality mismatch effect across repetitions using three types of modality i.e. auditory, visual and cross-modal (Experiment 6). Using ERPs, the effect of modality mismatch on the processes supporting recognition memory was investigated (Experiment 8)

6.2 Summary of findings

6.2.1 Spacing and age on recognition memory

In chapter 2, two experiments were presented to test the space effect in visual recognition memory among older and younger adults. In experiment 1, participants were tested in four different paradigms. Stimuli were presented for the first time (new), repeated again for the first time (R1) after either a short lag (SL) (between 0-19 intervening items) or long lag (LL) (above 20 intervening items); and repeated for the second time (R2) after a short (0-19 intervening items) or long retention interval (20-100 intervening items). Therefore R2 items can be SL items repeated after a short retention interval (SRSL), or long retention interval (LRSL); or LL items repeated after a short retention interval (SRLL), or long retention interval (LRLL).

In terms of R1, consistent to past studies (Ally et al., 2008; Friedman, 2003; Kılıç et al., 2013; Nielsen-Bohlman & Knight, 1995; Swick & Knight, 1997) results were clear that at each lag, older adults made more percentage errors compared to younger adults, and overall participants made lower percentage errors for items repeated for the first time following a short lag, compared to long lag.

With respect to retention interval (R2) on percentage errors, there were four types of repetition to compare. These were the SRSL, LRSL, SRLL and LRLL. Participants made significantly more errors in long retention items (R2) that were presented at 1st repetition as short lag items, i.e LRSL compared to all other retention types. In this case, the results were consistent with the space effect, showing that at longer retention intervals, long lag items that were difficult to retrieve at R1, were better remembered at R2, compared to short lag items that were easily retrieved at R1. For short lag items, if they were repeated soon after (short retention interval) they would be easily retrieved (SRSL), otherwise at the longer retention intervals, participants would have difficulty in retrieval.

While age effects were found on retrieval of R1 items, no age effects were observed in retrieval of R2 items. Hence, results suggest that repetition serves as a compensatory mechanism in recognition memory for older adults. It has been suggested that recognition is spared in older adults as older adults seemed to rely more on familiarity (Danckert & Craik, 2013), and results seem to concur as repetition can enhance the feeling of familiarity.

One aspect that should also be considered with respect to the age effects in R1 trials is the effect of ageing on attention that contributes to poor recognition performance. It has been shown that that older adults above the age of 60 show declines in attentive abilities. However, this decline was not in all areas, but more specifically in resistance to distraction (Commodari & Guarnera, 2008). Additionally, using EEG, it was shown that older adults show more deficits in attentional suppression of task irrelevant stimuli and semantic operations during encoding of a word recognition task, which contribute to poorer memory performance (Finnigan, O'Connell, Cummins, Broughton, & Robertson, 2011). Hence, if poor attention contributed to the impaired recognition performance in R1, it is likely that repetition may serve as a compensatory mechanism by facilitating the capture or encoding of items upon subsequent exposure if they had been missed during the first exposure.

It should also be noted that there was too much of variation among the number of intervening items between the new presentation and R1, and the number of intervening items between R1 and R2. These limitations were corrected in experiment 2 by increasing the number of stimuli for each category of new, R1 and R2; and also controlling the number of intervening items between new and R1; and between R1 and R2, thus reducing the variability.

This study was extended in experiment 2 by employing ERPs to investigate the underlying neural correlates of recognition memory. Of particular interest was the role of the underlying processes of familiarity, recollection and post-retrieval monitoring that contributes to retrieval of memory when items are repeated for the first time at short delay (R1), and then repeated again for the second time after a longer delay (R2). Contrary to previous studies, there were no old/new effects for the familiarity component, i.e. FN400. As for recollection, although no old/new effects were seen for both the R1 and R2 trials, it appears that the right posterior superior (RPS) site recorded significantly higher mean amplitude compared to the right and left posterior inferior regions (both RPI and LPI). Lastly, in terms of the LFE effect representing post-retrieval monitoring, a reverse old/new effect was seen for the R1 trials but not for the R2 trials but only at the LAS region. This is not consistent with the findings by Ally and Budson (2008) who found the reverse old/new effect, but in the LAI region. Taking into consideration the behavioral results, which show that participants make significantly more errors for R1 compared to R2, while the accuracy is similar between new and R2. The LFE effect could reflect participants' retrieval difficulty in R1 compared to R2, as the LFE has shown to index retrieval difficulty (Ally & Budson, 2007; Budson et al., 2005; Goldmann et al., 2003; Li, Morcom, & Rugg, 2004; Morcom & Rugg, 2004). Hence although the processing speed between R1 and R2 was similar (no significant difference in response time), item retrieval at R1 is marked by difficulty and memory evaluation compared to R2, which is more automatic and made with greater confidence. This could explain the absence of the recollection old/new effect as items at R1 could be relatively difficult to retrieve, marked by the LFE old/new effect as participants were not able to recollect the items fully and need to rely on post-retrieval monitoring. However, at R2, this retrieval is more automatic, where although old/new effects are not seen, mean amplitudes were significantly higher in the RPS regions, which is argued to underlie the process of recollection. The relationship between the LPC and LFE was explained in the study by Ally and Budson (2007), which found that when recollection fails or is difficult, further post-retrieval monitoring processes were engaged, given by the presence of the LFE old/new effect.

The finding that familiarity was not elicited at all is surprising, however, since it is a recognition test, this supports the dual-process theory where recollection and familiarity are two distinct processes supported by distinct neural networks (Woodruff et al., 2006; Yonelinas et al., 2005). Hence, viewing the repeated stimuli in the same form could engage the recollection neural networks compared to the familiarity neural network and participants either recollect the information, or are unable to retrieve the information in this recognition memory test.

Overall, the ERP results from experiment 2 suggest that modality of the stimuli affects recognition memory, by modulating the processes supporting recollection (indicated by the present LPC effect, but absent FN400 effect), further elaborating on to cognitive theories emphasizing modality such as the ‘picture superiority effect’ (Nelson et al., 1976). Here, the findings provide neurophysiological support to the ‘picture superiority effect' by showing that pictures may lead stronger recognition as it facilitates recollection, rather than familiarity. However, a comparison of the neurophysiological pattern of recognition of pictures and another medium, such as words should be carried out before this can be conclusive.

6.2.2 Modality and age on recognition memory

In chapter 3, two experiments were conducted to determine the effect of modality on recognition memory. First, in experiment 3, modalities tested consisted of visual, auditory and cross-modal stimuli, i.e. pairs of visual presented with its associated spoken word. The main result obtained from this experiment was that there was also no significant difference in percentage errors made for auditory condition between R1 and R2, unlike the visual and cross-modal recognition, which showed participants recognition memory improved on R2 trials compared to R1 trials. While past research has generally shown that participants show poorer recognition memory on auditory stimuli compared to visual stimuli (Bigelow & Poremba, 2014; Cohen et al., 2009), findings from this experiment clearly show the extent to which auditory stimuli is inferior to visual stimuli, whereby even with repetition, there is no improvement in recognition. It can be also be said that the space effect may not apply to stimuli in the auditory format as it does in the visual format. Finally, although there were no significant differences in participants accuracy in the visual and cross-modal modalities, participants exposed to the cross-modal stimuli recorded significantly higher *d'* scores compared to visual stimuli which shows that participants discriminability was significantly higher to cross-modal stimuli compared to visual stimuli alone.

Experiment 4 was conducted to see if there were age effects in cross-modal recognition memory across repetitions. It was expected that since older adults show greater benefits in multisensory integration (Diaconescu, Hasher, & McIntosh, 2013; Laurienti et al., 2006; Mahoney et al., 2011; Peiffer et al., 2007) and repetition should also serve as a compensatory mechanism, any age effects that may be present in R1 trials be eliminated in the R2 trials. Interestingly, age effects were present for response times, percentage errors and *d'*. Older adults were slower than younger adults in all repetition types. Additionally participants were quickest to respond to R2 trials, compared to R1 trials, followed by new trials. In terms of percentage errors, the data was a little less clear-cut. Age effects were present in both R1 and R2 trials. These results were in contradiction to the results found in experiment 1, in terms of percentage errors made. For instance in Experiment 1, age effects were found at the first repetition (R1) but not at 2nd repetition where older adults and younger adults made comparable percentage errors. However this can be attributable to several differences. First, it is a different paradigm compared to experiment 4 where it only used visual stimuli. Second, there were fewer trials in the recognition memory paradigm of experiment 1 compared to experiment 4. However, it was reliable as there were significantly more participants in experiment 1. Another possibility could be due to experiment 1 consisting of fewer trials that could have caused a floor effect.

Additionally, the trend was different among the age groups. Older adults appeared to make significantly more errors in the R1 trial types compared to both R2 and new, which do not differ in percentage errors made. On the other hand, younger adults while making significantly less errors in R2, did not differ in errors made between new and R1. The data appears to show that older adults benefited more compared to the younger adults due to the large reduction in error rates from R1 to R2, compared to their younger counterparts. As in previous studies (experiment 1), *d'* scores for older adults were significantly less compared to younger adults, showing that with age comes a reduction in discriminability of correctly recognizing an item as new, with either a higher level of committing false alarms, or a lower hit rate. However, as there were no significant differences in percentage errors committed in the new trials between both age groups, it can be said that the lower discriminability scores can be attributed to the lower hit rate by older adults.

Overall, this chapter clearly shows that cross-modal stimuli led to higher discriminability and overall accuracy among younger adults. In particular, among uni-modal stimuli, auditory stimuli showed impoverished recognition memory where no improvement was observed over repetition. In terms of cross-modal stimuli, although there were age effects seen between older adults and younger adults in both repetitions, older adults seem to show more benefits compared to their younger counterparts, where this findings cannot be attributed to education, or language barriers.

6.2.3 Semantic congruency in recognition memory

In chapter four, two experiments were presented to explore the effects of semantic congruency of cross-modal stimuli across repetitions on recognition memory. Semantic congruency is the extent that the audio-visual pairs are semantically related. Past research has shown that it is not just multisensory experiences that improve recognition memory, but the stimuli must be semantically related in order to improve recognition (Lehmann &

Murray, 2005; Murray et al., 2005; Murray et al., 2004). However, these studies have shown the effect of semantic congruency only on the first repetition, and not on subsequent repetitions. In experiment 5, recognition memory was compared across four conditions, i.e. 1) when visual and auditory pairs are semantically congruent; 2) when visual and auditory pairs are incongruent; 3) visual stimuli presented alone and 4) visual stimuli paired with a meaningless tone. Additionally, younger and older participants were tested to determine if the effects of semantic congruency on recognition memory across repetitions differed across the age groups. Although older adults showed poorer performance compared to younger adults, both older and younger adults benefited from semantic congruency only on the first repetition, i.e. participants showed significantly better recognition memory on first repetition (R1), and there were no differences among the conditions on the second repetition (R2). This is inconsistent with past findings that showed the importance of semantic congruency in recognition memory (Lehmann & Murray, 2005; Moran et al., 2013; Thelen & Murray, 2013), where it was shown that with repetition, the significance of semantic congruency disappeared.

Although in line with much research showing that semantically congruent information leads to better recognition memory compared to incongruent information (Lehmann & Murray, 2005; Murray et al., 2005; Murray et al., 2004; Thelen et al., 2012), a reason that could account for this is higher attention. Studies have reported that semantically incongruent information is more salient and hence captures more attention due to a violation of expectancies. For instance, when objects were presented among natural scenes that do not match in meaning, eye gaze was found to be attracted to incongruent objects (LaPointe & Milliken, 2016). However, much research has reported contradictory results, where no evidence has been shown to indicate more attention towards incongruent objects (Mack, Clarke, Erol, & Bert, 2017). These conclusions that more attention is directed to incongruent objects are seen in binocular rivalry tasks, where more dominance or longer time is recorded in viewing incongruent objects with scenes. However, more dominance does not translate to more attentional capture or processing, as the researchers reasoned that the longer time taken to view incongruent objects is likely due to the difficulty in processing or recognizing the incongruent object rather than the ability to attract more attention (Mudrik, Breska, Lamy, & Deouell, 2011)

However, a neuroimaging study to determine how attention spreads between two modalities, when auditory and visual information is congruent and incongruent reveals greater spread of attention for incongruent information (Zimmer, Roberts, Harshbarger, & Woldorff, 2010). In this research, participants respond to either one of two visual letters ("A" or "H") presented laterally, while task-irrelevant letter sounds ("A" or "H") were presented centrally, which could either be congruent or incongruent to letter words. Results showed that in the incongruent conditions, there was enhanced activity in the anterior cingulate cortex and the contralateral visual cortex, likely due to conflict detection and an increase in attention to the visual stimulus. Additionally, this was accompanied by a bilateral increase in activity in the auditory cortices. In contrast, only a unilateral increase in activity was seen language-dominated side for congruent trials in the auditory cortices. This indicates that an incongruent sound stimulus can lead to a greater distraction compared to congruent sound, leading to greater capture in attention.

However, the results in this thesis showed contradictory findings, where it was found that participants made least errors in the congruent condition for R1 trials, with no significant differences in errors made in incongruent, tones and visual trials. If incongruent trials led to greater attention, it should be translated to lower errors. Hence although incongruent information could lead to higher bilateral activation in the auditory cortices, this processing does not mean an enhanced formation of memory traces, but could indicate a different processing mechanism for incongruent information, one that expends more resources, but is not necessarily efficient. Taking the results of the study by van Kesteren et al. (2013) which showed higher activity in the encoding-related activity in the medial prefrontal cortex (mPFC) for congruent object-scene pairs, and activity in the MTL correlated with decreasing levels of congruency, it could indicate that incongruent and congruent pairs of stimuli were processed via different mechanisms, where encountering congruent and incongruent pairs were processed differently from attention to memory formation. Although processing of incongruent pairs may expend more resources and more activation, this does not lead to better memory formation, as they are more likely to be processed more automatically by the MTL, whereas for congruent pairs, the role of the mPFC would contribute to the encoding process, which translates to better memory formation. This is seen in the reduction of errors in R1 trials for congruent pairs compared to incongruent pairs.

Experiment 6 was carried out in order to understand the effects of semantic congruency on the neural correlates of recognition memory to understand how the underlying processes of familiarity, recollection and post-retrieval processing contribute to recognition memory when information was semantically congruent and incongruent.

In contrast to experiment 2, which found no FN400 effects, experiment 6 found the typical old/new effect pertaining to familiarity in the LAS region, in line with past research (Curran & Cleary, 2003; Curran & Doyle, 2011; Curran & Friedman, 2004; Nyhus & Curran, 2009; Rugg & Curran, 2007). However, congruency did not modulate the familiarity effect as this was seen in both the congruent and incongruent conditions.

The result seems to suggest that cross-modal stimuli appeared to elicit the familiarity ERP signal compared to using uni-modal visual stimuli. There is a possibility that when participants were exposed to only one type of sensory information, retrieval is elicited in all-or-none recollection, given by the higher mean amplitudes in the posterior regions for R1 and R2 trials at the posterior sites in experiment 2, and the reverse LFE old/new effect seen for the R1 trials at LAS region. In comparison, when cross-modal stimuli are used, participants may be paying attention to one type of stimulus, such as visual, and the presence of the spoken word stimulus may elicit the familiarity signal, when participants endorse an item as old. In this case, there are two streams of information, which while both may not capture participants attention, it does aid in the process of familiarity.

Similar to experiment 2, a recollection signal (LPC old/new effect) failed to be elicited, however there was an effect of region where the superior sites recorded significantly higher mean amplitude compared to the inferior sites. In these two cases it has been shown that hits (correct recognition in R1 and R2) and correct rejections (accurate new trials) led to higher mean amplitude in these regions.

Lastly, the LFE also shows similar results to the LPC where an effect of region was seen, more specifically in the left hemisphere where the left anterior superior (LAS) region recorded significantly higher amplitude compared to the left anterior inferior (LAI) regions. This result was also in contrast to the ERP study in visual recognition of experiment 2 which found a reverse old/new effect for R1 trials in the LAS region. In past research, stimuli that was retrieved was typically in uni-modal stimuli although initial exposure was in the cross-modal stimuli. It could be that that using cross-modal stimuli during retrieval leads to the engagement of different neural networks compared to uni-modal stimuli where old/new effects may not be seen, but an overall increase in mean amplitude of the superior regions. ERP findings from experiment 2 and experiment 6 raises the possibility that in the presence of cross-modal stimuli, old/new effects for LPC and LFE may be absent compared to using uni-modal stimuli alone. This should be researched further.

Although contrary to expectations there was no effect of LPC or LFE, the neural correlate for recollection and post-retrieval monitoring. However the superior sites recorded higher mean amplitude compared to the inferior sites during these two time windows. Although EEG recording do not provide precise spatial resolution, these findings coincide with the location of the structures within the medial temporal lobe that support recognition memory, particularly the hippocampus, located closer to the superior region compared to the anterior region. Further, although limited by spatial precision, precise temporal resolution showing elevated voltage precisely at the time related to recollection (500 ms - 800 ms), and post-retrieval monitoring (1000 ms - 1800 ms) further coincides with previous model of recognition memory, indicating that the processes of familiarity, recollection and post-retrieval monitoring, or the underlying components of recognition memory occurs at specific time intervals (see **Figure 1-9**).

6.2.4 Modality-match effect on recognition memory

In Chapter 5, two experiments were presented showing the effect of modality mismatch on recognition memory across two repetitions, using auditory, visual and cross-modal stimuli. In Experiment 7, four types of conditions were compared, i.e Auditory-Cross-modal-Visual (A|C-M|V)'; 'Visual-Cross-modal- Auditory (V|C-M|A)' 'Cross-modal-Auditory-Visual (C-M-A-V) and 'Cross-modal-Visual-Auditory' (C-M-V-A). In all these conditions, the first modality refers to the initial presentation, the second refers to the R1 trials and the third refers to the R2 trials. In all levels of presentation, participants faced a modality mismatch. In contrast to the previous experiments in this thesis, new trials were not analyzed for two reasons: 1) results of experiment 3 has already compared recognition memory performance of new trials across the three modalities and found no significant effect of modality in new trials, and 2) the aim of the study was to determine the recognition memory performance when repeated presentations differ in modality from initial presentation. With respect to R1 trials, initial presentation in the auditory modality and R1 recognition in the cross-modal format (A|C-M|V) led to significantly lower accuracy on R1 trials compared to all other conditions. Additionally when comparing initial presentation in the cross-modal format and recognition in the auditory and visual modality (C-M|A|V) vs (C-M|V|A), results show that R1 trials in the visual modality led to significantly lower errors compared to the auditory modality (C-M|A|V).

In terms of R2 trials, results showed that there were no significant differences between the conditions. Unlike previous experiments from chapter 2-4, R2 repetition trials were repeated for the first time in this experiment because it was either presented the first time as a new trial such as in C-M|A|V, or C-M|V|A; or presented for the first time as an R1 trial, such as in A|C-M|V or V|C-M|A. Hence it was expected that there would be significant differences in R2 trial as the stimuli was not repeated again. There is a possibility that although the stimuli was repeated only once at R1, presentation of the stimuli with its associated pair either at new trials (such as in C-M|A|V and A|C-M|V) or at R1 trials (such as in A|C-M|V and V|C-M|A) may have led to better encoding of stimuli for recognition at the R2. Additionally, when in the conditions of C-M|A|V and C-M|V|A, participants had been exposed to the R2 stimuli for the first time at new trials. However, because it's paired associate was presented again at R1, this could have caused retrieval of the R2 stimuli in memory although the stimuli itself was absent.

The role of attention in retrieval of items should also be considered, as attention during retrieval has been shown to lead to increased recognition performance upon subsequent encounter (Dudukovic, Dubrow, & Wagner, 2009). Hence, although participants were only exposed to the R2 stimuli once, encountering its associated pair at R1, or during the first presentation may have led to the retrieval of the R2 stimuli in memory. Further, the role of attention during this retrieval process, may facilitate the strengthening of memory traces, consequently resulting in increased recognition performance at R2, regardless of the modality the stimuli was presented in.

d' offered insight into participants discriminability and results clearly shows that initial presentation in the auditory modality impairs participants discriminability. Hence it is safe to say that initial modalities or retrieval in the auditory modality in a modality mismatch paradigm appears to impair recognition memory compared to visual recognition memory.

The behavioral results of experiment 8 compared between two conditions alone, i.e. A|C-M|V and V|C-M|A while investigating the effects of modality mismatch on the ERP correlates of recognition memory. Results showed that participants made significantly more errors in the auditory format for initial presentation (new), and in the CM condition when initial presentation was in the auditory modality (A|C-M|V). However, in R2 trials, there were no significant differences in recognition for both visual and auditory modalities in both conditions, consistent to experiment 7, but not consistent to experiment 3, which found no effect of modality on new trials. The difference between the design in experiment 3 and 7 was in experiment 3 participants were only exposed to one type of stimuli, i.e. visual, auditory or cross-modal. In experiment 7, participants were exposed to new trials in both auditory and visual stimuli. There is a possibility that intermixing of items of different modalities within the same block could play a role in discrimination of new items, whereby participants ability to correctly discriminate an auditory stimuli as new is poorer if the stimuli is intermixed in a block of visual and cross-modal stimuli. It has been previously reported by Mulligan and Osborn (2009) that saliency brought about by either intermixing items of different modalities, or by presenting the items of different modalities in different block has an affect on recognition. In this case, visual and cross-modal stimuli are more salient compared to auditory stimuli, therefore capturing more attention, enhancing participants' ability to discriminate in those modalities compared to auditory modalities.

ERP analysis of experiment 8 showed no effect of familiarity, given by the absence of the FN400 effect. This could be because the FN400 is a component sensitive to perceptual match and is an indication of negative modulation of stimulus novelty as argued by Tsivilis et al. (2001). Hence the novelty of information presented via a new modality could trigger the novelty signal, leading to a negative familiarity ERP component.

Further, old/new effects of the recollection component (LPC) were reported in the RPI for the V|C-M|A condition for R2 trials, and the LPS, where R1 and R2 trials reported the old/new effect, but the V|C-M|A reported the reverse old/new effect for R2 trials. The lack of the FN400 old/new effect and the presence of the LPC old/new effect is consistent with the idea that when there is no perceptual match, or when there is a modality mismatch, participants may rely more on recollection rather than familiarity to guide their discrimination. Furthermore, findings from the recollection component, i.e. the LPC appears to suggest that the difference in the ERP correlate of recollection is likely due to the effects of modality. It is seen that auditory stimuli alone leads to a reduce mean amplitude compared to visual modality, which seem to suggest that modality plays a role in the old/new effect by indexing the amount of information to be retrieved as suggested by Fjell et al. (2005).

Lastly, the LFE component associated with post retrieval monitoring indicates that while condition or modality had no effect on the LFE component, it was sensitive to the type of repetition, whereby R2 showed a much bigger difference in mean amplitude to new compared to the R1 trials. Because the R2 trials were in uni-modal modality, while the R1 trials were in the cross-modal modality, this difference could be indicative of additional post retrieval processing associated with uni-modal modality compared to cross-modal modality.

Overall, ERP results show that modality mismatch has an effect only on the LPC component and the LFE component. Although modality mismatch did not have an effect on the FN400 component, the mismatch could indirectly be related to its absence due to the presence of novel stimuli that could render the signal absent, in line with Tsivilis et al., (2001). Additionally, results show that modality affects the neural correlate associated with recollection by indexing the amount of information to be retrieved modulating the LPC component.

Finally, modality also affected the neural correlates associated with post-retrieval monitoring, i.e. the LFE component such that when the cue for memory retrieval is in a single modality, participants retrieve additional information of information at initial presentation, subsequently manifesting itself as an enhanced old/new effect. Although, this was a reverse old/new effect seen for R2 trials. This could be due to the modality mismatch where more information was present at R1 compared to R2 (single modality). This lower mean amplitude for R2 could be a reflection of the modality (uni-modal) compared to R1 (cross-modal). Therefore, although type of modality may not directly have an effect on the old/new effect, the amount of information may play a role. There was no old/new effect seen for R1 trials. One reason could be because the R1 trials also contained a new presentation, whether in the auditory or visual modality, and so was not purely a repeated presentation. Additionally, when more information is available at retrieval, such as in cross-modal modality, participants do not perform much post-retrieval operation on it, leading to an absence of an old/new effect.

Overall, the findings of this study provide new theoretical implications to the model provided by Ally and Budson (2007, see **Figure 1-9**) where modality of stimuli should be considered in studies involving the neural correlates as indicators of recognition. While the FN400, LPC and LFE have previously been thought to be neural indicators of recognition only, results show that it is not only an indicator of recognition, but the signal can be modulated by modality of presentation or the type information presented, although it may be a repeated presentation. Thus, in situations where modality is mismatched, the old/new effect may not be apparent and it may not be a reliable indicator of recognition as previously used.

6.3 Conclusion

In this thesis, factors that affect recognition memory among older and younger adults were studied using a recognition memory paradigm that reflects the space learning effect (Greene, 1989) and repetition. It was found that when the interval between the first and second repetitions were short; and the interval between the second and third were longer, participants made significantly more errors in recognition (experiment 1). Additionally, ERP results (experiment 2) showed the processes of recollection and post retrieval monitoring contributing to the recognition process rather than familiarity.

Information presented in the auditory modality led to impoverished recognition memory compared to visual and cross-modal, even with repetition (experiment 3). Results also showed that older adults showed benefit with repetition on cross-modal recognition, they still showed poorer recognition compared to younger adults (experiment 4).

The effect of semantic congruency in multi-modal pairs facilitated recognition, but it only had an effect with first repetition. Upon second repetition, there was no effect of semantic congruency, and participants' performance in all conditions (semantically congruent cross-modal; semantically incongruent cross-modal; visual images paired with a brief tone; visual images presented alone) had no significant differences. This effect was also seen among older adults (experiment 5). In experiment 6, ERP results showed the role of familiarity playing a role in recognition rather than recollection and post retrieval monitoring which may suggest that familiarity may play a role in recognition compared when stimuli is multi-modal rather than uni-modal stimuli which would rely more on recollection. However, congruency of stimuli had no effect on the underlying processes of recognition memory.

When there is a modality mismatch, presence of auditory stimuli can impair recognition memory compared to visual or cross-modal stimuli (experiment 7). In the final study (experiment 8), results showed that modality mismatch did not have an effect on familiarity, but there was an effect on the recollection and post-retrieval monitoring. When there is a modality mismatch, participants rely more on recollection and post-retrieval monitoring to guide recognition decisions rather than familiarity, which has been shown to be dependent on perceptual match.

6.4 Implications and future directions

The findings in this thesis highlight the strategies that can be applied to optimize memory performance using repetition, multimodal sensory information, and modality mismatch scenarios. Furthermore, with well-documented effects of ageing on memory, it is important to understand how memory is affected during ageing and compensatory strategies that healthy older adults can employ.

These findings reported in this thesis have raised several research questions that I want to investigate further. First, I would like to explore the space effect theory further to determine its best use in the classroom to promote learning. Results of the first experiment showed the participants make more errors when information is repeated following a short lag, and then repeated again after another long interval. This strategy can be applied in different learning situations to determine the best strategy to optimize students learning potential. In addition, I would also like to expand upon my research on modality mismatch to see how this can be applied in the classroom to optimize learning potential. Current pedagogical trends involve moving away from traditional lectures delivered in large classrooms to approaches like a flipped classroom, where lectures are delivered in an audio format online that students listen to before class followed by in-class activities. Results in this thesis imply that retrieval is relatively poor when the initial presentation is in the auditory format. I would like to investigate whether the current flipped classroom approach can be improved by modifying the modality of the initial lecture material delivered online, through the use of video and audio for example or with other aids like subtitles. Furthermore, this can be tested for age effects in order to formulate compensatory strategies among healthy older adults who may show deficits in recognition memory.

Second, I would like to expand on my results showing the beneficial effect of repetition in facilitating recognition memory by investigating whether this effect exists for the tactile modality as well. This may be particularly relevant in the context of older adults who may have some sensory impairment related to the auditory or visual fields. This also has important implications for industry-related applications where information could be relayed to the user through tactile-feedback on computer trackpads and smartphone screens. Such feedback might also serve as a compensatory mechanism and enable faster learning in older adults, a demographic that traditionally has challenges using new technology.

Third, I would like to compare recognition memory performance between the modalities and incorporate a remember/know procedure, confidence judgments or a source task to understand the effects of modality on the processes of familiarity and recollection and how that contributes to recognition. This type of recognition task can provide more information regarding the type of recognition memory processes affected by the different modalities.

Finally, this research can extend the ERP studies by investigating age effects. As older adults have compensatory mechanisms to overcome deficits caused by ageing, it would be interesting to see how modality, semantic congruency and modality mismatch affects the underlying processes of recognition memory in older adults and how it differs from younger adults.

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APPENDIX A: SCREENING TOOLS

A.1 Beck's Depression Inventory (Beck, Steer & Brown, 1996).

Instructions: This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the **one statement** in each group that best describes the way you have been feeling during the past two weeks, including today. Circle the number beside the statement you have picked. If several statements in the group apply equally well, circle the highest number for that group.

1.
    0. I do not feel sad.
    1. I feel sad
    2. I am sad all the time and I can't snap out of it.
    3. I am so sad and unhappy that I can't stand it.

2.
    0. I am not particularly discouraged about the future.
    1. I feel discouraged about the future.
    2. I feel I have nothing to look forward to.
    3. I feel the future is hopeless and that things cannot improve.

3.
    0. I do not feel like a failure.
    1. I feel I have failed more than the average person.
    2. As I look back on my life, all I can see is a lot of failures.
    3. I feel I am a complete failure as a person.

4.
    0. I get as much satisfaction out of things as I used to.
    1. I don't enjoy things the way I used to.
    2. I don't get real satisfaction out of anything anymore.
    3. I am dissatisfied or bored with everything.

5.
    0. I don't feel particularly guilty
    1. I feel guilty a good part of the time.
    2. I feel quite guilty most of the time.
    3. I feel guilty all of the time.

6.
    0. I don't feel I am being punished.
    1. I feel I may be punished.
    2. I expect to be punished.
    3. I feel I am being punished.

7.
    0. I don't feel disappointed in myself.
    1. I am disappointed in myself.
    2. I am disgusted with myself.
    3. I hate myself.

8.
    0. I don't feel I am any worse than anybody else.
    1. I am critical of myself for my weaknesses or mistakes.
    2. I blame myself all the time for my faults.
    3. I blame myself for everything bad that happens.

9.

0. I don't have any thoughts of killing myself.
1. I have thoughts of killing myself, but I would not carry them out.
2. I would like to kill myself.
3. I would kill myself if I had the chance.

10.

0. I don't cry any more than usual.
1. I cry more now than I used to.
2. I cry all the time now.
3. I used to be able to cry, but now I can't cry even though I want to.

11.

0. I am no more irritated by things than I ever was.
1. I am slightly more irritated now than usual.
2. I am quite annoyed or irritated a good deal of the time.
3. I feel irritated all the time.

12.

0. I have not lost interest in other people.
1. I am less interested in other people than I used to be.
2. I have lost most of my interest in other people.
3. I have lost all of my interest in other people.

13.

0. I make decisions about as well as I ever could.
1. I put off making decisions more than I used to.
2. I have greater difficulty in making decisions more than I used to.
3. I can't make decisions at all anymore.

14.

0. I don't feel that I look any worse than I used to.
1. I am worried that I am looking old or unattractive.
2. I feel there are permanent changes in my appearance that make me look unattractive
3. I believe that I look ugly.

15.

0. I can work about as well as before.
1. It takes an extra effort to get started at doing something.
2. I have to push myself very hard to do anything.
3. I can't do any work at all.

16.

0. I can sleep as well as usual.
1. I don't sleep as well as I used to.
2. I wake up 1-2 hours earlier than usual and find it hard to get back to sleep.
3. I wake up several hours earlier than I used to and cannot get back to sleep.

17.

0. I don't get more tired than usual.
1. I get tired more easily than I used to.
2. I get tired from doing almost anything.
3. I am too tired to do anything.

18.

0. My appetite is no worse than usual.
1. My appetite is not as good as it used to be.
2. My appetite is much worse now.
3. I have no appetite at all anymore.

19.

0. I haven't lost much weight, if any, lately.
1. I have lost more than five pounds.
2. I have lost more than ten pounds.
3. I have lost more than fifteen pounds.

20.

0. I am no more worried about my health than usual.
1. I am worried about physical problems like aches, pains, upset stomach, or constipation.
2. I am very worried about physical problems and it's hard to think of much else.
3. I am so worried about my physical problems that I cannot think of anything else.

A.2 Geriatric Depression Scale (GDS)-15 (English version)- Respondent Form (Sheikh & Yesavage, 1986)

	Response	
	YES	NO
Are you basically satisfied with your life?		
Have you dropped many of your activities and interests?		
Do you feel that your life is empty?		
Do you often get bored?		
Are you in good spirits most of the time?		
Are you afraid that something bad is going to happen to you?		
Do you feel happy most of the time?		
Do you often feel helpless?		
Do you prefer to stay at home, rather than going out and doing new things?		
Do you feel you have more problems with memory than most?		
Do you think it is wonderful to be alive now?		
Do you feel pretty worthless the way you are now		
Do you feel full of energy?		
Do you feel that your situation is hopeless?		
Do you think that most people are better off than you are?		

A.3 GDS-15 Scoring Form

	Original Scoring	Patients Response
Are you basically satisfied with your life?	No	
Have you dropped many of your activities and interests?	Yes	
Do you feel that your life is empty?	Yes	
Do you often get bored?	Yes	
Are you in good spirits most of the time?	No	
Are you afraid that something bad is going to happen to you?	Yes	
Do you feel happy most of the time?	No	
Do you often feel helpless?	Yes	
Do you prefer to stay at home, rather than going out and doing new things?	Yes	
Do you feel you have more problems with memory than most?	Yes	
Do you think it is wonderful to be alive now?	No	
Do you feel pretty worthless the way you are now	Yes	
Do you feel full of energy?	No	
Do you feel that your situation is hopeless?	Yes	
Do you think that most people are better off than you are?	Yes	
Final Geriatric Depression Scale Score		

Scoring key: 1 point for each original scoring and patient response match

A.4 GDS-15 (Malay version)- Respondent Form (Teh & Hasnah, 2005)

	Jawapan	
	Ya	Tidak
Adakah anda pada asasnya berpuas hati dengan kehidupan anda?		
Adakah anda telah meninggalkan banyak kegiatan dan minat anda?		
Adakah anda berasa hidup anda kekosongan?		
Adakah anda sering bosan?		
Adakah anda bersemangat dalam kebanyakan masa?		
Adakah anda bimbang sesuatu yang buruk akan terjadi pada anda?		
Adakah anda berasa gembira dalam kebanyakan masa?		
Adakah anda sering berasa tidak terdaya?		
Adakah anda lebih suka duduk di rumah daripada keluar dan melakukan sesuatu perkara/hal yang baru?		
Adakah anda berasa bahawa anda mempunyai lebih banyak masalah daya ingatan daripada orang lain?		
Adakah anda fikir alangkah baiknya untuk hidup sekarang?		
Adakah anda berasa keadaan anda sekarang kurang berguna?		
Adakah anda berasa penuh bertenaga?		
Adakah anda berasa keadaan anda tidak ada harapan?		
Adakah anda fikir bahawa kebanyakan orang adalah lebih baik daripada anda?		

A.5 GDS-15 (Malay version)- Scoring form

	Original Scoring	Patients Response
Adakah anda pada asasnya berpuas hati dengan kehidupan anda?	Tidak	
Adakah anda telah meninggalkan banyak kegiatan dan minat anda?	Ya	
Adakah anda berasa hidup anda kekosongan?	Ya	
Adakah anda sering bosan?	Ya	
Adakah anda bersemangat dalam kebanyakan masa?	Tidak	
Adakah anda bimbang sesuatu yang buruk akan terjadi pada anda?	Ya	
Adakah anda berasa gembira dalam kebanyakan masa?	Tidak	
Adakah anda sering berasa tidak terdaya?	Ya	
Adakah anda lebih suka duduk di rumah daripada keluar dan melakukan sesuatu perkara/hal yang baru?	Ya	
Adakah anda berasa bahawa anda mempunyai lebih banyak masalah daya ingatan daripada orang lain?	Ya	
Adakah anda fikir alangkah baiknya untuk hidup sekarang?	Tidak	
Adakah anda berasa keadaan anda sekarang kurang berguna?	Ya	
Adakah anda berasa penuh bertenaga?	Tidak	
Adakah anda berasa keadaan anda tidak ada harapan?	Ya	
Adakah anda fikir bahawa kebanyakan orang adalah lebih baik daripada anda?	Ya	
Final Geriatric Depression Scale Score		

Scoring key: 1 point for each original scoring and patient response match

A.6 Mini-Mental Status Examination (MMSE), (Folstein, Folstein, & McHugh,1975)

Orientation

- What is the year, season, date, day and month (1 point for each; maximum total 5 points).
- Where are we: town, county, country, which hospital, surgery or house, and which floor (1 point for each; maximum total 5 points).

Registration

- Name 3 objects (e.g., apple, table, penny) taking 1 second to say each one.
- Then ask the individual to repeat the names of all 3 objects.
- Give 1 point for each correct answer.
- Repeat the object names until all 3 are learned (up to 6 trials).
- Record number of trials needed (maximum total 3 points).
-

Attention and Calculation

- Spell "world" backwards. Give 1 point for each letter that is in the right place (e.g., DLROW = 5 points, DLORW = 3 points).
- Alternatively, do serial 7s:
    - Ask the person to count backwards from 100 in blocks of 7 (i.e., 93, 86, 79, 72, 65).
    - Stop after 5 subtractions.
    - Give one point for each correct answer. If one answer is incorrect (e.g. 92) but the following answer is 7 less than the previous answer (i.e., 85), count the second answer as being correct. 1 point for each subtraction (maximum total 5 points).

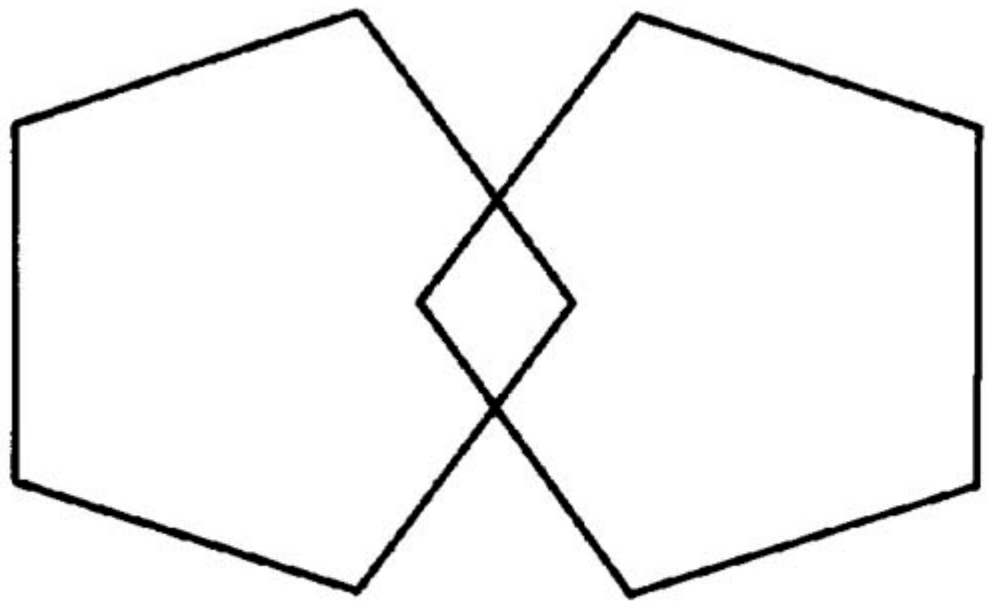
Recall

- Ask for the 3 objects repeated above (e.g., apple, table, penny). Give 1 point for each correct object (maximum total 3 points).

Language

- Point to a pencil and ask the person to name this object (1 point). Do the same thing with a wrist-watch (1 point). (maximum total 2 points)

- Ask the person to repeat the following: "No ifs, ands or buts" (1 point). Allow only one trial (1 point).
- Give the person a piece of blank white paper and ask them to follow a 3-stage command: "Take a paper in your right hand, fold it in half and put it on the floor" (1 point for each part that is correctly followed). (maximum total 3 points)
- Write "CLOSE YOUR EYES" in large letters and show it to the patient. Ask him or her to read the message and do what it says (give 1 point if they actually close their eyes).
- Ask the individual to write a sentence of their choice on a blank piece of paper. The sentence must contain a subject and a verb, and must make sense. Spelling, punctuation and grammar are not important (1 point).
- Show the person a drawing of 2 pentagons which intersect to form a quadrangle. Each side should be about 1.5 cm. Ask them to copy the design exactly as it is (1 point). All 10 angles need to be present and the two shapes must intersect to score 1 point. Tremor and rotation are ignored.



A.7 MMSE-Malay version, (Za, Zahiruddin, & Ah, 2007).

Maximum	Markah pesakit	
5		*Orientasi Masa*
		Tahun, bulan, hari, tarikh, waktu (+/- 1 jam)
5		*Orientasi Tempat*
		Negara, Negeri, Bandar,Tempat (hospital/rumah), bilik (wad/klinik)
3		*Pendaftaran*
		Saya akan menguji ingatan awak. Sila dengar dengan teliti, tiga objek yang saya akan baca, iaitu, oren, kunci dan sikat. Sila sebut semula tiga objek tadi. Ingat betul-betul, kerana saya akan bertanya kemudian.
5		*Perhatian dan Pengiraan (sila guna salah satu kaedah)*
		M-MMSE-7: Sila tolak 7 dari 100 dan teruskan. *M-MMSE -3*: Atau, tolak 3 dari 20 dan teruskan. *M-MMSE-S*: Atau, ejakan perkataan 'DUNIA' dari belakang ke depan.
3		*Ingat Kembali*
		Sila sebut kembali 3 objek yang telah disebut tadi.
2		*Penamaan*
		Namakan benda ini. (Pensel dan Jam Tangan)
1		*Ulangan*
		Sebutkan 'Tidak mungkin dan cukup mustahil'
3		*Arahan tiga peringkat*
		Ambil kertas dengan tangan kanan, lipat setengah dan letakkan atas lantai/meja.
1		*Pembacaan*
		Baca dan lakukan …..TUTUP MATA ANDA
1		*Penulisan*
		Tulis satu ayat yang lengkap.
1		Penyalinan
		Salinkan rajah berikut 
Jumlah		

A.8 LexTALE (Lemhöfer & Broersma, 2012)

For each of the words below, decide if it is an existing English word, or not. If you are sure the word exists, even if you do not know its exact meaning, you may respond "yes". But if you are not sure if it is an existing word, you should respond "no"

EXAMPLE		
Word	Yes	No
platery		✓
denial		
generic		

	Word	YES	NO
1	mensible		
2	scornful		
3	stoutly		
4	ablaze		
5	kermshaw		
6	moonlit		
7	lofty		
8	hurricane		
9	flaw		
10	alberation		
11	unkempt		
12	breeding		
13	festivity		
14	screech		
15	savoury		
16	plaudate		
17	shin		
18	fluid		
19	spaunch		
20	allied		

No	Word	YES	NO
21	slain		
22	recipient		
23	exprate		
24	eloquence		
25	cleanliness		
26	dispatch		
27	rebondicate		
28	ingenious		
29	bewitch		
30	skave		
31	plaintively		
32	kilp		
33	interfate		
34	hasty		
35	lengthy		
36	fray		
37	crumper		
38	upkeep		
39	majestic		
40	magrity		

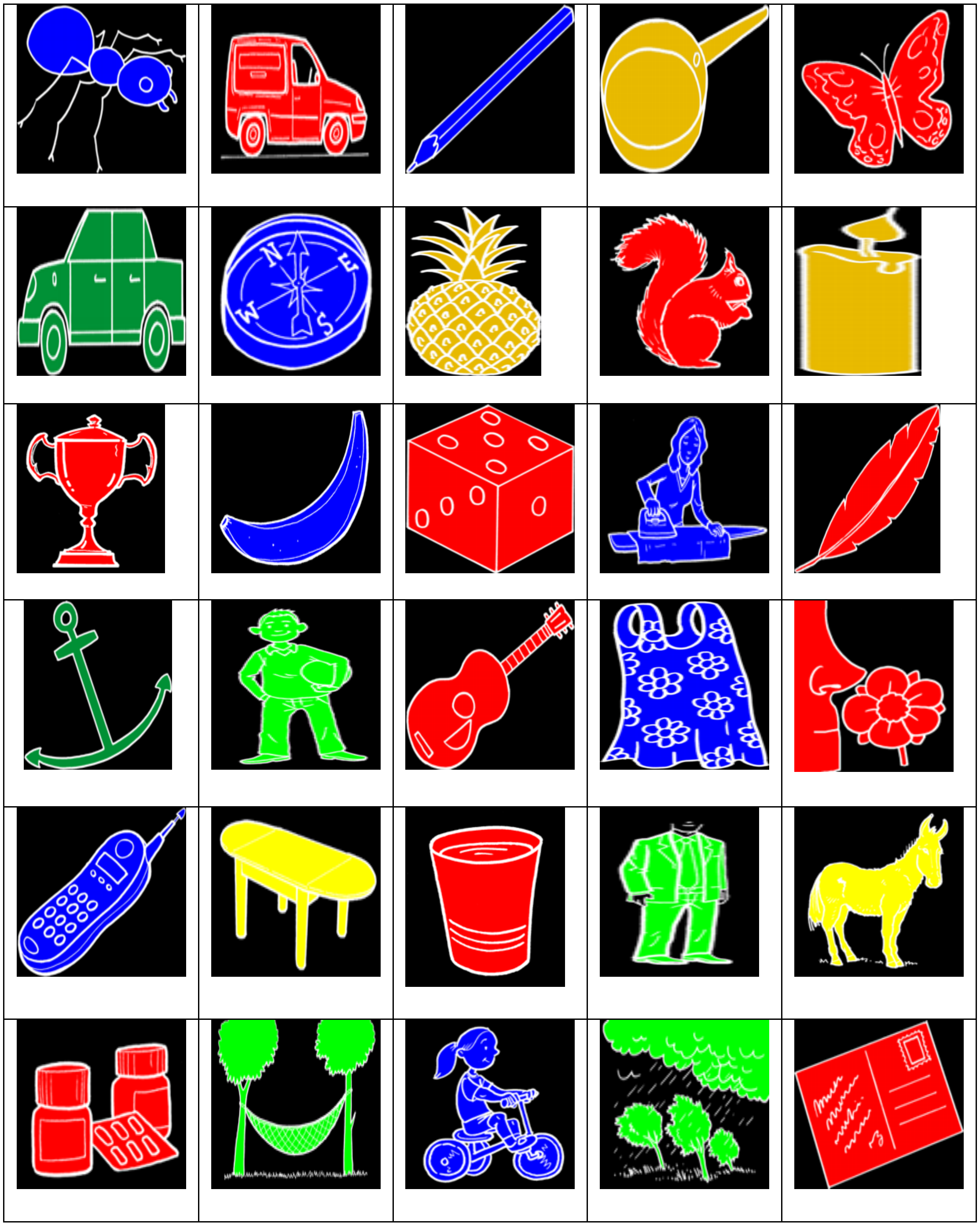
No	Word	YES	NO
41	nourishment		
42	abergy		
43	proom		
44	turmoil		
45	carbohydrate		
46	scholar		
47	turtle		
48	fellick		
49	destription		
50	cylinder		
51	censorship		
52	celestial		
53	rascal		
54	purrage		
55	pulsh		
56	muddy		
57	quirty		
58	pudour		
59	listless		
60	wrought		

A.9 Mean scores of participants in the scales.

Experiment	Beck's Depression Inventory (BDI)	Geriatric Depression Scale (GDS)	Mini-mental status examination (MMSE)	LexTale
	Mean(SD)	Mean(SD)	Mean(SD)	Mean (SD)
1	6.05 (3.67)	2.16 (1.77)	28.06 (2.17)	- -
2	5.04 (4.33)	-	-	-
3	5.02 (3.60)	-	- -	- -
4	7.76 (5.19)	1.82 (1.67)	28.62 (1.79)	
5	6.05 (3.80)	1.63 (2.09)	29.32 (0.89)	Younger adults: 75.62 (13.39); Older adults: 91.77 (SD = 6.93)
6	7.52 (3.40)	-	-	-
7	5.58 (4.32)	-	-	-
8	6.12 (3.71)	-	-	-

APPENDIX B : STIMULI

B.1 Sample of visual stimuli



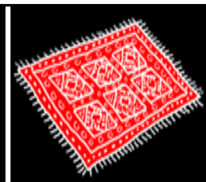
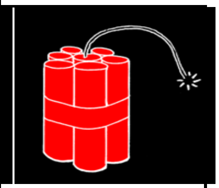
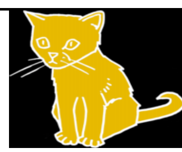
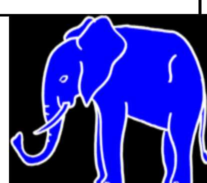
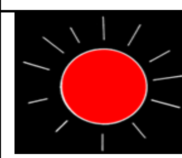
B.2 Auditory stimuli used in experiment 3 for participants in the auditory condition

Passenger
Buried
Persian
Soup
Cheese
Walk
Bird
Kitten
Disguise
Milk
Ring
Rod
Travel
Barber
Bee
Airline
Bouquet
Series
Sting
Fingernail
Blast
Bone
Wild
Stove
Steal
Lick
Spotted
Tobacco
Ticket
Stretch
Salary
Motorcycle
Classmate
Patient
Prisoner
Relay
Bite
Friend
Wine
Mouse
Point

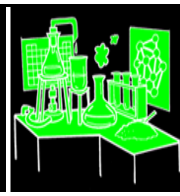
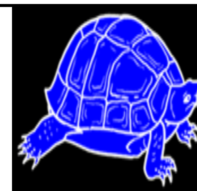
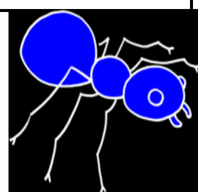
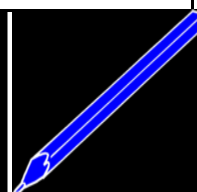
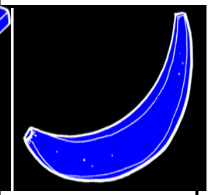
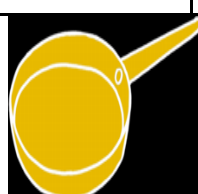
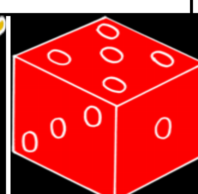
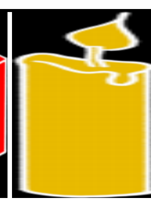
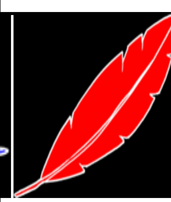
Baker
Tailor
Roast
Whiskers
Bishop
Cucumber
Animal
Dusty
Staff
Scared
Infants
Calculator
Emergency
Street
Floor
Boil
Dirt
Blanket
Swamp
Birthday
Cart
View
Changing
Storm
Horn
Husband
Thirsty
Angry
Tune
Queen
Reunion
Surfboard
Light
Actress
Smoke
Investigation
Heavy
Talk
Runner
Concert

Point
Tournament
Chilly
Poison
Slimy
Chicks
Knit
Agriculture
Dirty
Couple
Stripe
Palace
Egg
Throne
Farm
Railing
Lady
Open
Library
Novel
Peak
Clean
Tunnel
Shampoo
Loud
Performer
Hot
Tournament

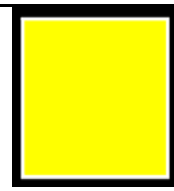
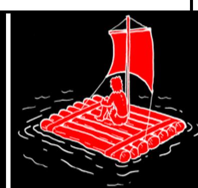
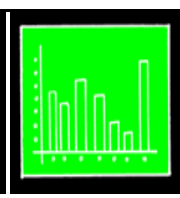
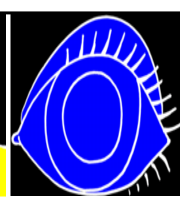
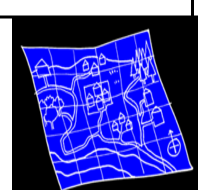
B.3 Sample cross-modal stimuli used in experiment 3 and 4.

Visual :				
Auditory:	Buried	Persian	Passenger	Bird
Visual:				
Auditory:	Wild	Sting	Bouquet	Blast
Visual:				
Auditory:	Mouse	Boil	Birthday	Scared
Visual :				
Auditory:	Heavy	Concert	Flash	Hot
Visual:				
Auditory:	Egg	Smoke	Stripe	Talk

B.4 Sample stimuli used in experiment 5 for the congruent condition

Visual :				
Auditory:	Sugar	chemistry	slow	wolf
Visual:				
Auditory:	Sweet	delivery	write	monkey
Visual:				
Auditory:	Driver	tart	nuts	location
Visual :				
Auditory:	Fry	game	wax	wings
Visual:				
Auditory:	Winner	sailor	wrinkle	light

B.5 Sample stimuli used in experiment 5 for the incongruent condition

Visual :				
Auditory:	Work	closet	banana	soul
Visual:				
Auditory:	Show	lecture	name	rain
Visual:				
Auditory:	Wooden	spider	Sprint	fragrance
Visual :				
Auditory:	Harbor	slice	night	fisherman
Visual:				
Auditory:	Address	poker	shop	chip