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Behavioural and Electrophysiological Correlates of Source Memory in Normal Ageing

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Source memory recall involves remembering the context in which an event took place. Studies have shown that a decline in source memory is evident in older adults who have not shown deficits in other areas of memory or cognition. Using the interfering effect of intervening stimuli it is possible to create a task that tests source memory ability in a laboratory setting using sounds, pictures, words or a combination of these stimuli. Studies have shown that healthy young adults can be affected by such designs, exhibiting deficits in source memory when asked to recall whether a stimulus was previously studied as a *target* or is a novel stimulus; a *distractor,* or *foil*. By repeating novel stimuli throughout a test phase, participants may respond to the repetitions as targets, despite them not being present in the study phase. Since source memory seems to affect older adults before any other obvious signs of cognitive decline, any task that can measure the presence of these deficits could be useful in determining if a participant might suffer from future, more general, memory impairments. The current thesis uses such a task to measure source memory deficits, both behaviourally and electrophysiologically, in groups of young, middle-aged and old participants. The behavioural results show a similar pattern of decline in recall among healthy young and middle-aged participants for repeated words compared to their immediate presentation, while older participants show a lower level of recall, especially for repeated stimuli, compared to both the other age-groups. This suggests that the onset of decline in source memory beginning after the age of 60 in a sudden manner, rather than as a gradual decrease in function through the lifespan. The electrophysiological results show a pattern of greater frontal area activations for repeated stimuli over first-presentation, as well as later parietal scalp area differences between these stimuli in young participants. These differences were correlated with the prefrontal cortex and the medial temporal lobe, both of which show more activation for repetitions. Older participants do not show these activations to the same extent, with little early frontal positivity, and instead exhibit a greater degree of later parietal activity and a pattern of temporal and parietal area activations, suggesting that their decrease in source memory recall ability may be linked to inefficient use of prefrontal and medial-temporal resources. Finally, an examination on the effect of a deeper level of encoding during processes, with participants asked to concentrate on the semantic features of stimuli, showed that this ameliorates source memory deficits caused by the task in both young and old groups, with recognition for repeated words increasing to a level equal to that of immediate presentations. This is in line with examinations of other memory types, but had not been found to occur during such a repetition-based procedure previously in the literature. The complete results suggest a network of medial temporal and frontal areas combine to retrieve the source of a memory in younger participants, compensated for in part by older adults through the use of areas in the temporal and parietal areas, such as the precuneus.

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Chapter 1

General Introduction

1.1 Memory

Memory is an intrinsic part of human existence and has been extensively studied by psychologists and neuroscientists. A myriad of theories as to how memories are encoded, stored and retrieved have been created, rebuffed and recreated. A table of the primary memory theories and their hypotheses on memory retrieval is included below (See Table 1.1). Squire and colleagues (e.g. 1989, 1993, 1995) implicated the hippocampus and other medial temporal lobe (MTL) structures in the creation, or encoding, of memories and believed that these structures were also used for short term storing of memory and consolidation of these memories into permanent storage in the neocortical areas of the brain. Retrieval of memories was also linked to the hippocampal regions and to the prefrontal cortex (PFC) by Squire's Classical Consolidation theory (Squire & Alvarez, 1995). The other major proponent in the field of theories of memory creation and retrieval is Multiple Trace theory, put forward by Nadel and Moscovitch and their colleagues (1992, 1997). They postulated that while the hippocampus and MTL were used to encode and retrieve memories, these memory "traces" were encoded directly into a distributed network throughout the cortex without any short term storage in the MTL. A number of variations on these two contrasting theories have also been suggested, including Auto-Association theory (e.g. Rolls & Treves, 1998), which sees no part for the PFC in retrieving stored memories from the cortex, and Representational Flexibility theory (Eichenbaum & Cohen, 2001), which attempts to explain the organization of memory traces within the cortex and how the MTL and PFC interact to form this organisation, a facet not examined by the work of Squire (1995) or Nadel and Moscovitch (1997).

While these theories differ widely in their approaches to memory, in both cognitive and neurological terms, there is a certain amount of agreement between them. The major theories divide memory into *encoding*, *storage* and *retrieval* processes, and attempt to link these processes with certain areas of the brain. The hippocampus and the frontal lobe receive the most attention, with the former linked strongly to initial encoding and storage, be it as a temporary store or as a facilitator to storage elsewhere in the cortex, and the recall process (Nadel et al., 2003). The latter is implicated in the recall process (Maguire, Burgess, Donnett et al., 1998) along with some areas of the parietal and limbic lobes, such as the posterior cingulate (Maddock, Garrett & Buonocore, 2001) and the retrosplenial cortex (Valenstein et al., 1987). Although most of the major theories have examined episodic, semantic and spatial memory processes, there has been little work attempting to link the normal ageing process to these major models of human memory, as the use of animals, Traumatic Brain Injury (TBI) sufferers or medically lesioned patients are used to formulate and to examine the efficacy of these theories.

It is hypothesised, however, that deterioration of the hippocampal system underlies short-term memory impairment and the consolidation of this information to long-term memory. Studies on the famous case of HM (e.g. Scoville & Milner, 1957; Corkin, 1984; Schmolck, Kensinger, Corkin & Squire, 2002), a patient with bilateral lesions to his MTL consisting of up to 70% of the area, found that he was unable to create new memories following the surgery, *anterograde* amnesia, despite his short term, or working, memory (e.g. Baddeley, 2003) remaining intact. His procedural memory, for learned motor skills, remained intact. Deterioration of regions of the neocortex, including the frontal lobe, is thought to be responsible for declining ability to voluntarily retrieve information from long term memory. An extensive study by Shimamura, Janowsky and Squire (1990) linked PFC damage to delayed recall and to the ability to sort memories by their temporal aspects (i.e. which memory was encoded first) which the experimenters linked to Source memory. More recently, functional Magnetic Resonance Imaging (fMRI) studies (e.g. Marklund, Fransson, Cabeza, Petersson, Ingvar & Nyberg, 2007) strongly implicate the PFC in long-term memory tasks of recall and recognition.

Table 1.1: *Brief summary of major theories of memory, in terms of some important brain areas implicated in the processes of encoding, storage and retrieval.*

Theory	Authors	Encoding	Storage	Retrieval
Classical Consolidation Theory	Squire & Alvarez (1995)	Hippocampal Formation (HF)	Short-term HF and medial temporal lobe (MTL), neocortex	HF, prefrontal cortex (PFC)
Multiple Trace Theory	Nadel & Moscovitch (1997)	HF	Neocortex	HF and PFC
Auto-Association Theory	Rolls & Treves (1998)	HF	HF and Neocortex	HF
Configural Association Theory	Sutherland & Rudy (1989)	HF	HF and Neocortex	HF and PFC
Representational Flexibility Theory	Eichenbaum & Cohen (2001)	HF	Short-term HF and Neocortex	HF and PFC

1.1 Ageing and memory

1.2.1 The Effect of Ageing on Memory

Ageing in humans refers to a multidimensional process of physical, psychological and social changes accumulated over time (Stuart-Hamilton, 2006). Some dimensions of ageing grow and expand over time, while others decline. Ageing is an important part of all human societies reflecting the biological changes that occur, but also reflecting cultural and societal conventions. Stuart-Hamilton (2006) describes a number of distinctions in the study of ageing. A distinction can be made between *universal ageing* (age changes that all people share) and *probabilistic ageing* (age changes that may happen to some, but not all people as they grow older, such as the onset of Alzheimer’s Disease). *Chronological ageing*, referring to how old a person is, is arguably the most straightforward definition of ageing and may be distinguished from *social ageing* (society's expectations of how people should act as they grow older) and *biological ageing* (a person’s physical state as they age). There is also a distinction between *proximal ageing* and *distal ageing* (age-based differences because of factors in the recent past compared to those that can be traced back to a cause early in a person's life). The current thesis is primarily interested in the phenomenon of biological ageing, as well as that of universal ageing, with respect to the age-related changes in memory that are found to occur in terms of behaviour and biology.

Although cognitive theories of ageing and memory differ in their descriptions of memory systems and stores, some consensus is present. In general, older adults seem to be more impaired at tasks involving free recall. Rakitin, Stern and Malapani (2005) found that older participants (aged ~70 years) could not replicate time intervals to the same level as young participants following a 24-hour delay. However, memories of word meaning or ability in word-primed tasks seem to be less impaired, or in some cases equal to that of younger groups. For example, Taconnat, Clarys, Vanneste, Bouazzaoui and Isingrini (2007) found that if words to be recalled were not cued or primed with reminders from a study task, performance was poor in a group of older adults, whereas by priming the words, this gap in performance closed significantly.

Early models of cognitive ageing (e.g. Atkinson & Shiffrin, 1968) used a tripartite division of sensory, short-term and long-term memory. In old populations, long-term memory seems impaired, while short-term and sensory stores seem unaffected. Schacter and Tulving (1994) elaborated on this theory, creating five memory stores; procedural memory, the perceptual representational system, primary memory, episodic memory and semantic memory. This representation of memory stores has been used retroactively to account for deficits in patients such as HM (Scoville & Milner, 1957) (impaired episodic memory, intact procedural and primary memory) and KC (Rosenbaum et al., 2004) (impaired episodic memory, intact semantic and procedural memory). Schacter and Tulving (1994) extended the framework to normal cognitive ageing, postulating that the procedural and perceptual stores are left largely intact throughout the process of normal ageing, while episodic memory is worst affected. The semantic memory was seen to be affected in some aspects.

Evidence for this theory in respect to cognitive ageing can be found in a number of studies. Laver and Burke (1993) carried out a meta-analysis on simple word-priming tasks, often used as an analogue for procedural memory ability, and found no effect for age. Studies of primary, or working memory, have found increases in reaction time (i.e. slower responses) for older adults in such tasks as digit-spans, but no general trend for lower ability for recall (e.g. Zanto, Toy & Gazzaley, 2009). Studies of semantic memory take a number of guises, and age-related changes differ according to the form of the task. Vocabulary tests show little difference between young and old groups, although differing methods of examination rendered different strengths in the groups (e.g. Somberg & Salthouse, 1982; Bowles & Salthouse, 2008). However, word-finding decreases and tip-of-the-tongue problems increase with age (e.g. Burke, McKay, Worthley & Wade, 1991) as does name retrieval (Maylor, 1990; James, 2000). Episodic memory problems have been studied using free recall of words and pictures, as well as sentences, stories etc. A pattern of age-related decline in free recall has been heavily linked to problems with episodic memory.

A number of possible reasons for this age-related decline have been postulated. Park and Schwarz (2000) state that the brain is a biological organ, much like the liver and kidneys, and it would be strange if it did not show similar decreases in efficacy over the course of a lifetime to these other organs. Chalfonte and Johnson (1996) found that the ability of participants to bind associative connections among mental events was reduced in older participants, thereby making it more difficult to recall related words or phrases in relation to younger participants. However, it is difficult to determine the causes for these memory declines using behavioural data and cognitive theory alone. As such, neuropsychological evidence in the realm of ageing and memory must be examined.

1.2.2. Neuropsychology of Ageing and Memory

Examinations of changes in memory ability in older participants using imaging techniques have pointed to two major areas in the brain; the Medial Temporal Lobes (MTL) and the Frontal Lobe (FL), especially in prefrontal areas. The MTL consists of a number of anatomically-related structures bilaterally in the sub-cortical portion of the temporal cortices of the brain. The system consists of the hippocampal region (CA1, CA2, CA3 dentate gyrus, and subiculum) as well as the adjacent perirhinal, entorhinal and parahippocampal cortices. The FL takes up the frontal part of the human brain, and is divided from the parietal lobe by the central sulcus and from the temporal lobes by the lateral sulcus. The anatomy of the FL includes the motor cortex and the premotor cortex to the posterior of the lobe, the prefrontal cortex to the anterior of the lobe, and the anterior cingulate cortex in the interior of the cortex, as well as a number of smaller areas (see Figure 1.1).

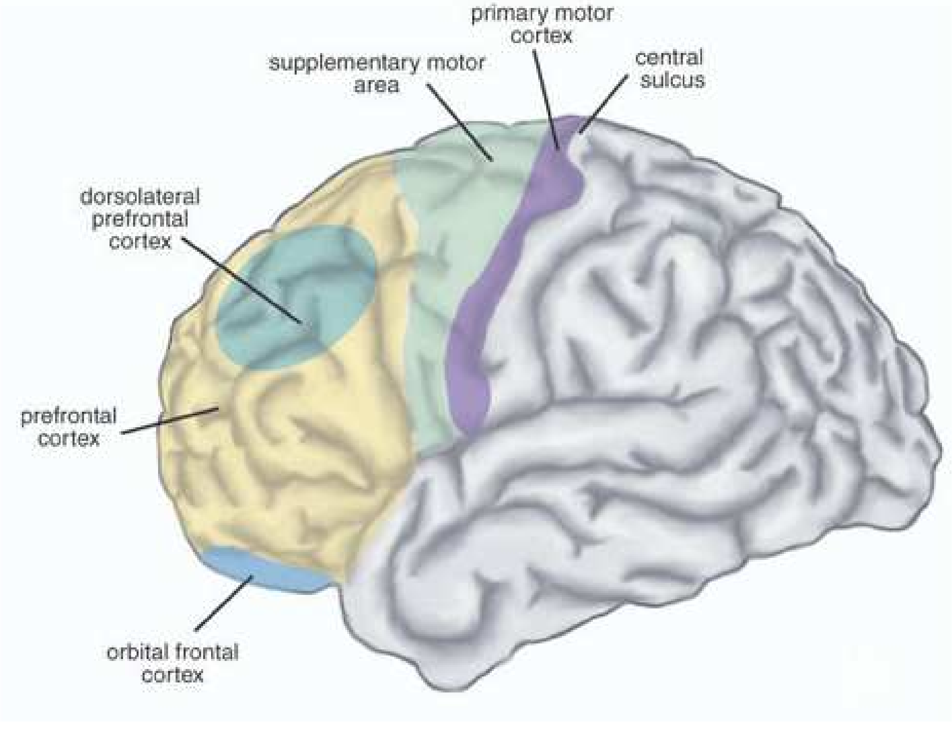


Figure 1.1: *The Anatomy of the Frontal Lobe, showing the outer cortical areas (Anterior Cingulate not shown). From stahlonline.cambridge.org*

Evidence for the deficits in, or changes in, the role of the MTL in memory during ageing comes from imaging, electrophysiological and patient studies. Grady et al. (1995) used PET to examine older participants, finding a significant decrease in right MTL activation during encoding of a face recognition task which was followed by significantly poorer task accuracy for the older group. Lye, Piguet, Grayson, Creasey, Ridley, Bennett and Broe (2004) examined normally ageing patients from 80-95 years old, finding decreased size of MTL and decreases in memory performance across a wide variety of scales. Daselaar, Fleck, Dobbins, Madden and Cabeza (2006) also used fMRI, and found strong links between MTL activity in older adults and accuracy results in a test for recollection and familiarity.

An electroencephalographical study by Chao, Nielsen-Bohlman and Knight (1995) linked an N4 component to MTL structures during an item recognition task featuring a long delay, and found that the lower scores achieved by older adults correlated with a change in the N4 waveform. In terms of patient studies, individuals with greater hippocampal atrophy (identified post-mortem) have scored lower in tests of recall than those with less atrophy in this MTL structure (e.g. Raz et al., 2004). Mori, Yoneda, Yamashita, Hirono, Ikeda and Yamadori (1997) used fMRI with Alzheimer’s patients, finding significant atrophy in MTL structures as well as the expected deficits in recall. Machulda et al. (2003) also reported less activation in the MTL and poorer performance among Alzheimer’s patients than other participants in a recall task.

A number of studies have implicated frontal lobe functioning/deficits with age-related memory changes. Tulving, Kapur, Craik, Moscovitch and Houle (1994), using PET, found that in young adults, large portions of the left frontal lobe showed activation during encoding of a word list, while similar structures on the right side of the cortex showed greater activations during retrieval, an effect which they dubbed Hemispheric Encoding-Retrieval Asymmetry (HERA). This finding led to a number of studies examining older adults to determine if a similar pattern was present. Grady et al. (1995) found similar patterns for the retrieval phase, but a significantly lower level of left frontal lobe activation in older adults during the encoding phase, which was linked to the lower scores achieved. Cabeza et al. (1997) elaborated on these findings, with evidence for bilateral activation at retrieval among an older group, although at a lesser magnitude to that of the younger control group. Again, the old adults scored more poorly. Park and Schwarz (2000) put forward three possible reasons for these changes: firstly, that the left hemisphere activation is a compensatory mechanism to make up for an inability of the right frontal area alone to perform the recall; secondly, that the retrieval processes in older adults is functionally different to that of younger groups, and the differing activations reflect this, and finally, that the left frontal activation may be due to impaired interaction between the hemispheres and acts as a disruptor on recall performance. An fMRI study by Duarte, Henson and Graham (2008) showed lower frontal activations in old groups compared to young controls, even though the old group was designated as "High Functioning".

Electrophysiological studies have also pointed to changes in frontal activations being partly responsible for memory change with age. Lawson, Guo and Jiang (2007) used a repeated priming experiment for recollection, finding that older adults had poorer working memory performance as well as a lower level of frontal scalp electrical activation in comparison to younger adults. Gutchess, Ieuji and Federmeier (2007) compared young and old participants' abilities to recall a scene from memory, finding that recognition levels were unaffected by age, but that the older groups showed lower activations in frontal and parietal areas. Wolk et al. (2008) used EEG to examine age-related changes in item recognition memory, finding that early frontal area activity was markedly lower for the poorer-performing older group. Patients have also been used to examine frontal area deficits in aged populations, particularly those with Specific Memory Impairments (SMI) and Alzheimer’s Disease (AD). For example, Duarte et al. (2006) found severe atrophy in frontal areas for AD patients, accompanied by memory deficits in recall tasks.

These studies point towards a number of important changes in the brain from young to old age, a combination of which seem to reduce the memory ability of participants over a wide variety of tasks related to a number of different forms of memory. While a more comprehensive study of memory would be ideal, it is not possible to cover all aspects. As such, the current thesis will focus on age-related change in one form of memory, in an attempt to understand more fully the effects of ageing on the brain; Source Memory. Source memory has been chosen as it has been identified as one of the earlier forms of memory problem to be associated with cognitive ageing (Jennings & Jacoby, 1997).

1.2 Source Memory

1.3.1 Source Memory and Ageing

Source memory can be defined as the ability to recall the specific context in which an event took place (Glisky, Rubin & Davidson, 2001). This can involve where the event occurred, who was present at the time of the memory being encoded and when the actual encoding happened. As source memory capacity dictates the successful recall of the context in which a piece of information was learned, it is particularly important for day to day recollection of occurrences. Siedlecki, Salthouse and Berish (2005) stated “it may not be meaningful to refer to source memory as a construct distinct from episodic memory”. However, the difference between the two is that episodic memory is a memory for a specific event, whereas source memory is a memory for the processes involved with making a memory, be it episodic or semantic.

Jennings and Jacoby (1997) state that source memory deficits appear to be a better indicator of age-related memory impairment in comparison to failures of other types of memory, such as item memory, as it can be tested without the possible masking effect of *familiarity*. Older adults appear to have more difficulty than young adults when it comes to placing remembered events into the appropriate context with respect to time and place (Jennings & Jacoby, 1997). Since knowledge of source can be critical in the evaluation of ideas, in determining the appropriateness of the path one’s conversation is taking, and in making decisions regarding the quality of products or services being considered for purchase, this can cause problems for older adults. As stated by Dywan, Segalowitz and Webster (1998), source monitoring is generally self-initiated, and must proceed during active discussion or while making decisions. A breakdown in this online monitoring could lead to the kind of errors that may be attributed to either growing egocentrism or declining judgment.

To study source memory and its possible decline with advancing age, a number of behavioral paradigms have been created. These paradigms generally adhere to an Old/New format, where participants are presented with a study list of stimuli followed by a test list composed of studied and new stimuli, with participants then asked whether the test stimuli were presented in the original study list. In the majority of cases, older adults have shown significantly greater numbers of errors in these Old/New tests, a pattern which has been attributed to source capacity deficit (Craik, Morris, Morris & Loewen, 1990; Dywan & Jacoby, 1990; Peters & Daum, 2009). The Famous Names paradigm (e.g. Dywan & Jacoby, 1990) comprises a list of non-famous names in a study phase followed by a test list consisting of famous names, names from the study list and new non-famous names. Participants with low source memory capacity have more difficulty discriminating between the famous names and the previously seen non-famous names. Older adults were less likely than young adults to spontaneously recollect the source of familiarity for previously read non-famous names and were more likely to call old non-famous names famous when subsequently encountered in the test phase. According to Dywan and Jacoby (1990), poor source monitoring by the elderly could not be accounted for by the inability to recognize earlier read non-famous names when specifically asked to do so as they scored similarly to the young group when tested, and concluded that both source-monitoring errors and recognition memory performance were based on attributions made about the experience of familiarity. Bartlett, Strater and Fulton (1991) demonstrated the same effect using famous and non-famous faces in place of names. They concluded that older individuals rely relatively more on perceived familiarity, and relatively less on recollection of context, in making recognition decisions. Howard, Bessette-Symons, Zhang and Hoyer (2006) used pictures for a similar task. The Old/New procedure is therefore acknowledged as a robust method of testing capacity for source memory, having been demonstrated with words, names and pictures.

There is also evidence indicating that older adults are less likely than younger adults to recollect the modality in which successfully recalled words were originally presented. This is generally examined through the use of two study lists, one of written words and one of spoken. Words will then be provided in a test list and participants are asked to decide if they were originally heard or read. Peters and Daum (2009) paired words with a sound, a picture of a face or a picture of a scene and requested old/new decisions from participants, finding that older participants scored lower at the test phase. A number of earlier studies (Lehman & Mellinger, 1984; Light, La Voie, Valencia-Laver, Albertson-Owens & Mead, 1992) have also found that older adults score significantly lower than younger adults. Older groups have also been found to be less likely to remember the order of recalled events using a simple listing test (Kausler & Wiley, 1990). Fabiani and Friedman (1995) studied both young and older participants with trials testing memory for recognition memory and temporal order (Recency Memory) that were presented randomly with study trials. They found dissociations between recency and recognition memory performance for pictorial stimuli in older participants. Older adults performed at chance on recency memory trials whereas they were not impaired on recognition memory relative to younger adults.

Spatial source memory has also been examined, with older adults less likely to recall the original position of otherwise successfully recalled pictures (Zelinski & Light, 1988) or the current spatial location of objects that had been recalled from a list of items (Puglisi, Park, Smith & Hill, 1985). Henkel et al. (1998) found that relative to younger adults, older adults are more adversely influenced by similar items when judging the source of a memory, and the phenomenal features of their correctly and incorrectly attributed memories have a greater overlap than a younger sample group. Even when the recognition of specific information is reasonably good in older adults, they are more likely than younger adults to make errors when attempting to identify which of two speakers initially presented the to-be remembered information (Bayen & Murnane, 1996).

These tests reveal a general pattern of age-related source memory decline, when seen as a body of evidence. Jennings and Jacoby (1997) suggest that the finding of older adults scoring significantly lower than younger adults in memory tasks is not attributable to a failure to understand the task. Therefore, it could be concluded that lower source memory recall accuracy, or a deficit in source memory recollection, could be the reason for these lower scores.

1.3.2 The Opposition Task and Ageing

One specific task used to tax source memory is the Opposition Task (Jennings & Jacoby, 1997), so called as it places two memory processes in opposition with each other in order to examine the effects of their interference, much like Old/New paradigms. Familiarity and recollection are put into opposition through a simple process. However, it differs from the well-documented Old/New paradigm in an important way. A study phase occurs first, where a number of words are presented to the participant. Following this study list, a test phase takes place where words from the study phase and new foil words are presented, and participants must determine whether the word is from the study list or is a new word. Where this test differs from the standard Old/New paradigm is in the presentations of words during the test phase. Words from test list, known as distractors or foils, are repeated during the test phase at differing intervals, known as lags. Lags vary between studies, from a lag of 0, meaning that the word is presented a second time directly following the first presentation, up to a gap of 48 words between presentations of the target, with different lag layouts having been studied. Source memory capacity can be measured by the participants' ability to discriminate between re-presented foil words and target (studied) words. The assumption involved in such a design is that the first presentation of these new items should increase their familiarity (Fischler & Juola, 1971; Underwood & Freund, 1970), and participants may misattribute this familiarity to having seen the word in the study phase, confuse repetitions with old words, and mistakenly respond that the second presentation of a new word is in fact a word from the study list. However, if participants can recollect the source of a word's initial presentation (study vs. test) or recollect that they have already responded to a word, then any influence of familiarity is opposed, and participants will correctly respond that the word was not on the study list.

Since the original design of the paradigm, a number of studies have been completed to examine source memory using the Opposition Task or similar procedures. The original Jennings and Jacoby (1997) study was divided into 2 separate examinations. The first experiment involved lags of 4, 12, 24 and 48 words, while the second involved lags of 0, 1, 3 and 7 words. In both cases, young participants were compared to older participants. The older group scored lower in accuracy to the younger group in the two experiments, even at the short lag conditions. Dywan, Segalowitz and Webster (1998) and Dywan, Segalowitz and Arsenault (2002) used a lagged task to examine source deficits in repeated words, with participants being asked to read study words aloud and to attend to them for recognition later in the experiment. Mathewson, Dywan and Segalowitz (2005) used an opposition procedure as part of a battery of tests to examine source memory-related differences in the ERP results of young and old adults. Again, lagged words showed lower accuracy scores in both groups, and the older group showed less accuracy and longer RTs than the young group. Bridson, Fraser, Herron and Wilding (2006) examined recognition for studied words using an opposition procedure with a lag of 7-9 words versus original presentations. The experiment achieved similar results to others, with less accuracy being shown for the lagged words.

While a number of Opposition Task based studies have been conducted, there is by no means a large body of literature on the subject. The effect of different lag lengths on performance has not been examined in detail, nor has the effect of any possible interval between the study and test lists been tested, unlike the Old/New paradigms. The use of the first presentation of words prior to the lag presentation is to familiarize the participant with the word to place it in opposition to test list words. Since the original design it has not been determined if increasingly long lags continue to show decreases in performance or if a plateau or floor is reached at a certain lag length. The effect on increased inter-phase intervals, meaning the gap between the original study phase and subsequent test phase, has not been examined, despite the possibility that this could detrimentally affect recall of original target words. Also, the use of specific learning strategies has been examined in Old/New tasks, including Wegesin, Jacobs, Zubin, Ventura & Stern (2000), finding some increases in the performance of older adults. A similar study using the lag-based opposition procedure has not been carried out. Results from these forms of examinations could increase the efficacy of the task in future studies, and such variations constitute an aim of the current thesis.

1.4 Neural Correlates of Source Memory

1.4.1 ERPs and Old/New tasks

Any study on the neural correlates of source memory retrieval should consider the ERPs associated with simple Old/New studies, due to the similarities that exist between the methods. This *Old/New effect* has been linked to recognition studies, and is characterised by greater frontal positivity when items are correctly recalled in comparison to incorrect recollection (Wilding, Doyle & Rugg, 1995). This frontal positivity is a key part of source memory recollection according to a number of ERP studies in the area. Wilding & Rugg (1996) found greater positivity for correctly recognized words in a word recognition source task at both frontal and parietal sites. The effect began between 400ms and 500ms post-stimulus. In the frontal areas, this positivity continued for the duration of the epoch, while the parietal sites showed positivity from 500ms to 800ms. Interestingly, the parietal site showed this pattern for correctly recognized target and non-target words, particularly in left parietal areas, while only correctly identified target words elicited the reaction in frontal areas, with a noticeable right frontal bias. In a later study by the same authors (Wilding & Rugg, 1997), this effect was again demonstrated using words that were spoken aloud by participants or heard by participants during the study phase. Despite the difference in the presentation modality, a similar waveform was elicited, although the frontal component was further divided into an early and late positivity. The authors linked the parietal positivity to long-term memory retrieval, while concluding that the frontal positivity is linked to task-dependent processing specific to retrieved information, as only correct targets showed positivity in the region.

More recently, Hayama, Johnson and Rugg (2008) found that the frontal Old/New effect is present regardless of the semantic attributes of a test, or of the depth of processing needed to correctly respond. Osorio, Ballesteros, Fay and Pouthas (2009) found a decrease in amplitude and length in frontal Old/New activation among older adults as well as a later onset of parietal activity during an explicit memory task, in both shallow and deep semantic groups. These results match with the theories put forward by both Squire, Knowlton & Musen (1993) and Moscovitch (1994), who label long-term memory retrieval as one of two distinct processes underlying memory for source. Wilding & Rugg (1998) concluded from their collated evidence that the recollective processes used to make inclusion or exclusion judgments (target vs. non-target words) may be two dissociable processes, as the right frontal positivity was only found in inclusion judgments, and also that the parietal and frontal positivities may be neural correlates of a further two dissociable memory processes.

1.4.2 ERPs and the Opposition Task

This Opposition Task format has been used by a number of researchers to examine source memory capacity, especially among older participants. Dywan, Segalowitz & Webster (1998) used the task in conjunction with a divided attention task to collect ERP data for younger and older adults. They found that younger adults were less likely than older adults to make source monitoring errors and that the younger adult ERPs showed more discrimination between target stimuli and non-targets. Along with making more source error judgments, ERP results showed that older adults produced late positivities to the non-targets even when they were rejected correctly. In a follow-up study, Dywan, Segalowitz, Webster, Hendry and Harding (2001) used a similar design (this time to examine new word repetitions) and found that the younger population was less likely to make source errors, as was found in the previous study. Electrophysiologically, correct trial ERPs indicated that the younger group produced late positivities of greatest amplitude in response to whichever word type was designated as a target, whether it was familiar or not. Older adults had generally more similar ERPs across conditions and showed higher late positive deflections for recently repeated words irrespective of their designation; either target or foil. Dywan, Segalowitz and Arsenault (2002) showed changes in electrophysiology between a young and old group using a single lag procedure, showing significantly more late positive activity in frontal and parietal electrodes for the younger group. Mathewson, Dywan and Segalowitz (2005) found response conflict error-related negativity (ERN) was higher among older groups than younger groups during source memory retrieval. Bridson, Fraser, Herron & Wilding (2006) studied a homogenous group of participants using a single lag randomized between 7 and 9 words through the trials. The results showed that ERPs elicited by misses were reliably more positive-going than those elicited by correct rejections.

Functional MRI studies have also shown that the prefrontal area is less active during source memory procedures in older adults (Dennis, Hayes, Prince, Madden, Huettel & Cabeza, 2008). Also, Czernochowski, Fabiani and Friedman (2007) reported that older adults with higher socio-economic status (SES) can use strategies to compensate for the adverse effects of aging in complex source memory tasks by recruiting additional neural resources apparently not required by the young. These results seem to show changes in source retrieval-related neural activity attributable to aging and also to the accuracy of the response.

The overall findings with respect to source memory and Opposition-based tasks in terms of ERPs implicate the frontal and parietal lobes in the majority of cases, with increased frontal P600 amplitudes being found in response to any correctly recalled information in comparison to incorrectly recalled information. Positive parietal activity seems to be earlier, with latencies from 400-500 ms being reported. Studies have also reported earlier frontal positive deflections. When comparing younger and older groups, it seems that the older group has less frontal activity during source retrieval, but similar levels of parietal activity. This may be indicative of the use of different mechanisms by older adults to process source information, as mentioned by Swick et al. (2006), although this has not been pursued in the literature.

1.4.3 Brain areas associated with source memory retrieval

While the previous sections have suggested that source memory is associated with frontal and parietal areas, as well as the MTL, Wilding & Rugg (1998) examined where the neural generators of the scalp components might occur. In terms of the frontal activity, they cited Stuss, Eskes and Foster (1994), who described how prefrontal damage greatly impaired source memory capacity, and also PET studies, including Fletcher et al. (1996) and Fletcher, Frith & Rugg (1997), who found right anterior and dorsolateral prefrontal cortex activity for episodic memory, using source-memory like Old/New recognition tasks. The activity located at parietal scalp electrodes was proposed to be linked to activation of the medial temporal lobe, especially the left hippocampal area. Gold, Smith, Bayley, Shrager, Brewer, Stark, Hopkins and Squire (2006) have also implicated the hippocampal region, along with the perirhinal cortex and parahippocampal cortex in the prediction of source memory success using a source task and fMRI with brain injured patients, indicating that the temporal lobe has a part to play in source processing.

Ragland et al. (2006) found prefrontal and parietal activations in healthy controls during an fMRI source memory task, and also found these activations in schizophrenic patients for correct responses. Lundstrom et al. (2005) also found frontal activations, this time in the left inferior prefrontal cortex, and found strong activations in the posterior precuneus of the parietal lobe for source memory based trials. Uncapher, Otten and Rugg (2006) used a complex source memory procedure involving colour and location recall and found that the parietal area, particularly the intra-parietal sulcus (IPS), was the only area to show activity for responses which were correct for all details. These findings show a high level of correlation between ERP and neuroimaging results, as well as implicating the hippocampus, which, given its subcortical location, proves difficult (though not impossible) to examine with ERPs. The hippocampus has been strongly linked to memory encoding, storage and retrieval (see Moscovitch et al, 2005, for a detailed analysis of the importance of the hippocampus to memory). These repeated findings give a measure of support to the ERP findings in source memory tasks, in particular the Opposition Task, which is the focus of this thesis. In sum, imaging and electrophysiological evidence posit the role of a number of critical structures that seem to be involved in source memory recall, including the PFC, areas of the parietal lobe and the areas of the MTL, particularly the hippocampus (see Figure 1.2).

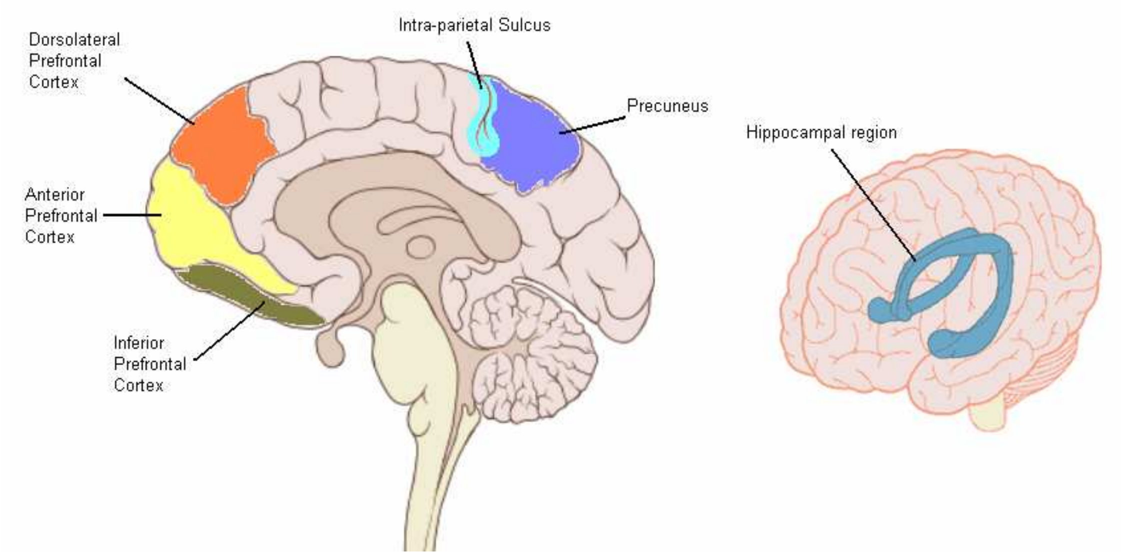


Figure 1.2: *Diagrams of the brain showing the areas found to be associated with source memory recall from fMRI and PET data. Adapted from www.brainconnection.com.*

1.5 Aims of the Thesis

The overall aim of the thesis is to examine the neural basis of source memory and in particular to identify the neural markers associated with source memory in an aged population. These aims will be achieved through a series of experiments that will employ electrophysiological techniques in conjunction with the behavioural data from a source memory task. To do so, a computer-based Opposition Procedure is used, as described in detail in Chapter 2. Recording from scalp electrodes for EEG data and subsequent averaging of data into ERPs, and further into dipole source locations, are used to examine the neural correlates of the processes involved in the task. Young, middle-aged and old participants are examined, as well as the procedure of the task itself, and the interaction of learning strategies and source memory retrieval ability.

In an initial set of experiments (Chapter 3) we aim to take the Opposition Task as created by Jennings and Jacoby (1997), and examine a number of behavioural properties of the task in a sample of healthy young adults. Such properties include the effect of differing lag lengths and the effect of the elapsed interval between the presentation of the study and test portions of the task. Earlier attempts at using the Opposition Task since its inception have not examined in detail the task itself. Having established a basic, working paradigm and behavioural procedure for this Opposition Task, specifically created to be used with young and old groups and with high-density ERP recording, we attempt in Chapter 4 to identify neural changes that are associated with the differing lag lengths by examining ERPs associated with the different lags in a healthy group of young adults. This provides a greater understanding of the neural correlates of the lag-based deficits seen in the task. We expect to find a higher level of frontal scalp-area activity for the longer lag lengths over the shorter length, as reported by Dywan, Segalowitz and Webster (1998) and others. The introduction of a second lag length will examine if ERP data changes due to length of lag, or if the introduction in any lag changes the pattern of ERPs similarly. Also, the use of dipole source modeling will add further depth to the analysis of the lagged data.

Chapter 5 builds on the previous chapters and expands on them by applying the task to a number of different age-groups. We compare source memory deficits in three age-groups; a group of young adults from 20-30 years old, a group of middle-aged adults from 40-50 years old, and a group of older adults from 60-70 years old. Previous studies have examined the behavioural differences in source memory deficits between young and old adults, and our addition of a middle-aged group will allow us to examine whether these deficits occur gradually through the normal ageing process, or if they are a feature of only the older age group. Having established that these deficits in source memory seem to be linked to the old group only, we then examine the neural correlates of these deficits. This is carried out in Chapter 6, which compares young and old groups in an ERP-based study using the Opposition Task to examine both between and within-group differences. The experiment involves a group of young (20-30yrs) and old (60-70yrs) participants completing the task while EEG is recorded on a 128-channel system. Previous studies have examined differences between similar groups; however generally a single lag-length is used, and they have not used the high-density ERP results to describe possible neural generators of the scalp topographies.

In the final set of experiments, (Chapter 7) we attempt to attenuate the source memory deficits shown by young and old participants, through the use of instructions for participants to place words in sentences during the study phase. As Craik and Lockhart (1972) showed, this increasing of the depth at which participants study the original list of words should lead to increased accuracy at recall. However, this has not previously been examined in conjunction with the use of lagged words in a task designed to show deficits in memory. We use the Opposition Task to examine whether a simple change in instructions to participants will significantly increase their capacity to recall items from the study list, regardless of the lag of the word. Positive results in this final experiment allow for the creation of a body of research based on any improvements in memory, in an attempt to show the possibility of alleviating deficits using simple tasks. The thesis therefore examines the Opposition Task and its uses, in relation to behavioural and ERP results, as well as using it to examine areas as yet unstudied, such as the changes through middle age in source memory capacity, and the effect of a change in instruction on accuracy. The use of more than a single lag, high-density ERP results and dipole modeling adds to the literature, attempting to link specific brain areas with both source memory capacity and deficits therein.

Chapter 2

Methods

Part of this chapter has been published as: Scanlon, Commins and Roche (2006).

High Density Event-Related Potentials: Current Theories and Practice,

The Irish Psychologist, 33:1, p5-8

Preamble

This chapter will discuss the methods used for the duration of the thesis, including the creation and procedure of the Opposition Task used, a description of the Cognitive Failures Questionnaire (CFQ) which is used to examine the everyday memory of participants and the electrophysiological set-up used to record the scalp EEGs from participants during the relevant chapters. Also included is a brief history of the area of electroencephalography as well as an examination of the pros and cons of the technique. The physiology is also described along with the major components studied by neuropsychologists. Finally, the chapter discusses the use of dipole models and their uses in examining the neural underpinnings of scalp-recorded ERPs.

2.1 The Opposition Task

2.1.1 Programming of the task

The task used for the study was the Opposition Task developed by Jennings and Jacoby (1997). The task was created using the E-Prime experimental presentation program and the Visual Basic (VB) program. This allowed for the creation of a task that could accurately measure source memory recall in the most simple way possible.

E-Prime (Psychology Software Tools Inc., USA) is regarded as one of the more powerful and flexible experiment generators available. Consisting of a number of applications, it allows the generation of experiments and data collection precise to the millisecond through data handling and processing. With user-defined experimental procedures, E-Studio employs a graphical user interface (GUI) that lets the researcher ‘drag-and-drop’ text and pictures into their experiment with fully programmable stimulus onset times, duration, presentation order (e.g. sequential, random), response criteria and continuous pre-specified data logging. Combined with a VB-created lag algorithm program to allow for a random presentation of lagged stimuli, this software created a modified version of the Opposition Task that could be changed to allow for differing conditions with a minimum of effort or programming.

2.1.2 Procedure of the task

The Opposition Task (described in more detail below) is a flexible task which can be altered to suit the demands of the study. Experimenters have used a variety of lag lengths and inter-phase intervals to examine source memory. There is neither agreement as to which lags give optimal results, nor to the effect of the time between studying and recall of the words. As such, the first experiment in the thesis will examine a number of lag lengths and inter-phase intervals to gauge their relative effects. The results found will be used to create a procedure tailored to the specific demands of the current thesis.

For all studies, the word lists were chosen from the Toronto Noun Pool (Friendly, Franklin, Hoffman & Rubin, 1982), and were matched for length (5-7 letters), as well as being matched for imageability, frequency and concreteness (see Appendix I for examples of words used). Words were presented in white Arial Bold 36pt script on a black background for ease of reading and clarity (see Fig 2.1). For the study block, stimuli were presented for 2000ms, with a 500ms intertrial interval. For the test block, words were presented on screen until a response was recorded, with a 500ms intertrial interval. Participants were told that if a word from the study list was presented during the following test list, the “S” key on the keyboard should be pressed. If the presented word was new, (i.e. not shown on the study list) the “N” key on the keyboard should be pressed. These keys were marked with coloured stickers on the keyboard to facilitate reactions, especially among the older groups. In order to test for source memory capacity, the test lists used were manipulated. Words from the study list (Targets) and new words (Distractors or Foils) were repeated throughout the test list at a number of differing lags following the first presentation dependent on the specific study (see Fig 2.2). Those participants with a lower source memory capacity tend to mistake more repeated new words for study list words than those with better capacity for source memory; that is they assign to the word an incorrect source (Jennings & Jacoby, 1997).

Prior to testing, all participants were briefed and informed that they would be taking part in a simple study of recall. The experiment took place in a 9x9ft cubicle located in the Department of Psychology in NUI Maynooth. Experiments were completed on a Dell Optiplex GX 280, located approximately 1 metre from the participant. Participants were allowed short breaks between phases and told that they could withdraw at any time, as well as being asked to sign an Informed Consent Form (See Appendix II). The instructions given to participants were kept as simple as possible in order to minimize confusion among participants. The beginning of the experiment was an instructions screen, laid out as follows:

For the first task, words will be presented one at a time at an even pace. Your task will be to read each word in the list aloud and to try to remember it using whatever strategy you think will help you. Then, after the study list, we will test your memory for the words you just saw.
If you have any questions, please ask the experimenter now.

Following the study phase, the following instructions were given to all participants:

The next part of this experiment involves a memory test. We are going to show you a long list of words, some of which will be words that were on the study list that you just saw and some will be new words that weren't on the study list. Your job will be to decide which words were on the study list and which words are new. If you think a word was on the list, press the "S" key (for "studied"); if you think a word is new, press the "N" key. Take as much time as you need to make your responses.

< Press the SPACE BAR to continue >

This was followed by a second instruction screen, with further details on the procedure:

> **What makes this test tricky is that sometimes words from the earlier study list will be presented more than once during the test, and sometimes words that were not on the study list will also appear more than once. It doesn't matter how often a word is presented during the test. This does not change your task. Every time you see a word that you studied, you are to press the "S" key and every time you see a word that was not on the study list, press the "N" key.**
>
> **If you have any questions, please ask the experimenter now.**

Following this, all participants were debriefed and asked if there were any further questions, then thanked. Due to the age of some participants, care was taken to ensure that they left the department safely and could make their way home from there.

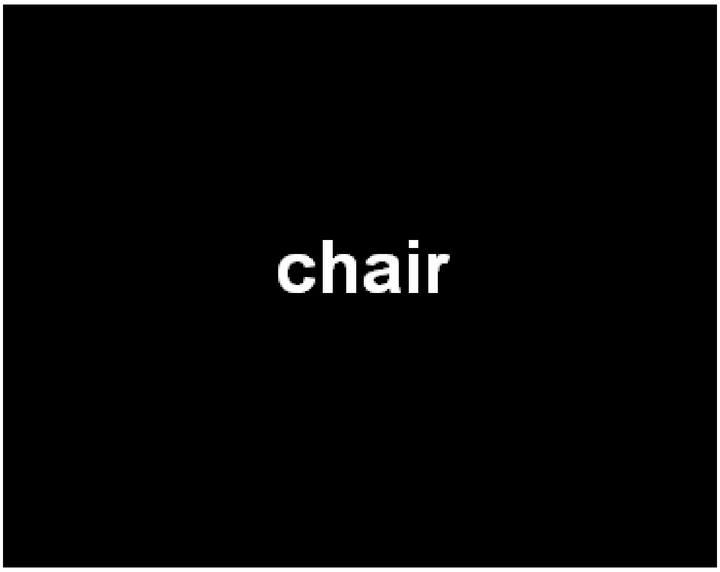


Figure 2.1: *Example of the view of a participant during the study and test blocks of the procedure.*

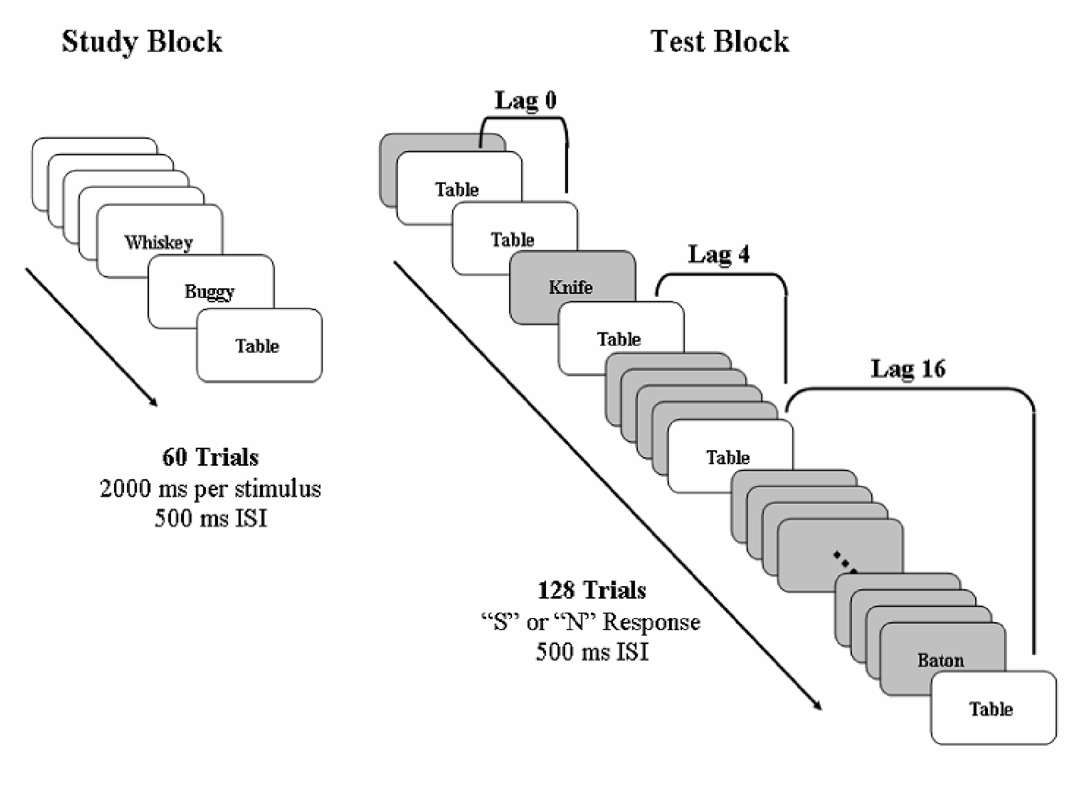


Figure 2.2: *Graphical representation of the Opposition procedure used, showing the study block and the use of lag lengths of 0, 4 and 16 in the test block.*

2.1.3 Analysis of scores

Correct responses and reaction times were both recorded during the test phase of the experiment. A correct response occurred when the participant pressed "S" when a word from the study list was presented and pressed "N" when a new word was presented. Reaction times were measured as the interval between presentation of the stimulus and the response. Reaction times were recorded for both correct and incorrect trials. For the purposes of the study, all correct responses to target words shall be referred to as *Hits*, incorrect responses to target words will be referred to as *Misses*, correct responses to distractor words will be referred to as *Correct Rejections,* and incorrect responses to distractor words will be referred to as *False Alarms*, in line with the terms used by Jennings and Jacoby (1997). Generally, participants were also asked to complete the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper & Fitzgerald, 1982; See Appendix III) to examine their everyday lapses in memory.

2.2 The Cognitive Failures Questionnaire

A common method used for examining everyday memory capacity is the Cognitive Failures Questionnaire. The CFQ was developed by Broadbent, Cooper and Fitzgerald (1982) as a simple measure of self-reported failures in memory, perception and motor function. Cognitive failure can be defined as a person's failure to complete a task that he/she is normally capable of completing (Wallace, Kass & Stanny, 2002). Several common examples of cognitive failure have been presented over the years such as putting flour in coffee in place of sugar, or throwing away an item that was meant to be kept and retaining the undesired item. While such errors can often be seen as trivial, other more serious errors can also occur under relatively simple and familiar conditions (e.g., turning the wrong way on a one-way street).

The CFQ consists of 25 short questions ranging from lapses in attention (e.g. Do you read something and find you haven't been thinking about it and must read it again?) and memory lapses (Do you leave important letters unanswered for days?) to gross motor function problems (Do you bump into people?), based on the last six months of the participant's life. Studies have found that participants with high scores on the test, i.e. a self report of poor memory, are particularly aware of their propensity to make errors and, in task situations when external demands are high, self-focusing could impair performance (Stratta, Daneluzzo, Rinaldi, Gianfelice & Rossi, 2003). The use of this questionnaire in the thesis is to ensure that the general cognitive abilities of participants is within certain boundaries, without using a complicated battery of memory and cognition examinations. All participants were asked to complete a CFQ prior to taking part in experiments.

2.3 Electrophysiology

2.3.1 Brief History of Electrophysiology

Electrophysiology involves studying the electrical changes and currents generated by biological cells and what is signified by these changes in current. These voltage changes may be examined externally or internally, depending on the area of interest of the researchers and the nature of the participants. The use of single-cell recording and invasive intra-cortical recording through the means of depth electrodes, known as Electrocorticography (ECoG), is common in the study of the neurophysiology of animals and occasionally in human patients. However, the invasive nature of these procedures means that their use on humans is rare, although excellent spatial data is available due to the precise nature of the method. These ethical problems, along with the surgical skills needed to carry out the procedure, mean that the preferred method for examining electrophysiological data in humans is by scalp-recorded electrodes, through the process of electroencephalography (EEG). EEG as a method involves the use of scalp-based electrodes arrayed over the head of the participant which measure voltage changes from the brain through the meninges, skull and scalp. This allows them to operate over a larger area than ECoG, which decreases the precision, but increases the versatility of the method.

Caton (1875) first described the electrical responses evoked from animal brains, using monkeys and rabbits. EEG studies became popular, with Beck (1890) using the method to examine the responses of animals to sensory stimuli, and Berger (1929) publishing his findings of recording on human participants, in which he first used the phrase electroencephalogram, which is now widely known as EEG. Since these early works, a number of advances have occurred in the field of electrophysiology, allowing for more accurate and reliable methods of studying the changes in electrical charges in human participants. Perhaps the most useful of these has been the development of a procedure to examine short periods of EEG data which were recorded in response to certain stimuli, known as Evoked Potentials (EPs).

Dawson (1954) began averaging large numbers of these EPs to increase the signal-to-noise ratio, thereby reducing the amount of conflicting data being recorded for each response. The averaging procedure allowed for the most prominent and reliable voltage changes to be examined clearly, without the “noise” of occasional, possibly unrelated, voltage changes from single trials. Dawson is therefore credited with creating the study of Event-Related Potentials (ERPs), the use of which is still widespread today, and with which this thesis deals directly. ERPs are calculated through the averaging of a large number of epochs in a recorded EEG which are specifically time-locked to the occurrence of an experimental event, generally either the presentation of a stimulus or the response to a certain stimulus (Handy, 2005). An epoch is the timeframe in which a response to a stimulus occurs, with the ERPs measured according to either the stimulus

(stimulus-locked) or the response given (response-locked). These ERP “waveforms” are plotted by voltage in the Y-axis, in microvolts (µV), and over time in the X-axis, in milliseconds (ms). This allows for the creation of a detailed account of neural stimulation induced by the repetition of a certain stimulus or response. The more repetitions used, the higher the ratio of useful signals to background noise. As Handy (2005) states, the components involved among the majority of the individual epochs will be shown more profoundly in the averaged ERP.

ERPs have been used to study a vast number of cognitive processes, from simple attention tasks (Dockree, Kelly, Robertson, Reilly & Foxe, 2005), through to so-called higher cognitive functions, including language (Démonet, Thierry & Cardebat, 2005), learning (Roche & O’Mara, 2003) and, importantly, memory (e.g. Dywan, Segalowitz & Webster, 1998). The simplicity of the procedure, along with a number of other benefits, has allowed ERP study to become one of the most widespread methods of examining the brain during cognitive processing.

2.3.2 Physiology of ERPs

EEG and ERPs measure the electrical activity produced by the brain through the summated activity of the currents produced post-synaptically. The Central Nervous System (CNS), including the brain, communicates through the constant transmission of electrochemical signals between the nerve cells which make it up, known as neurons (See Figure 2.3). Each signal sent by a neuron will either inhibit or excite the connecting neurons as messages are passed across the synaptic cleft from the axon in the presynaptic (signalling) cell to the dendrites or cell body of the post-synaptic (receiving) cell, via the release of a variety of neurotransmitters.

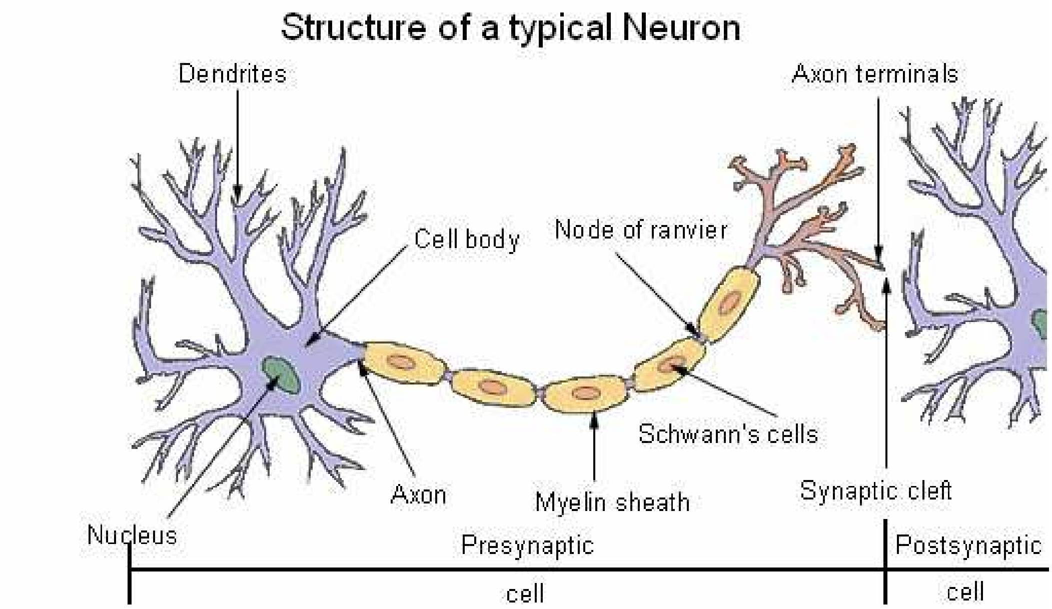


Figure 2.3: *The anatomical structure of a typical neuronal cell, showing connectivity of neurons in the brain and the neural communication pathway. Adapted from www.Web-books.com/physiology/Nervous*

When a neuron is not in the process of sending or receiving transmissions, it has a negative charge of ~-70 millivolts (mV) relative to the charge of the surrounding tissue. This status of equilibrium is referred to as the *resting potential* of the cell. This is due to the presence of charged particles across the cell membrane: sodium ions (Na+), chloride ions (Cl-), potassium ions (K+) and protein anions (A-). The negative charge produced by the anions is largely balanced by the presence of the potassium ions. It is the occurrence of deviations in the amount of chloride and potassium that gives rise to the possibility of the cell generating an excitatory post-synaptic potential, or EPSP. If the flow of ions in a cell is changed due to stimulation of the cell by electricity, sodium ions flow into the cell membrane, causing a rise in voltage of the cell by up to 100mV, to a threshold of ~+30mV. Following this, potassium ions flow in and then out of the cell, rapidly exciting then repolarising the membrane. This change in voltage causes an *action potential,* releasing neurotransmitters across the synaptic cleft, to begin the process in adjoining neurons (Kolb & Whishaw, 2003; see Figure 2.4). If the ion flow results in a decrease in voltage, from an inhibitory post-synaptic potential (IPSP), *hyperpolarisation* can occur, making it less likely that the cell will create an action potential, thereby inhibiting any further neurons from firing. Summed changes in polarisation across large numbers of cells are measured by EEG equipment, rather than merely action potentials.

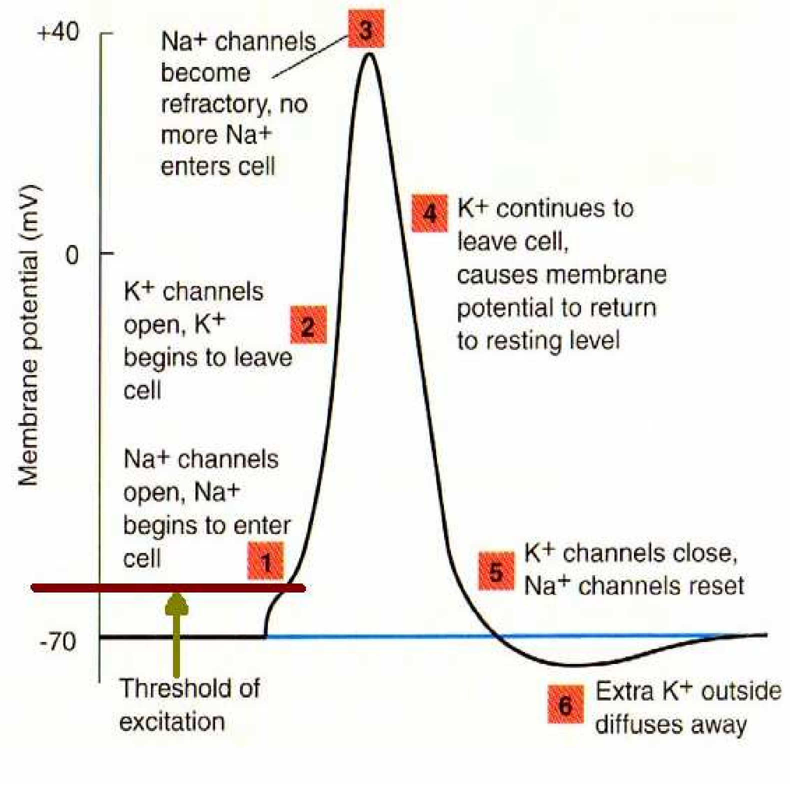


Figure 2.4: *The processes involved with the firing of an action potential from the resting potential in a nerve cell. Adapted from gregalo.com.*

The complex working of the CNS also causes the creation of two important phenomena, known as *sinks* and *sources*. A sink occurs when an EPSP is in progress. This process involves an influx of positive ions into the cell, thereby moving the voltage of the cell closer to 0mV. This reduces the positivity of the surrounding extracellular space, creating a sink, which can be seen as a negative source. This influx of ions into one area of the neuron is balanced through an outflow in another area, removed from the EPSP, causing a positive source in the area surrounding this outflow as the ions are released. IPSPs cause an opposing situation, with a positive source around the hyperpolarised area and a negative sink elsewhere in the neuron from the intake of ions necessary for equilibrium. Due to the co-occurrence of sources and sinks in each cell, a neuron can be described as a dipole; causing simultaneous positive and negative electrical activity (See Nunez & Srinivasan, 2006, for a detailed overview).

EEG and ERPs record the overall occurrences of sinks and sources from thousands of neurons with similar spatial orientation, radial to the scalp (Otten & Rugg, 2001). This means that tangential currents are not picked up by EEG, which precludes the ability to examine deep sources, particularly sub-cortically, using the method. The configuration of EEG recorders means that the majority of recordings are from pyramidal cell populations which form the cortical surface in grey matter areas. The constant firing of these cells disallows single-cellular accuracy, and instead EEG records *single dipole sources* from areas of the cortex less than 1cm^2, or from *homogenous dipole layers*, which occur when a large number of dipoles in a general area of the outer cortex fire synchronously, as all their positive terminals, or sources, are adjacent to other positive sources. However, due to the nature of the cortex, these dipole layers are rarely homogenous, instead being formed of both positive and negative dipoles, in which case the potential recorded by the EEG will be a reflection of the majority polarity, be it positive or negative.

Animal studies (e.g. Kramer & Szeri, 2004) have found that the polarity of ERP recordings are related to either excitation or inhibition in neurons by co-recording scalp EEG and intracranial ECoG. These studies have shown that the firing of cortical cells seem to result in negative components in ERP recordings, while cortical cellular inhibiting seems to result in the recording of positive potentials. So at a cortical level, an EPSP is positive, it elicits a negative recording on the scalp, and negatively-charged IPSPs result in a positive recording from EEG. Coenen (1995) links this to the sinks and sources explanation, claiming that sinks at the firing sites cause extracellular surface sources, and that sources at the firing sites cause extracellular surface sinks.

2.3.3 Spatial and Temporal Resolution

Any tool used in the field of cognitive Neuropsychology can be assessed for its performance in two important areas; *temporal resolution* and *spatial resolution*. Temporal resolution is the accuracy in terms of timeframe that a recording method can achieve, with a good method allowing almost instant recording in sequence. Spatial resolution is the accuracy with which a method can pinpoint the area in the cortex being used during a recording (Kolb & Whishaw, 2003).

There are numerous techniques used in the recording of brain activity in humans during cognitive tasks, all of which vary in their spatial and temporal resolution. In terms of spatial resolution, functional Magnetic Resonance Imaging (fMRI) and Positron

Emmision Tomography (PET) stand out as the most accurate forms of equipment. Both of these methods involve the recording of increases in regional cerebral blood flow (rCBF), which can be described as the changes in blood flow around the brain to allow for maximum oxygen demands to be met in the brain areas being recruited for a task. PET measures this through the invasive injection of a radioactive compound which can be read by the equipment, while fMRI, a more recent invention, is non-invasive, instead recording changes in the magnetic orientation of haemoglobin using a powerful electromagnet. Both these techniques give a high level of spatial resolution, with 3-dimensional images with millimetre accuracy created from the data. These spatially-precise data come at the cost of a reduction in temporal resolution, as studies are often forced into a blocked design, rather than an event-related design, meaning that real-time recording is impossible. The speed at which blood flows through the brain also impacts on the temporal resolution, especially when compared to electrical impulses.

ERPs have excellent temporal resolution. Voltage changes in the cortex pass through the meninges, skull and scalp in milliseconds, allowing ERPs to be created based closely on the presentation of a stimulus. This almost instantaneous transfer of information allows for ERPs to be elicited within milliseconds of the processes being initiated. However, as for spatial resolution in fMRI and PET, this excellent temporal resolution comes with the price of poor spatial resolution, due to the interference of the intervening layers of tissue. Electrodes on the scalp record data from sources within the brain, which travel through the cortex, the meninges, the skull, the scalp and possibly hair on the way to being recorded. All of these layers cause deflections and dispersions of the electrical charge, resulting in a recorded ERP that may have originated from any point within the brain, regardless of where on the scalp the voltage changes are measured. However, the brain is essentially a volume conductor, meaning that any potential recorded on the scalp should be able to be traced back to its source within the cortex or even sub-cortex, as long as researchers are provided with the conductive or resistive properties of the layers and media involved. This is despite the inhomogeneity of the areas in terms of conduction and restriction of the potentials.

Two innovations in the field of neuroimaging that are becoming more widespread are Magnetoencephalography (MEG) and Transcranial Magnetic Stimulation (TMS). MEG involves measuring the electromagnetic fields which occur when neurons fire. The temporal resolution is similar to that of EEG given that the fields pass through the cortex and skull at much the same speed as electrical impulses, although the method records from tangentially rather than radially oriented sources. The intervening layers have less of an impact on the spatial resolution for MEG, allowing for greater accuracy in the pinpointing of neural generators (Cohen, 1972). However, the cost and time consumption involved with MEG restricts its use as a tool for research. TMS involves using a magnetic field generated on the surface of the scalp to cause a firing of all neurons underlying the area in the cortex. This acts as a temporary lesion, effectively allowing the area to be discounted from concurrent tasks. The centimetre level spatial resolution is quite high, although not on the level of fMRI, and the temporal resolution is near instant (Nunez & Srinivasan, 2006). The most exciting aspect of this procedure is the *functional resolution*, in that it can be used to transiently inhibit activity in areas necessary for a certain task to be performed from firing, rather than those merely correlated to the task (Walsh & Pascual-Leone, 2003).

2.3.4 Components of ERPs

Components are parts of the ERP waveforms that are of interest to the experimenter. They are generally a sustained peak or trough in the data that remains reliable over a large number of trials and can be replicated from study to study, in response to a replicable stimulus. Originally, experimenters created components based on their polarity, latency and scalp distribution, resulting in the likes of the P300, P3a and P3b. The *P* stands for a positive deflection, the *300* for the component peaking 300ms following presentation of the stimulus, and the *a* and *b* differentiated between the earlier frontal component and the later, more posterior component. However, recently this trend has changed to accept that these attributes of a component vary by large degrees between stimulus and study types, leading to a more general description of components as any scalp-recorded neural activity that is generated in a given neuroanatomical module when a specific operation is performed (Luck, 2005). Despite this shift in thinking, the use of named components by experimenters remains widespread as the most expedient method in which to convey the general properties of a given component, and will be used in the current thesis.

The four main identified components with which memory function, and by extension source memory, are associated are the N1 and P1, generally seen as early sensory and attentional components, and the P3a and P3b, which are later and often linked to higher cognitive functions (see Fig 2.5). The P1, or P100 is usually to the posterior over the occipital lobes and tends to peak between 80 and 120ms. Mangun (1995) links it to the ventral stream of visual processing and may reflect automatic rather than controlled processes. However, the amplitude of the P1 has been found to be higher for active tasks that require direct responses over passive tasks which require only attention (Paz-Caballero & Garcia-Austt, 1992) allowing for the possibility that there is an element of control to even this early component. The N1, or N100, is elicited by both auditory and visual stimuli and modulated by attention (Coull, 1998). The N1 is often divided into a frontal N1 which is linked to spatial cueing of target stimuli (Luck, Fan & Hillyard, 1993) and passive task viewing (Paz-Caballero & Garcia-Austt, 1992), and the posterior N1 which has been linked to symbolic cues and both the dorsal and ventral streams of visual processing (Lange et al. 1999).

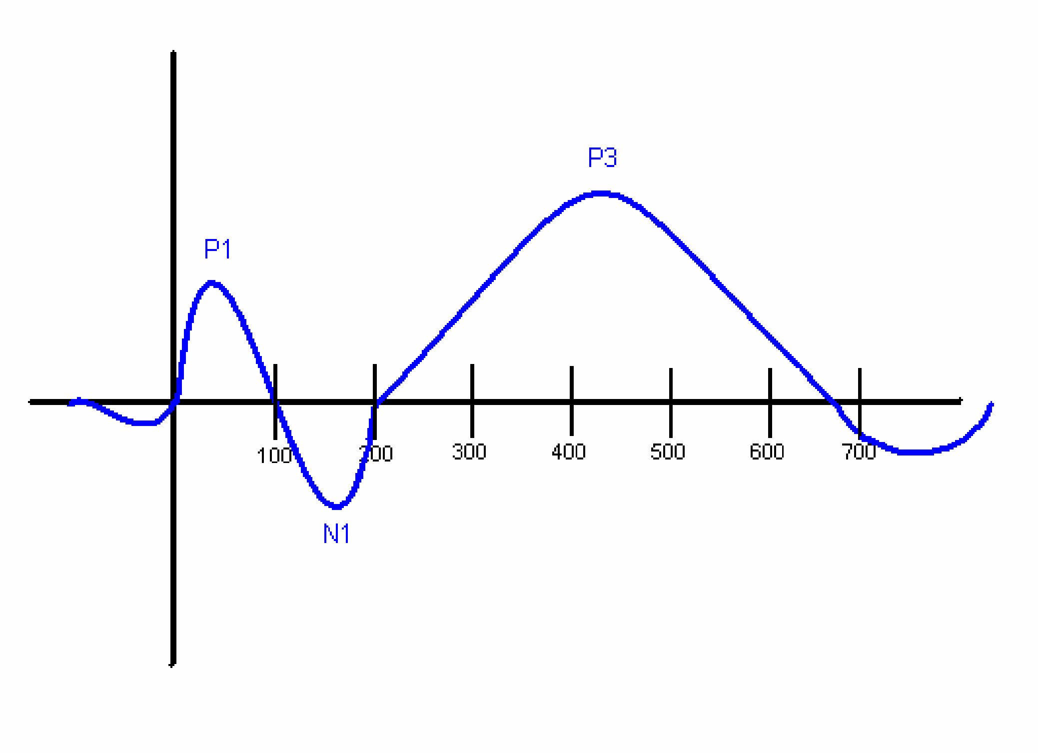


Figure 2.5: *Examples of major components involved with ERP analysis, showing P1, N1 and P3 components.*

The P3a is implicated in the response to novel items in oddball tasks (Acosta & Nasman, 1992) and has been linked to the prefrontal lobe (Kertesz, 1994). The P3b has been strongly linked to response selection (Falkenstein, Hoorman & Hohnbeim, 2001) and auditory stimuli (Bennington & Polich, 1999). Comerchero and Polich (1999) found that the P3b is more positive for targets over non-targets in tasks for easy discrimination. For more difficult discriminations, the P3a was found to be larger for non-targets while the P3b remained larger for targets, concluding that the difficulty in discrimination determined the generation of a P3a. The P3b is probably the most studied ERP component, with thousands of published studies available (Luck, 2005). Despite this, it is still unclear as to the cause for the component. However, it has been reliably found to respond to the probability of a target occurring (Duncan-Johnson & Donchin, 1982) as well as to the amount of effort necessary to complete a task (Israel et al., 1980b).

2.3.5 Setting Up and Recording EEG

For the EEG recording chapters in the thesis, participants were seated in a darkened, copper-shielded and sound-attenuated testing cubicle for the duration of the experiment. All electrical equipment was removed from the room prior to examination apart from the screen, keyboard and EEG Amplifier.

EEG data were collected from 128 channels over the surface of the scalp, using the extended version of the International 10-20 system for electrode placement (see Figure 2.6) (Jasper, 1958). Tin electrodes were used along with a specially produced electrode placement cap (Brain Vision). The impedance level was kept to below 10kΩ in all cases. This was achieved through a number of steps in the experimental procedure. The Easi-cap system was used, with Abralyte gel being placed in each electrode holder using a blunt ended syringe prior to attachment of the electrode. The electrodes were then placed in the proper pattern, with the 4 EOG electrodes being placed at the external canthi of the eyes to record horizontal movements (HEOG), and on the inferior and superior ridges of the orbit of the left eye to record vertical movements (VEOG). These electrodes would be subsequently linked to the blink reduction algorithm to reduce the artifacts. Impedance was reduced to below 10 kΩ through this process and via the manipulation of the gel at each electrode site using cotton swabs. On completion of the experiment all electrodes were removed, cleaned and disinfected to ensure hygienic re-use of the equipment.

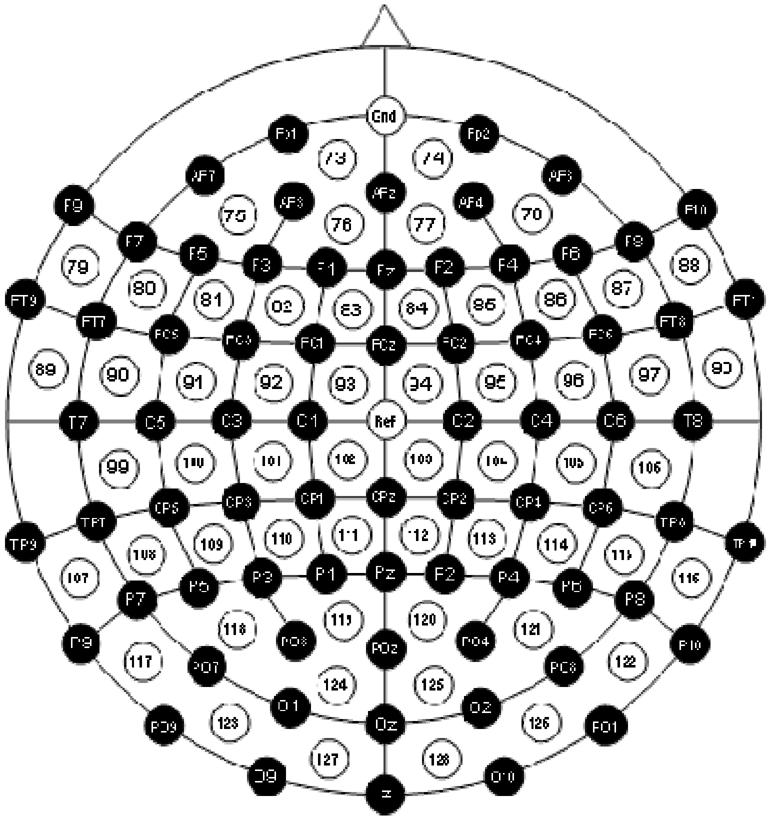


Fig 2.6: *Expanded 10-20 system of electrode placement used in 128-channel electrode set-up and EEG recording. Adapted from www.behavioralandbrainfunctions.com.*

The amplifier used was supplied by Brain Vision (BrainProducts GmbH, Germany). EEG activity was amplified using a band-pass of 0.16-100Hz and a gain of 1000. Recordings were notch filtered off-line at 50Hz. EEG data were digitized at a sampling rate of 500Hz, and were averaged offline using BESA software (MEGIS Software GmbH, Germany). A high cut-off filter of 60Hz was used, along with an auto-rejection procedure to cut off negative amplitudes of greater than 50μv. The 100ms pre-stimulus period was used as a baseline for the baseline correction procedure.

2.3.6 The Reference Electrode

The reference electrode is used as a measure by which the other EEG signals can be compared. Ideally, the reference electrode should be attached to an area of the participant where no electrical signals from the brain of the participant will be recorded. Such a reference is called a *true reference*. In reality, the use of such a reference is rare, as any reference point used on the participant's head will find some degree of interference from neural electrical signals. Reference electrodes are generally placed on areas with thick bone or cartilage, as bone is less conductive than neuronal tissue. The tip of the nose, the earlobes and the mastoid bone behind the ear have all been utilized in an attempt to create a quiet reference electrode. If the ears or mastoids are used, it is normal to use a linked pair of references either by a physical wire or a mathematical equation to avoid bias towards the potentials on one hemisphere (Luck, 2005). It has also been found to be possible to use an *average reference* to compare the data. This method uses the average voltage of all the active electrodes to compare between them, allowing for experiments to be run without a physical reference electrode. However, Dien (1998) warns that this is only possible if the electrodes are over the entire scalp and in sufficiently high density, otherwise the data will be distorted.

Each form of referencing has its own caveats. Linked mastoid or ear electrodes must have great enough contact resistances or the current may flow between the ears, altering the recorded patterns. The resistances must also be kept equal, or there is a risk of creating a single reference from the stronger reference. The nose electrode, located on the *naison* where the bone and cartilage meet at the bridge of the nose, does not have these problems, but instead its proximity to the eyes can cause electrical changes through ocular movements and blinking. This problem can be alleviated through the use of blink-reduction algorithms (e.g. Berg & Scherg, 1994). Whichever method is chosen for referencing will have problems, but these can be countered through precise locating of the reference point between participants and the use of mathematical models. The current study uses the naison electrode, as it is a simple and relatively robust method of referencing. However, the use of high-density equipment also allows for an average reference to be created.

2.3.7 ERP Averaging and Analysis

Following the recording of the EEG information, the files were transferred to the BESA ERP and source localisation program. The contiguous EEG information was converted to BESA binary format. The data were then examined for bad channels and artefacts. Bad channels are those with above average amounts of distortion, caused by outside influences or bridging between electrodes. If more than 10 were reported in a single participant, the participant was removed from the study. An automatic blink algorithm was run to minimise the effects of those artefacts on the data. The artifact correction employed was a variation of the Berg and Scherg (1994; see also Ille et al., 2002) spatial components method for correcting eye artifacts, as laid out in the BESA program. Artifact and brain signal subspaces are described in terms of spatial topographies. The correction process consisted of four steps: Step one is to define the topography for each type of artifact. Step two determines the brain signal topographies underlying the displayed EEG segment. Step three involves the reconstruction of the artifact signal at each scalp electrode with a spatial filter taking into account artifact as well as brain signal subspace. Finally, step four is to subtract the reconstructed artifact signal from the original EEG segment. This allows the blink potentials to be removed with a minimum of distortion of the data.

The data were then split into ERPs dependent on conditions. These ERPs were collated to form conditional averages, and a single grand average ERP for each group in the particular study. Components were identified based on these grand averages and compared across groups through visual and statistical analysis, using the mean amplitude of the data between specific time points as well as the highest peak in each studied component. The length of the positive or negative deflections, or *latency*, was also used for comparative analysis. This allowed for statistical comparisons using ANOVAs and Bonferroni corrected t-tests to be completed.

2.4 Dipole Source Location

2.4.1 Spatial localisation of ERPs

Since the 1970s, attempts have been made to enhance the spatial resolution of ERP data using a number of different, generally mathematically-based, methods. The primary drawback to these attempts is the *inverse problem*. This is the problem that all the EEG recordings from the scalp are based on sources in the cortex, but it is possible that any number of sources could be contributing to the recorded waveforms. Identifying the sources using mathematical models is essentially impossible due to the mass of interactions and voltage changes occurring across the cortex at any given time. Even during a simple attention task, a number of brain areas (both related and unrelated to the task) may be excited or inhibited, resulting in a near-infinite number of possible sources for a recorded component.

Hjorth (1975) created a method of increasing the spatial resolution of ERP data using *scalp current density (SCD)* or the Laplacian method. This is a filter that mechanically increases the emphasis on sources close to the area of interest while simultaneously reducing the contribution of sources from more distant areas. This has led to the creation of SCD maps (see Fig 2.7) which allow for a rapid visual inspection of scalp. The New Orleans spline-Laplacian model (Perrin et al., 1987; Nunez, 1989) and the Melbourne dura imaging algorithm, also known as spatial deconvolution, (Gevins et al., 1991) are more modern variations of this using high-density ERP recording arrays of 64 or more electrodes. These methods do not deal with the inverse problem to a great extent as no assumptions about the cortical sources are necessary. The dura imaging method requires a volume conductor head model, usually using 3 spheres to represent brain, menginges and skull conductivity. The Laplacian model requires only that the outer surface shape of the volume conductor be specified, typically by applying a best-fit spherical model. Nunez and Srinivasan (2006) give a spatial resolution of 2-3cm to these methods.

The other major method of increasing spatial resolution in ERP studies involves the inverse problem directly. The use of *Dipole Source Localisation* is becoming more common in the field of ERP analysis. Through the study of prior examinations of brain volume and conductivity, as well as the acceptance of prior hypotheses of boundary information, a head model can be created in 3 dimensions that closely resembles an average human brain and its surrounding area, typically with a 3-shell model: thus an artificial *forward solution* to the inverse problem can be devised. Using these models, a series of dipole sources can be extrapolated from the ERP data, generally through matching dipoles to sources using *principal component analysis* (PCA). A dipole is created for each component identified in the data, and an attempt is made to mathematically match each dipole with a major component, resulting in a 3-dimensional model of the head with either discrete dipoles affixed to certain areas of the cortex or graded areas of activity (see Fig. 2.8). The shorter the time-span being studied, the more accurate this method will be. Structural data from MRI scans has been used to create a *boundary element model*, which allows for more accurate dipole localisation. Dipole models include *Brain Electrical Source Analysis (BESA;* Scherg, Vajsar & Picton, 1989) and *Multiple Signal Characterisation (MUSIC;* Mosher, Lewis & Leahy, 1992). The current thesis utilises the BESA method. The method allows for a certain level of improvement in the spatial resolution of ERP data, and is useful in finding general areas of the cortex involved with the carrying out of mental tasks. However, as Nunez and Srinivasan (2006) state, the use of mathematical models is an oversimplified estimate of actual source localisation.

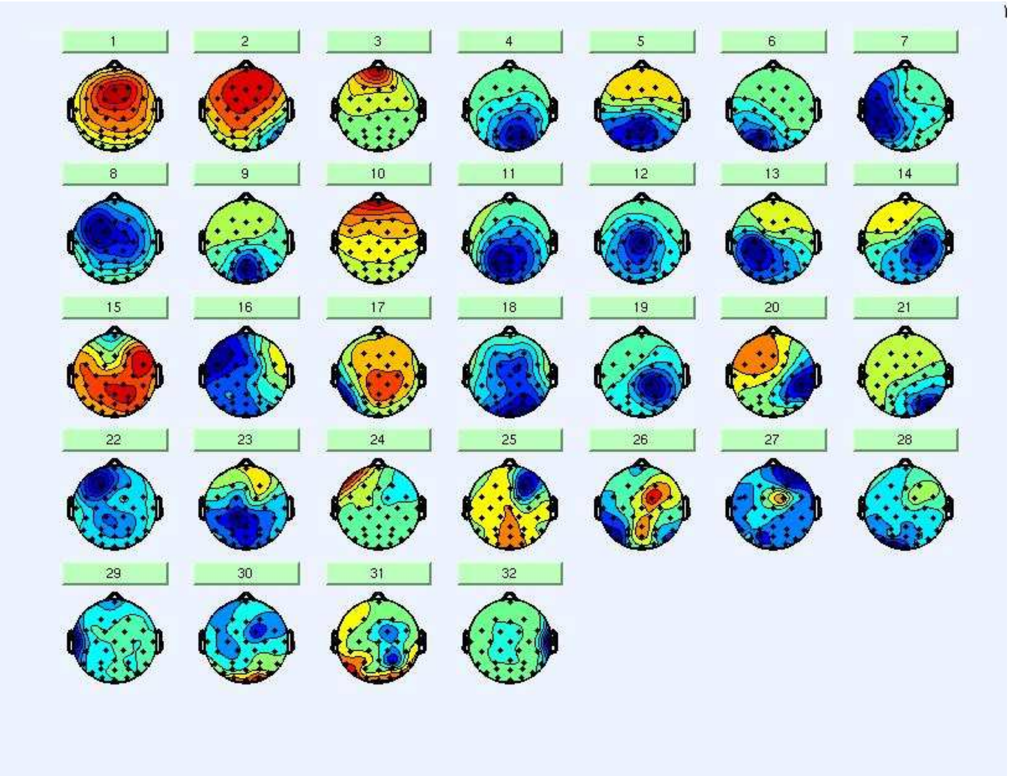


Fig 2.7: *Example of a Scalp Current Density Map, showing improved spatial resolution through the localisation of sinks and sources over time. Adapted from sscn.ucsd.edu/tutorials*

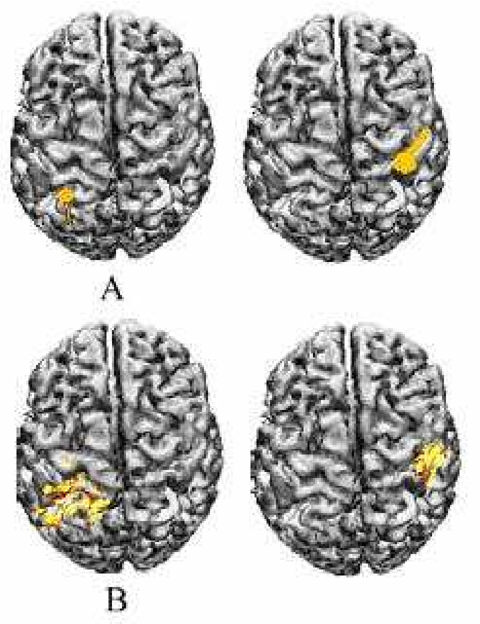


Fig 2.8*: Examples of discrete dipole localisation results (A) and distributed areas of activity (B) during a movement imagination task. Adapted from* www.tc.umn.edu/~binhe

2.4.2 BESA Analysis

Following the completion of ERP analysis, BESA software was used in order to examine the neural generators of the ERP components by creating a discrete multiple source model (See Fig. 2.9). This model is used as a source montage to transform the data from sensor level into brain source space in the form of a 4-shell ellipsoidal head model, providing source waveforms of the modeled brain regions as a direct measure for their activities on a trial-by-trial basis. Each dipole had optimal parameters created by searching for a minimum in the residual variance (RV) coefficient, that being the percentage of variance in the recorded distribution not explained by the dipole model. For bilaterally located early sensory potentials (P2 and N2), a symmetry restraint was placed in respect for location. It is important to note that, in dipole source analysis, the modeled dipoles represent an oversimplification of the activity in the areas and should be considered as representative of centers of gravity of the observed activity rather than pinpoint localizations of exact generators (Nunez & Srinivansan, 2006).

Source models were estimated for the time windows in the overall grand mean waveform, in which any elicited components reached peak values. Source models were then estimated for the differences between conditions in order to maximize the signal to noise ratio. For each waveform, the time-dependent RV was computed for the model. Parameters were optimized for individual data at the time point at which the minimum RV was computed, within the predetermined latency window. Data with an RV of greater than 30% were excluded from further analysis, as well as those participants whose analysis showed anatomically implausible solutions, with dipoles outside the brain area, such as in the neck or ocular regions.. Following analysis of the grand mean waveforms, the source solution was applied to individual averages. Subtraction waveforms were also analysed for source, in order to examine the neural correlates of the differences in potentials between conditions.

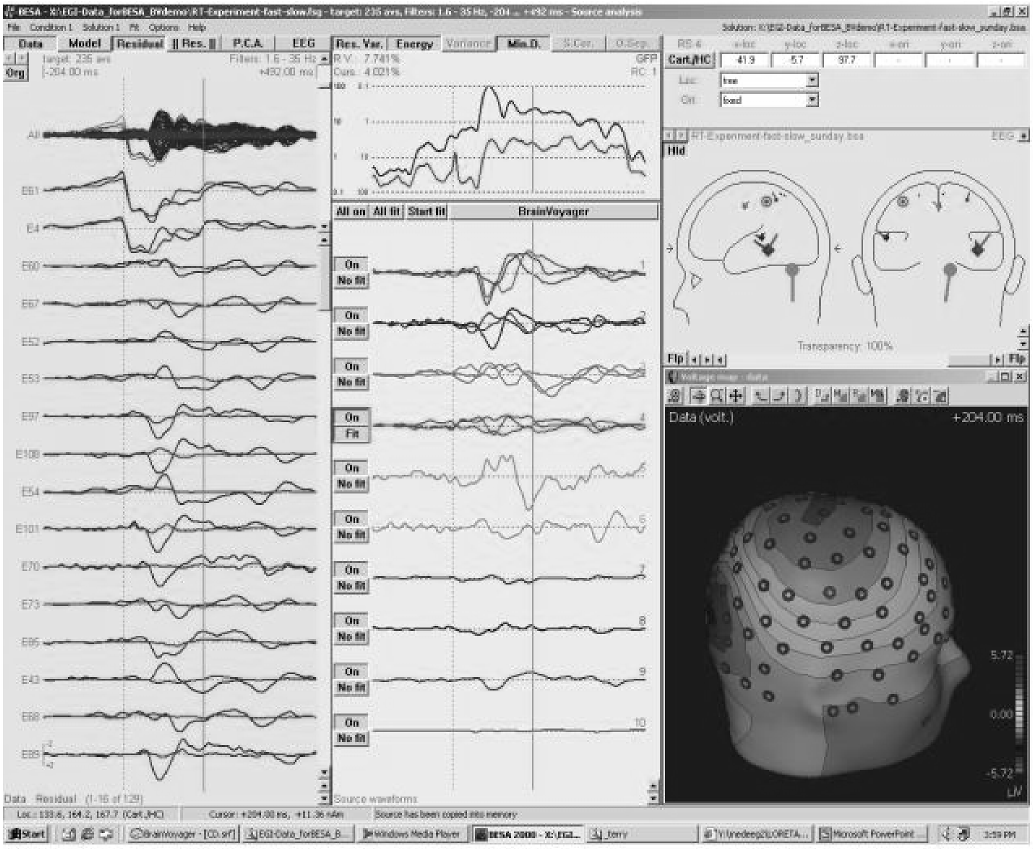


Fig 2.9: *Example of the BESA interface for dipole analysis. Adapted from brainimaging.waisman.wisc.edu*

Finally, anatomical loci and Brodmann’s areas were estimated using a Talairach Daemon software application (The Research Imaging Centre, UTHSCSA, Texas). This software maps the X, Y and Z co-ordinates obtained using BESA onto the Talairach co-planar stereotaxic atlas of the human brain (Talairach & Tournoux, 1988) in order to locate the Brodmann’s Area and gyrus of each dipole. The program allows researchers to map the BESA dipoles onto a standardized head model, thus giving anatomical locations and Brodmann’s Area data on the dipoles found. This information can then be used to compare the ERP source locations with neuroimaging methods such as PET or fMRI, allowing the results found in the studies to be compared to a wider variety of other studies in the area.

2.5 Conclusions

The use of EEG, and from that, ERP results allows for a thorough examination of activity over the scalp during trials. Adding dipole source imaging will enable us to tentatively locate the neural correlates of the results found in the task. The straightforward nature of the Opposition Task devised should create clear ERP results and enable comparisons between lag lengths, condition types (Correct targets, False Alarms, etc.) and age groups. The CFQ will give a simple index of participants' everyday memory problems, allowing us to use relatively homogenous groups for study.

Chapter 3

Temporal Aspects of Source Memory: Effects of Inter- and Intra-task Variations on the Opposition Paradigm

The Experimenter would like to thank Ms Jennifer Murphy and Ms Monica Donaghy for their aid in initial data collection

Abstract

The Opposition Task has been used to examine source memory capacity in numerous clinical and non-clinical groups. In this chapter, we examined the task itself using groups of healthy young adults. Experiment 1 employed 25 participants to examine at what lag lengths the task shows the greatest differences from lag 0. Based on the findings of Jennings and Jacoby (1997), 6 lag lengths were used for the experiment; 0, 2, 4, 8, 12 and 16. Participants were presented with a study list of 70 words and asked to remember them. During the test phase immediately following the study list, study and distractor words were presented and participants were asked to respond as to whether they recognised the word from the study list. Results from Experiment 1 showed no decrease in accuracy from Lag 0 to any longer lag length. There was a trend in the reaction time data towards longer reaction times for the longer lags over short or immediate lags. The use of a high number of lags my have increased the familiarity of the participant for the design, this increasing their accuracy for lagged trials. Experiment 2 divided 24 participants into three groups (N=8) based on the interval between the study and test phases (Immediate recall, 1-hour delay or 24-hour delay) and were given the same task as those in Experiment 1, though with 3 lags, to examine if an interval between the phases would produce either an adverse or ameliorating effect on accuracy and reaction times during the test phase. The results from Experiment 2 showed some decreases in accuracy for longer lags in all three conditions, though none significant, while the reaction time data showed significant increases for the lagged trials over the lag 0 trials. No differences were found between the conditions. These results suggest that the interval between encoding and recall phases does not affect source recall.

3.1 Introduction

3.1.1 General Introduction

Since the original use of the Opposition Task in examining source memory (Jennings & Jacoby, 1997), there have been a number of studies in the area using similar procedures, particularly with regards to the lags used. In two similar tasks examining the effects of repeated words on EEG data, Dywan, Segalowitz and Webster (1998) and Dywan, Segalowitz and Arsenault (2002) created studies that used a six word lag to examine deficits in source memory. For both tasks, a two minute interval occurred between the study list and the subsequent test list. Bridson, Fraser, Herron and Wilding (2006) also completed a study testing recognition for studied words using an Opposition Task where one lag length was used, though it was randomised to between a lag of 7 and 9 between words. They compared reaction times and correct responses for the lagged stimuli to those of unlagged stimuli, i.e. the first presentation of the word in the test list. All three experiments reported similar patterns of results, with lagged stimuli causing a decrease in accuracy and an increase in RT.

While typically a short delay between the study and test blocks is used, a matter of minutes, this is not always the case. Mathewson, Dywan and Segalowitz (2005) used an opposition-based test as part of a study examining memory differences between young and old adults. Again, the lag length used was six intervening items, as in the previous studies by the group. During this task, a 25-minute interval was introduced between the study and test phases, during which a separate task was completed. Despite this added short interval, a similar pattern of behavioural results was found to occur to those of the previous studies, with lagged words showing lower accuracy scores and longer RTs. This seems to show that performance on an Opposition Procedure is unchanged by inter-phase interval; however, the immediacy of the test list following the study list is a possible procedural problem that has not been examined during the use of the Opposition task beyond this 25 minute interval. Immediate or close-to-immediate examination of the study block is almost universally used. The use of a 25-minute interval with an intervening task is a slight variation on this, but no longer intervals have been reported to examine the possibility of the impact of longer intervals before recall on source memory. A word recognition task that is superficially similar to an opposition or Old/New procedure was carried out by Wolk, Schacter, Lygizos, Sen, Holcolme, Daffner and Budson (2006) who found that a 24-hour delay between study and test blocks produced a deficit in recognition for words as being from a study or test list in comparison to those examined immediately following the study block. It is noteworthy that these authors did not use a Lag procedure, and this phenomenon has not been examined in terms of lag-based manipulations.

The original Opposition study (Jennings & Jacoby, 1997) examined the task using two different sets of lags during the test phase; 0, 1, 3 and 7 in Experiment 1, and 4, 12, 24 and 48 in Experiment 2. For both these interval lags a decrease in accuracy was found as the lag length increased. However, they did not compare the two experiments, despite finding increased RTs with lag 12 compared to lag 4 in the first experiment and no difference in RTs between lag 3 and 7 in the second experiment. Furthermore, Jennings and Jacoby (1997) concluded that *“these declines seem to asymptote after four intervening items have occurred, remaining constant for up to at least 48 intervening words,”* despite the original experiment not examining whether a number of further lags would create any deviation of this asymptote. A design beginning with a lag of 0 and extending to include lags beyond 12, or a design involving more than 4 lag lengths including lag 0, has not been examined in the literature to date.

3.1.2 Overview of Current Experiments

This chapter attempts to examine two fundamental changes to the procedure of the Opposition Task. The first (Experiment 1) attempts to increase the number of lag lengths from 4 (as used by Jennings & Jacoby, 1997) to 6 (0, 2, 4, 8, 12 and 16). This will test the idea that any lag beyond a first or immediate (lag 0) presentation will show a decreased level of accuracy, regardless of the intervening number of stimuli. This is important as it will allow for the creation of a simple version of the task depending on the results found. We hypothesise that first presentation and lag 0 responses will show higher accuracy than all lagged responses, as found by Jennings & Jacoby (1997). In Experiment 2 we will attempt to examine whether a longer interval between the study and test blocks will have an effect on the RT and accuracy scores of a group of participants. We use three lag lengths (0, 4, and 16) during the test phase, and 3 intervals (Immediate, 1 hour, 24 hour) between the study and test phases. Similar to Wolk et al. (2006), we may find lower accuracy levels among participants that have had the test phase 24 hours post-study compared to those tested immediately following the study phase. However, it may be possible that participants' RTs and accuracy will equal or better those of the immediately tested group if given a 24 hour delay, as some studies have demonstrated that memory retrieval can be enhanced following sleep as memories are further consolidated over time (e.g. Ficca, Lombardo, Rossi & Salzarulo, 2000; Ellenbogen, Hulbert, Stickgold, Dinges & Thompson-Schill, 2006).

3.2 Experiment 1

3.2.1 Method

3.2.1.1 Participants

The sample used for this experiment consisted of 25 participants, 13 male and 12 female (Age=19-28, mean=21.2). All participants had normal or corrected-to-normal vision and were self-reported free from serious memory problems. Participants gave written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information Act (1997). The Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982) also measured the participants' everyday memory failure rate to ensure all participants were within normal limits. The experiment was conducted in accordance with the Code of Ethics of the World Medical Association (World Medical Association, 1964) and the Ethical Standards of the APA (American Psychological Association, 2002).

3.2.1.2 Design

This study consisted of a 2x6 repeated measures/ within-group design, with Trial Type and Lag Length as the two independent variables. Trial type was operationalised on two levels: Target and Distractor; Lag length was operationalised on six levels: Lags 0, 2, 4, 8, 12 and 16. The dependent variables to be measured were accuracy and reaction time on the test block.

3.2.1.3 Apparatus

This experiment made use of the Opposition Task as described in the Methods Chapter (Chapter 2), with a number of methodological and procedural changes in place. The task consisted of a single study and test-block with 60 study words as well as 5 buffers for primacy effects and 5 for recency effects. Each of the 60 study words was presented twice during the test phase in a pseudo-random order. Sixty distractor (foil) words were included in the test phase, also with 2 repetitions of each. In order to examine the effects of differing lags on participants' source accuracy, target words were presented for the second time at lags of 0, 2, 4, 8, 12 and 16 in the test phase. All distractor, or foil, words were also presented using these 6 lag lengths. All other details were as outlined in the Methods Chapter.

3.2.1.4 Procedure and Data Analysis

Prior to testing, all participants were briefed and informed that they would be taking part in a simple study of recall. The experiment took place in a 9x9 cubicle located in the Department of Psychology in NUI Maynooth, with the screen located approximately 1 metre from the participant. Participants were allowed short breaks between phases and told that they could withdraw at any time. Following completion of the experiment, all participants were fully debriefed. Individual data obtained were kept confidential. Data were subjected to repeated measures ANOVAs to examine for statistically significant differences in the accuracy scores and reaction times between the differing lag lengths for participants. Bonferroni-corrected paired-sample t-tests were used to further examine the differences found. Correct responses to target words are described as *Hits*, correct responses to distractor words are described as *Correct Rejections*, incorrect responses to target words are described as *Misses* and incorrect responses to distractor words are described as *False Alarms*. The accuracy data records only the Hits and Correct Rejections, as the Misses and False Alarms are simply those responded to incorrectly by participants. For the CFQ, participants were found to have a mean score of 33.6 (SEM= 8.12), allowing them to be considered as having within the normal range of cognitive failures.

3.2.2 Results

3.2.2.1 Accuracy

To ascertain if there was an effect of lag length and trial type on accuracy during the test phase, a repeated measures ANOVA was performed. The results of this test revealed a significant main effect of Trial Type [F (1, 25) = 6.424, p<0.05] with participants more accurate at reporting distractors (Correct Rejections) compared to targets (Hits). There was also a significant main effect of Lag Length [F (1, 25) = 3.052, p<0.05]. There were no significant interaction effects between trial type and lag length [F (1, 25) = 1.285, p = 0.275], as illustrated by Figure 3.1.

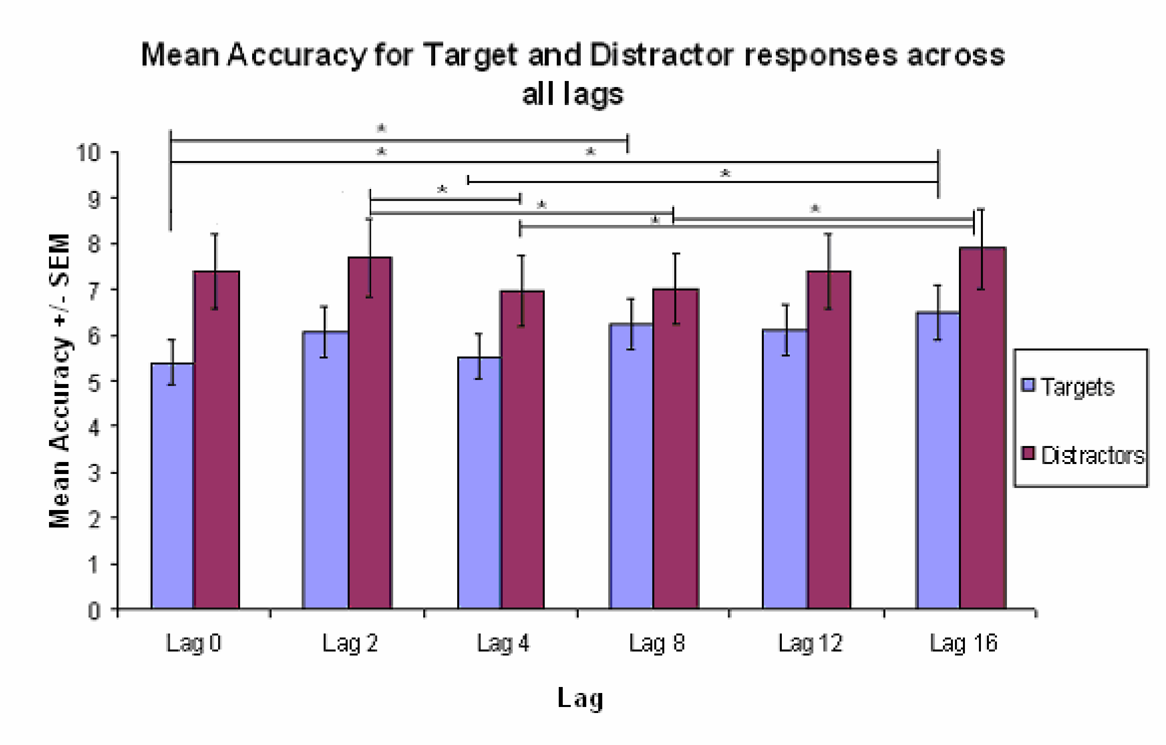


Figure 3.1: *The Effects of Lag Length and Trial Type on Accuracy for second presentation (* denotes a significant difference).*

A series of Bonferroni-corrected paired sample t-tests were performed to compare the accuracy means of different lags. For target words, lag 0 trials were significantly less accurate than those at lag 8 [t (24) = 2.339, p<0.05] and lag 16 trials [t (24) = 3.094, p<0.01]. Trials at lag 4 were also found to be less accurate than at lag 16 [t (24) = 2.027, p<0.05]. In the accuracy means for distractor words, there was a significant difference between lags 2 and 4 [t (24) = 2.216, p<0.05], with lag 2 showing higher accuracy, as was the case between lags 2 and 8 [t (24) = 2.221, p<0.05]. Lag 4 was found to be significantly lower in accuracy than lag 16 [t (24) = 2.602, p<0.05], as was lag 8 compared to lag 16 [t (24) = 2.281, p<0.05]. When target and distractor word accuracy means were compared by a t-test (e.g. lag 0 target accuracy compared with lag 0 distractor accuracy), there were significant differences at lag 0 [t (24) = 3.397, p<0.01] and lag 2 [t (24) = 3.222, p<0.01], with the distractor responses showing higher accuracy in both cases.

Following these results, lag lengths were combined into short (0, 2, 4) and long (8, 12, 16) lengths. A 2x2 repeated measures ANOVA was performed to examine the effect of short and long lags on accuracy for target and distractor words. This would reveal overall at which type of lag length participants performed better. The results of the ANOVA revealed no significant main effect for Lag [F (1, 25) = 13.121, p= 0.083]. There was, however, a significant main effect for trial type on accuracy [F (1, 25) = 6.424, p<0.05] with significantly greater accuracy for distractors. Figure 3.2 demonstrates that participants attained higher levels of accuracy for distractor words compared to target words. There was a significant interaction effect between trial type and short/long lags [F

(1, 25) = 9.54, $p<0.05$]. T-tests showed a significant difference between targets and distractors at the short lag condition [t (24) = 1.642, $p<0.05$] and no other significant differences.

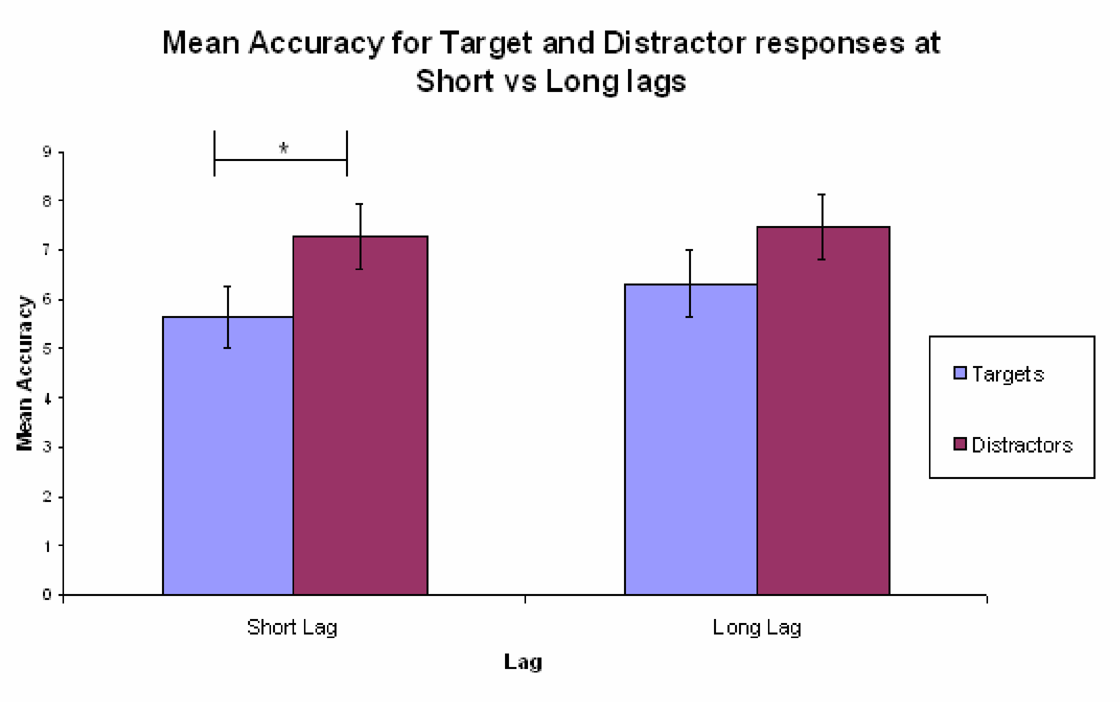


Figure 3.2: *A comparison of the mean accuracy scores obtained by participants in the short and long lag length trials.*

3.2.2.2 Reaction Times

A one-way repeated-measures ANOVA was carried out on the reaction time (RT) data for correct responses to target words (Hits). The results showed no statistically significant differences between the 6 lag lengths studied for this response type [F (5, 24) = 1.215, p=0.307]. Figure 3.3 shows the means and standard errors for the Hit responses, with mean RTs between 780 and 1050ms, with a slight increasing tendency with longer lags.

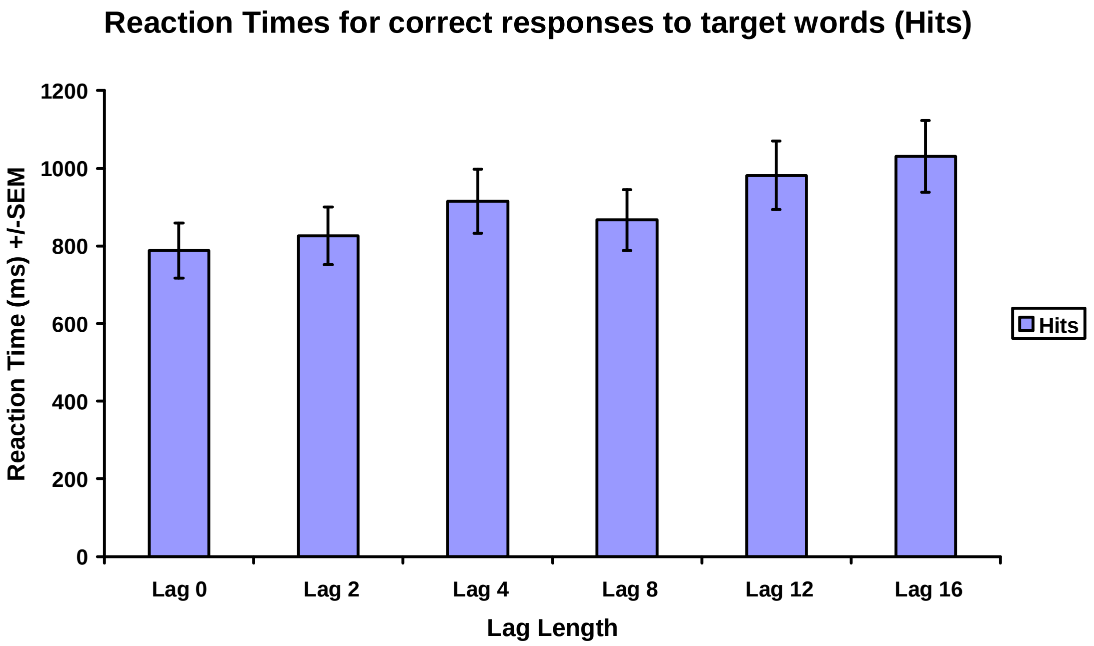


Figure 3.3: *Mean reaction times for correct responses to target stimuli across all six lag lengths.*

A second one-way repeated-measures ANOVA was carried out to examine the reaction time differences between the lags for incorrect responses to the target stimuli (Misses). As with the Hits condition, no significant differences were found between the lags for Misses [F (5, 24) = 2.28, p=0.215]. Figure 3.4 shows the means and standard errors for the six lag lengths for the Miss condition, showing mean RTs ranging from 770ms for the lag 2 condition to 1010ms for the lag 8 condition, again, showing a slight increase in RT length with longer lags.

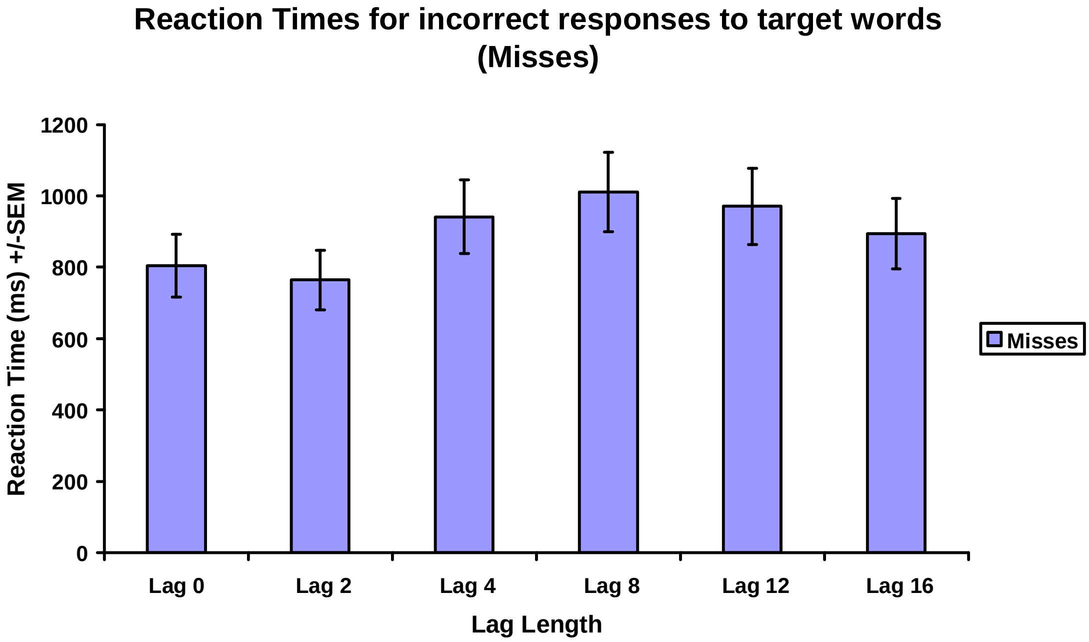


Figure 3.4: *Mean reaction times for incorrect responses to target stimuli across all six lag lengths.*

Following this, a one-way repeated-measures ANOVA was applied to the data for correct responses given by participants to distractor, or foil, words (Correct Rejections). The results showed an effect for Lag Length [F (5, 24 = 5.026, p = 0.019]. Following this, a number of Bonferroni-corrected paired-sample t-tests were carried out on the data to further investigate which lag lengths showed significant differences. The results showed that lag 0 results were significantly quicker than lag 8 [t (24) = 3.381, p<0.05], lag 12 [t (24) = 3.107, p<0.05] and lag 16[t (24) = 3.710, p<0.01], and that participants were significantly slower to react at lag 16 than at lag 2 [t (24) = 5.284, p <0.01]. Figure 3.5 shows the means and standard errors for the lag lengths in the Correct Rejection condition, with RTs ranging from 760ms at Lag 0 to 980ms at lag 16, with a continuous upward tendency with lag length.

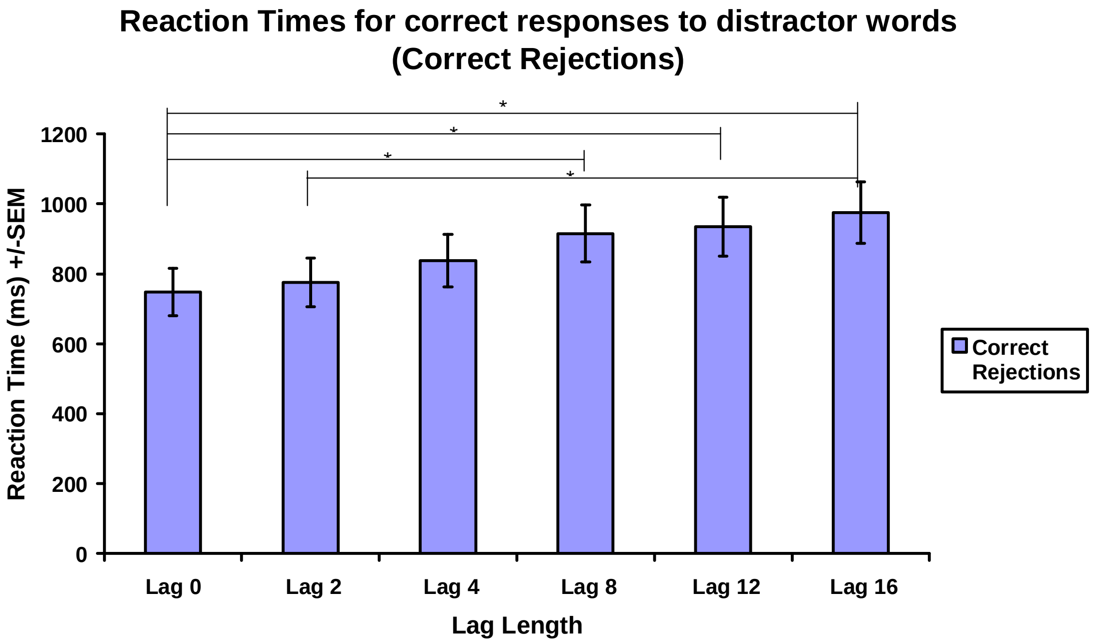


Figure 3.5: *Mean reaction times for correct responses to distractor stimuli across all six lag lengths.*

Finally, a one-way repeated measures ANOVA was carried out on the data for incorrect responses to distractor words (False Alarms). An effect for Lag was found to be present in the False Alarm data [F (5, 24) = 6.73, p<0.01]. Bonferroni-corrected paired-sample t-tests were used to examine these data and find which lag lengths differed significantly from each other. Lag 0 responses were found to be significantly faster than lag 12 responses [t (24) = 2.768, p<0.05] or lag 16 responses [t (24) = 3.422, p<0.05]. Lag 2 responses were found to be significantly faster than lag 8 [t (24) = 5.326, p = 0.008], lag 12 [t (24) = 3.822, p<0.01] and lag 16 responses [t (24) = 4.179, p<0.05]. Finally, lag 4 responses were significantly faster than lag 12 responses [t (24) = 5.234, p<0.01] and lag 16 responses [t (24) = 2.713, p<0.05]. Figure 3.6 shows the means and standard errors for this data group, showing RTs from 730ms for lag 2 responses to 1040ms for lag 12 responses, again showing generally longer RTs for the longer lag lengths.

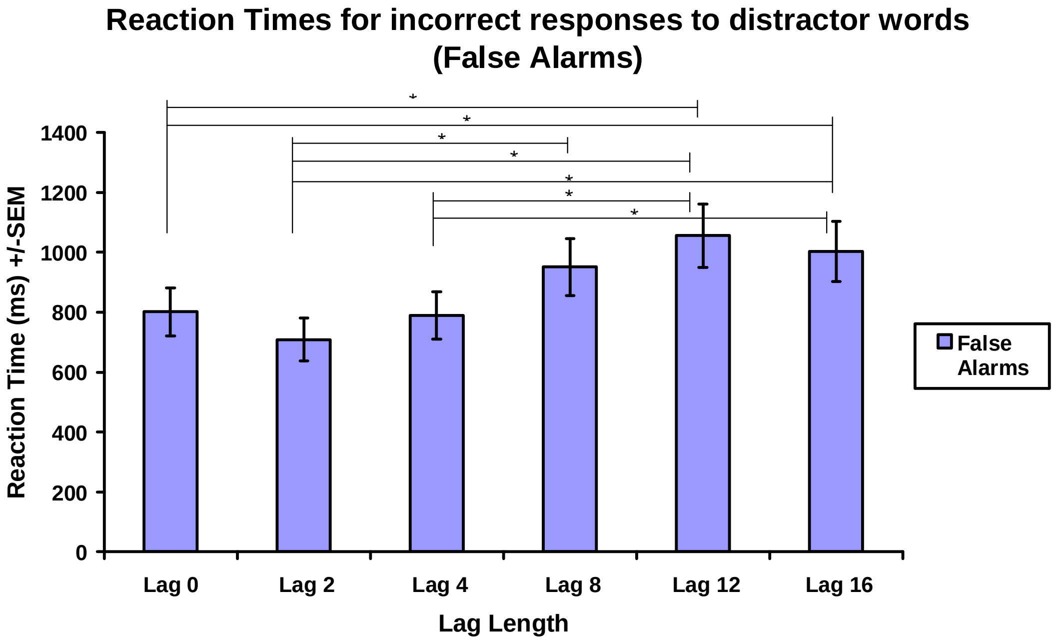


Figure 3.6: *Mean reaction times for incorrect responses to distractor stimuli across all six lag lengths.*

In sum, the accuracy results showed generally higher accuracy for distractor words over targets, with some significant differences found, especially at shorter lags, although a high level of accuracy was shown across lags. The reaction time results show a general trend for longer RTs at longer lag lengths, particularly for the foil words, with participants responding more quickly to both correct rejections and false alarms quicker at the shorter lag lengths (0, 2 and 4) in comparison to the longer lags (8, 12 and 16).

3.2.3 Conclusions

The accuracy results of the data found in the experiment do not agree with those found in earlier experiments in the area (e.g. Jennings & Jacoby, 1997), with an increase in accuracy found to be present in longer lags in some cases. This may be due in part to the high number of lags included, as with 6 lag lengths, many words are repeated throughout the test phase, perhaps allowing participants to become familiar to the design of the experiment. This would cause lagged data to be recognized more easily, thereby creating a situation where lagged stimuli increase in accuracy over unlagged, or first presentation, stimuli. As it was the absence of the effect of familiarity that caused Jennings and Jacoby (1997) to create the task (as discussed in Chapter 1), the current design is flawed. The RT results show a similar trend to those found previously, with generally longer RTs for the long lags over short or immediate lags. The presence of these data led to the conclusion that the lagged basis of the task itself was not at fault, allowing for the creation of a task with fewer lags. As such, one long lag and one short lag were chosen for experiment 2. A lag of 16 was used as the long lag, as any longer would create an unwieldy test. For the short lag, a lag of 4 was chosen as being an intermediary between lag 0 for controls and the long lag of 16. This created a simpler, more streamlined task to examine the effect of different intra-phase periods in the Opposition Task.

3.3 Experiment 2

3.3.1 Method

3.3.1.1 Participants

The sample used for Experiment 2 consisted of 24 participants, 5 male and 19 female (Age=19-24, mean=20). Participants were randomly assigned to one of three experimental conditions (n=8 per condition); Immediate Recall, 1-hour Delayed Recall or 24-hour Delayed Recall. All participants had normal or corrected-to-normal vision and were self-reported free from serious memory problems. As before, the CFQ (Broadbent et al., 1982) measured the everyday memory lapses of participants to ensure they were within accepted norms. Participants gave written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information Act (1997). The experiment was conducted in accordance with the Code of Ethics of the World Medical Association (World Medical Association, 1964) and the Ethical Standards of the APA (American Psychological Association, 2002).

3.3.1.2 Design

The study consisted of a 3x3 mixed-factorial design with the Inter-Trial Interval length and Lag Length being the factors. The between-group variable, Inter-Trial Interval (or Group), was operationalised on 3 levels: no delay between trials, one hour delay between trials and 24-hour delay between trials. The within-group variable, Lag Length, was also operationalised on three levels: lag 0, lag 4 and lag 16. These lags were chosen on the basis of results from Experiment 1.

3.3.1.3 Apparatus and Procedure

The Opposition Task used for this experiment was similar to that used in Experiment 1 and described in Chapter 2 (Methods), though with 3 lag lengths rather than 6. The task consisted of a single study and test-block with 60 study words as well as 5 buffers for primacy effects and 5 for recency effects. Each of the 60 study words were presented twice during the test phase, and were presented in a pseudo-random order. Sixty distractor words were also included in the test phase, with 2 repetitions of each, creating a test battery of 240 words. The *immediate recall* group were subjected to the testing phase immediately on completion of the study phase. The *1-hour delayed recall* group were given a 1-hour interval between the study block and test block. The *24-hour delayed recall* group were given a 24-hour interval between the study and test blocks, returning the following day.

3.3.1.4 Data Analysis

Both Accuracy and Reaction Time scores were analysed. Accuracy was examined using 2 Mixed-factorial 3x3 ANOVAs; one for targets and the other for distractors, with Group (Immediate, 1-hour and 24-hour) as the between-subject variable and Lag Length (0, 4, and 16) as the within-subject variable. RTs were examined using 4 separate 3x3 ANOVAs, using the same variables. Hits, Misses, False Alarms and Correct Rejections were subjected to separate analyses. As in Experiment 1, CFQ scores were within acceptable parameters for the group, with a mean of 39.77 (SEM= 7.04).

3.3.2 Results

3.3.2.1 Accuracy

An initial mixed-factorial ANOVA was conducted to compare the scores of target accuracy at lag 0, Lag 4 and Lag 16 across the three groups. No significant main effect for target accuracy at the different lag lengths was found [F (2, 42) =8.693, p>0.05], nor was there a significant Group [F (2, 42) = 0.395, p>0.05] or interaction effect between Group and lag [F (2, 21) = 1.109, p>0.05]. Behaviourally, all groups scored means of between 10 and 14 out of 20, with lag 0 responses showing slightly higher accuracy than the longer lags between lag 0 and lag 4. Figure 3.7 shows the mean accuracy for target words.

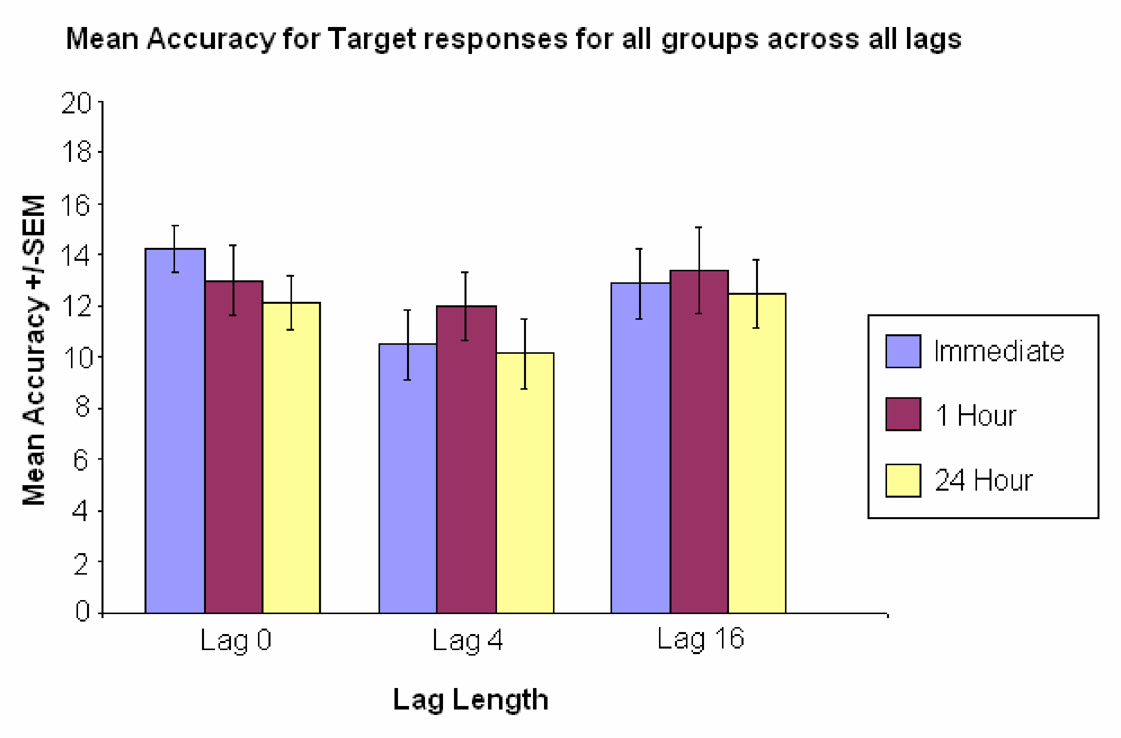


Figure 3.7: *Mean accuracy for all groups for target words across lag lengths*

A mixed-factorial ANOVA was also conducted to compare the distractor accuracy at lag 0, lag 4 and lag 16 for the three groups. For distractor responses, little difference in accuracy was visible between the groups or the lags, with all scores averaging 15-17 out of 20. As with the target results, there was no significant effect for distractor accuracy at the different lag lengths found [F (2, 42) = 0.846, p>0.05]. Again, there was no significant group effect present [F (2, 42) = 0.253, p.>0.05]. The interaction also yielded no significant effects [F (2, 21) = 0.237, p>0.05]. Figure 3.8 shows the mean accuracy for distractor words.

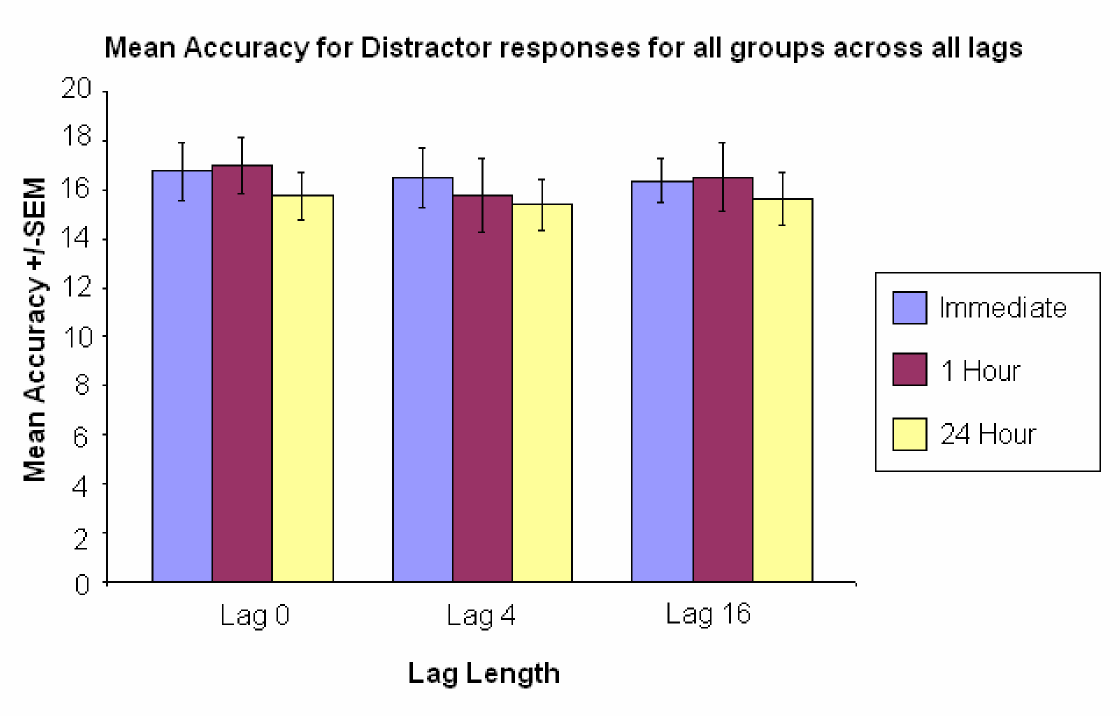


Figure 3.8: *Mean accuracy for all groups for distractor words across lag lengths.*

3.3.2.2 Reaction Times

A mixed-factorial ANOVA was then used to compare the RTs for Hits. There was a significant effect for the RTs of these target words recorded as correct at the different lag lengths [F (2, 42) = 6.379, p<0.05]. No significant group effect [F (4, 42) = 4.389, p>0.05] or group*lag interaction effect [F (2, 21) = 1.056, p>0.05] was found for Hits. Figure 3.9 shows the mean RTs for Hits. Bonferroni-corrected t-tests showed that RTs for the Immediate group were slower for at lag 4 [t (7) = 5.012, p<0.05] and lag 16 [t (7) = 3.161, p<0.05] than for lag 0. This pattern was repeated in the 1-hour Delay group, with lag 0 RTs again significantly faster than lag 4 [t (7) = 3.122, p<0.05] or lag 16 [t (7) = 4.428, p<0.05] responses. For the 24-hour Delay group, again lag 4 [t (7) = 6.004, p<0.05] and lag 16 responses [t (7) = 7.342, p<0.01] were found to be significantly slower than at lag 0.

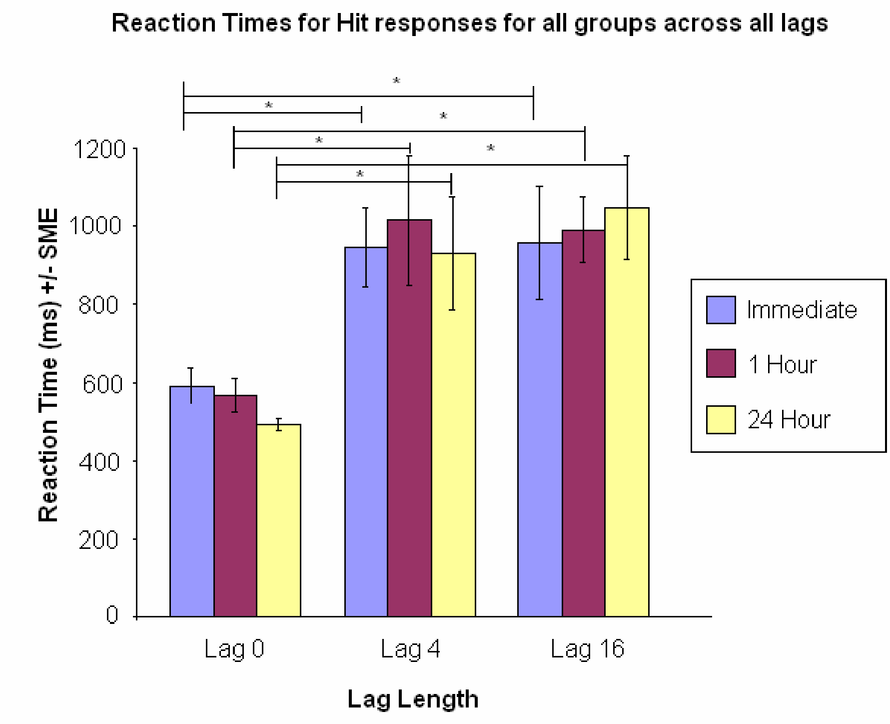


Figure 3.9: *Mean reaction times for correct responses to target words for all conditions across lag lengths.*

A mixed-factorial ANOVA was also used to compare the RTs for Misses at lag 0, lag 4 and lag 16. Figure 3.10 shows the mean RTs for Misses. There was a significant effect for the reaction times for lag [F (2, 42) = 15.555, $p<0.05$]. No significant group effect [F (4, 42) = 0.939, $p>0.05$] or interaction effect [F (2, 21) = 1.36, $p>0.05$] was found. Bonferroni-corrected t-tests reported that for the Immediate group, lag 0 responses were significantly faster than lag 4 [t (7) = 5.011, $p<0.05$] and lag 16 responses [t (7) = 4.329, $p<0.05$]. For the 1-hour Delay group, lag 4 [t (7) = 8.612, $p<0.05$] and lag 16 [t (7) = 4.63, $p<0.05$] responses were again found to be significantly slower than lag 0 responses. Finally, lag 0 responses for the 24-hour Delay group were also found to be significantly faster than those at lag 4 [t (7) = 5.712, $p<0.05$] and lag 16 [t (7) = 7.034, $p<0.05$].

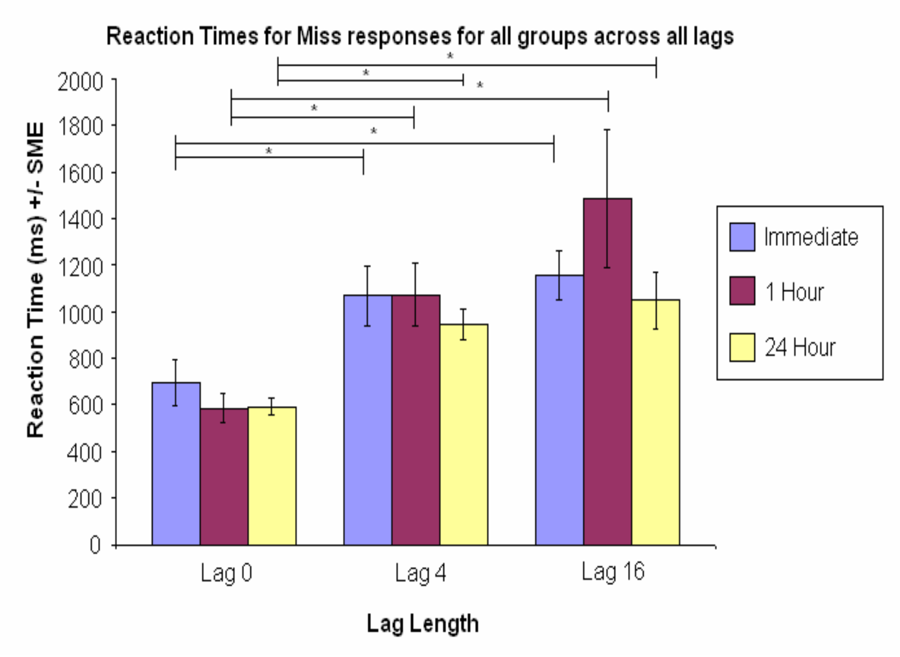


Figure 3.10: *Mean reaction times for incorrect responses to target words for all groups across lag lengths.*

Again, a mixed-factorial ANOVA was used to compare Correct Rejections at the three lag lengths. Figure 3.11 shows the mean RTs for Correct Rejections. There was a significant effect at the different lag lengths [F (2, 42) = 42.349, p<0.05]. A significant result for group [F (4, 42) = 8.995, p<0.05] was also reported. No interaction effect between lag and group [F (2, 21) = 1.511, p>0.05] was reported. Bonferroni-corrected t-tests found that lag 0 responses were significantly faster than lag 4 [t (7) = 4.211, p<0.05] and lag 16 responses [t (7) = 4.975, p<0.05] for the Immediate group. For the 1-hour Delay group, lag 0 responses were recorded as significantly faster than those at lag 4 [t (7) = 6.163, p<0.05] and lag 16 [t (7) = 5.204, p<0.05]. Lag 0 responses for the 24-hour Delay group were also found to be significantly faster than those at lag 4 [t (7) = 3.961, p<0.05] or lag 16 [t (7) = 4.299, p<0.05]. Between the groups, at lag 4 the Immediate group reacted significantly faster than the 24-hour delay group [t (14) = 3.882, p<0.05]. No other differences were noted.

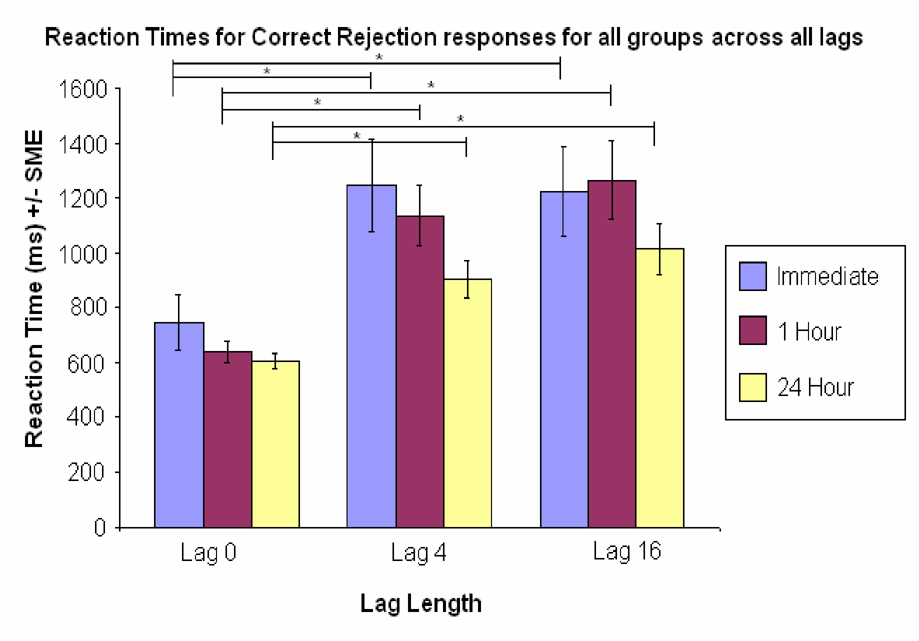


Figure 3.11: *Mean RTs for correct responses to distractor words for all groups across lag lengths.*

Finally, False Alarm responses, i.e. incorrect responses to distractor words, were examined using a mixed-factorial ANOVA. Figure 3.12 shows these results in graph form. There was a significant effect found at the different lag lengths [F (2, 26) = 13.382, p<0.05]. No group [F (4, 26) = 0.442, p>0.05] or interaction effects [F (4, 26), p>0.05] were found to be statistically significant. Bonferroni-corrected t-tests were used to examine the groups for differences. For the Immediate group, lag 0 responses were reported as significantly faster than lag 4 [t (7) = 5.618, p<0.05] and lag 16 responses [t (7) = 6.367, p<0.05]. For the 1-hour Delay group, a similar pattern was found, with lag 0 responses significantly faster than those at lag 4 [t (7) = 4.139, p<0.05] and lag 16 [t (7) = 5.755, p<0.05]. Lag 4 [t (7) = 3.464, p<0.05] and lag 16 [t (7) = 5.982, p<0.05] responses for the 24-hour Delay group were also found to be slower than those at lag 0.

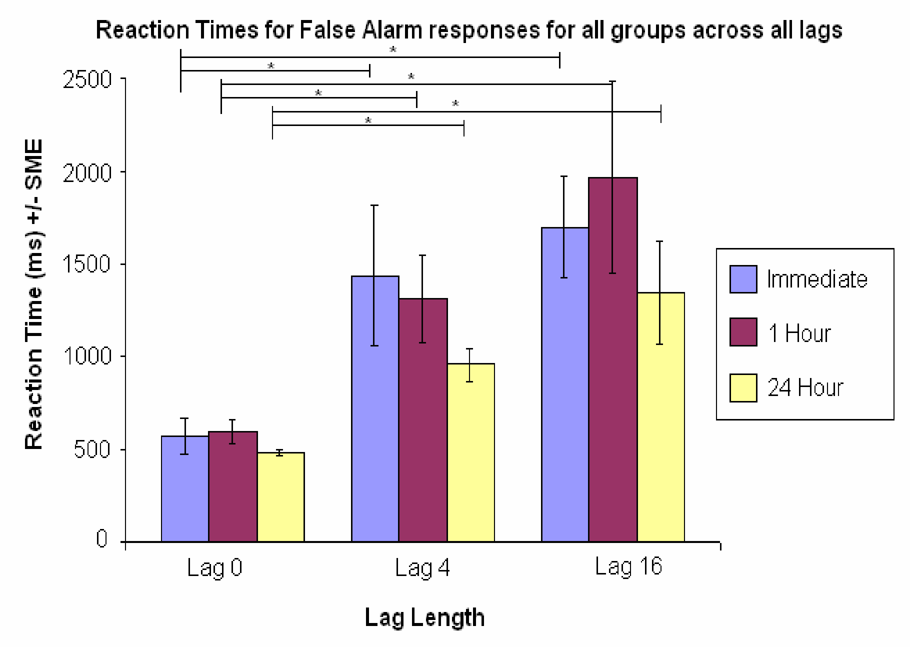


Figure 3.12: *Mean RTs for incorrect responses to distractor words for all groups across lag lengths.*

To summarise, the results showed no significant differences for target accuracy or distractor accuracy at the different lag lengths within each group or between the different groups. There was a significantly shorter reaction time at lag 0 than lag 4 and lag 16 for all 4 experimental conditions; Hits, Misses, Correct Rejections and False Alarms. For correct rejections, RTs were faster for the Immediate group than the 24-hour delay group at lag 4, but not at lag 0 or 16.

3.4 Discussion

3.4.1 General Discussion

In the above two experiments we attempted to examine whether changes in the number of lags introduced during the test block or increasing the interval between study and test blocks would have an effect on source memory recall through the medium of an opposition procedure. Experiment 1 examined the effect of adding further lag lengths to the test block, compared to the single lag length used by Dywan and colleagues (1998, 2002) or the 4 lags used in the two experiments by Jennings and Jacoby (1997). Given the results showing a plateau in performance after 12 lags found by Jennings and Jacoby (1997), the longest lag used in the current study was 16 intervening words. Six lag lengths were used in Experiment 1; 0, 2, 4, 8, 12 and 16. The experiment indicated that the use of a larger number of lags and a longer word list may have caused a disruption in the established results for the task in previous experiments, with no decreased accuracy being found at any lag compared to lag 0, and a slight increase in accuracy being recorded for long lag lengths (8, 12, 16) compared to short lags (0, 2, 4). This may have been due to increased familiarity with the procedure of the study, allowing for an artificial increase in accuracy across the lagged stimuli.

Experiment 2 examined the effect of longer intervals between the study and test phases on accuracy and reaction times. Again, a 70-word test list was utilised. In this case, only lag 0, 4 and 16 were examined, as it was deemed unnecessary to use the 6 different lag lengths from Experiment 1 given the lack of effects found therein. Instead, we used three lag lengths, finding a middle ground between the one lag of Dywan et al. (1998, 2002) and the four lags of Jennings and Jacoby (1997). The results showed similar trends for accuracy across all three time conditions, regardless of lag, suggesting that the interval between study and test phases has little bearing on the accuracy of recognition. Within groups there was no difference found between the accuracy results for lag 0 and the longer lag conditions. While this seems to point towards the length of interval between study and test phases having little impact on the results found, it also seems to show a difference with the methodology in comparison to other opposition-based experiments. Wolk et al. (2006) found deficits in recognition after a 24 hour delay in a simple recognition task compared to an immediate testing, but this was not found in the present work. The increase in RT length for the longer lags in Experiment 2 did mirror the findings from the earlier lag-based experiments, such as that of Jennings and Jacoby (1997).

Experiments 1 and 2 both used a 70-word study list, more than the 60 used by Jennings and Jacoby (1997), and containing significantly more trials than the 25-word lists used by Dywan et al. (1997, 1998). As the length of the study list was withheld from participants, it may have caused the use of rote learning in an attempt to memorise the words. The length of the study list may have had a negative effect on the memory capacity of participants, as the capacity for rote-learned information is generally accepted to be 7 +/- 2 pieces of information, as evidenced by the digit-span task (Miller, 1956). This may have led to a floor effect in the Target conditions (Hits and Misses), where a low score would be recorded regardless of lags. This is reflected in the data, in that there are no significant differences between any of the Target condition lag lengths, and the Target scores were found to be generally lower than the corresponding Distractor scores. As the Distractor words appear for the first time in the test phase, they may enforce a novelty effect, whereby participants know they have not seen the stimuli before, and are therefore more likely to respond accurately to them. This phenomenon has been found in studies of simple recognition (e.g. Izquierdo, 1987). Another possibility is that the longer length of the study list in comparison to other studies in the area and the monotonous nature of the task due to its length may have led to increased activation of hippocampal areas given the presentation of new words on-screen, therefore affecting the consolidation and retrieval of a distractor word (Izquierdo, Barros, Medina & Izquierdo, 2002). However, without imaging or EEG data, it is difficult to examine if this was the case.

For Experiment 2, the use of only three lag lengths compared to the six from Experiment 1 did not lead to an increase in accuracy for target or distractor words, although it did lead to a trend towards lower accuracy at lagged trials and significant RT increases for lagged trials. The RTs reported in Experiment 1 showed a trend towards longer RTs for longer lags, but not to the same extent as Experiment 2, perhaps due to the slightly simpler nature of the three-lag task in comparison to the six-lag design. The target responses for the three conditions (Immediate, 1-hour delay and 24-hour delay) show a general trend towards lower accuracy at longer lags, although this is absent in the distractor responses for the most part. A reason for the difference between these results and those of the studies being compared to may be the small number of participants used, decreasing the variance in the data and requiring a greater effect size to achieve significance. The use of a relatively homogenous sample of university-level students could also be a factor in the generally high scores reported regardless of lags length.

While neither experiment found accuracy data similar to that of the previous research, the Reaction Time data showed a more consistent pattern. Experiment 1 showed a trend towards longer RTs at longer lags in all conditions, although only the Correct Rejection and False Alarm conditions showed significant differences between the short and long lags, particularly between lag 0 and lag 16. These findings led to the use of these lags in Experiment 2, as well as lag 4 as an interim lag. The results for RTs in Experiment 2 showed very consistent and significant RT changes dependent on lags, with conditions showing longer RTs for lag 4 and 16 when compared to lag 0. As previously stated, these results closely mirror the findings from the earlier opposition-based paradigms, despite the changes made to the task for the current study. Bridson et al. (2006) did not report the same magnitude of difference in RT data based on responses to lagged vs. unlagged stimuli as other studies in the area, although the comparison may be sufficiently different to that between lag 0 and longer lags to explain this anomalous result.

3.4.2 Conclusions

These experiments elicited a number of interesting results which encourage the use of a standard version of the Opposition Task for the remainder of the current thesis. Firstly, the length of lag used seems to have little impact on the accuracy of results, as long as the stimuli are lagged. As such, further experiments following Experiment 1 were designed with 3 lags, lag 0 (immediate lag), lag 4 (short lag length) and lag 16 (long lag length). While a further, longer lag may find more pronounced results due to the remote nature of the second presentation in comparison to the first, it would also create a longer test phase, which could interfere with memory for the study list, and so was not incorporated. Experiment 2 revealed that inter-phase intervals showed no discernable impact on the recall accuracy levels, and as such, subsequent experiments could be carried out using the immediate recall condition, allowing for the creation of a simple experiment for EEG recording, as seen in Chapters 4 and 6. Finally, the possible effect of a long study list disrupting encoding was taken into account, resulting in the use of a shorter list, composed of 40 words. The first and last five stimuli remain as primacy and recency buffers in an attempt to create an even recall level without primacy or recency distortions occurring.

Given the results of Experiment 2, larger group sizes will be incorporated into the following studies to increase the chances of significant differences being found between lag lengths and conditions. These adaptations, based on the current results, have led to the generation of a reliable and flexible example of the Opposition Task for further behavioural and electrophysiological examination throughout this thesis. With this in mind, Chapter 4 attempts to investigate the scalp-recorded electrical brain activity as well as potential neural generators associated with the execution of the Opposition Task as created, using EEG to create ERP waveforms, and extrapolating possible neural generators from these through the use of dipole source modeling.

Chapter 4

The effects of lag on ERP amplitude and Dipole Models in an Opposition Task

Abstract

This chapter uses a modified Opposition Procedure, based on that developed by Jacoby and colleagues (Jennings & Jacoby, 1997) and on the results found in the previous chapter. The task tests source memory capacity by drawing on repetition errors in a word recall task in which novel words are presented repeatedly at 3 differing lags (0, 4 and 16 trials), using a sample aged 18-28. The current chapter also repeats previously studied words. In this chapter we recorded 128-channel EEG from 22 normal healthy participants while they executed the Opposition Task. The behavioural results showed that accuracy decreased significantly ($p<0.05$) for longer lag trials compared to lag 0 trials, with an associated significant increase in reaction times ($p<0.05$) for the longer lag conditions, replicating previous results. A distinct pattern of ERP componentry associated with the task was observed, particularly a frontal P3 component which showed a greater positive deflection for correctly identified target words and a parietal P3b component which showed greater positivity for all correct over incorrect responses. Dipole source analysis showed more definite prefrontal cortex and parietal area dipoles for correctly recalled stimuli over incorrectly recalled stimuli, suggesting that these two areas are vital in accurate recall of source.

4.1 Introduction

Electrophysiological data from source memory studies using young adults show a number of consistent results. Dywan, Segalowitz and Webster (1998) had a young control group in their study involving one lag length and found that these participants showed different ERP components for target words and distractors (foils), with targets showing higher positivity at frontal sites at ~400ms compared to distractors. Lagged distractors were found to show similar results to new distractors, although with slightly more parietal positivity at ~500ms, but still less positive-tending than unlagged targets. Dywan et al. (2001) added to this by finding that young adults showed higher frontal positivities in response to target words over distractors. In a further study, Dywan, Segalowitz and Arsenault (2002) again compared target, lagged target and distractor words in young adults, finding that target words elicited an early frontal positivity absent in the foil words or in lagged words.

A more recent study involving one variable lag length (from 7-9 words) was carried out by Bridson et al. (2006) using a young healthy group. Their findings were that both correct target responses (Hits) and lagged Hits showed higher frontal positivity than correct responses to distractor words (Correct Rejections). This pattern was repeated at parietal sites, though later in the epoch (~500ms). Also, Misses, or incorrect responses to targets, showed reduced late positivity over Hits. Another recent study by Kim, Roh, Yoo, Kang and Kwon (2009) examined speech-based source memory using EEG recording. Their results showed increased right frontal scalp activity for correct target responses compared to correct distractor responses, as well as greater right parietal scalp activity later in the ERPs for correct targets.

These EEG results point to an increase in frontal activity for correct responses to targets (Hits) over correct responses to distractors (Correct Rejections) and to lagged Hits, as well as increased activity for correct over incorrect responses in general, including later parietal areas. However, studies to date have not examined whether different lag lengths will create different ERPs. The addition of an intermediate lag between the first and lagged stimuli could determine if there is a stepped change in EEG activity for differing lags. They also do not examine the effect of repeating a target at lagged intervals. Both of these short-comings are examined in the current chapter.

In terms of neural generators, Kim et al. (2009) created a dipole model for the results of their "Source Correct" condition during an aural source task. They found that despite the right-sided bias in their scalp recordings, bilateral superior frontal dipoles were created in the healthy young group. An fMRI study by Dennis et al. (2008) using a face-recognition based source task found areas of the frontal lobe and connections with medial temporal lobe (MTL) were strong early in source recalls. Gold et al. (2006) also found that activations in temporal areas were linked to correct recall of source using fMRI.

The previous chapter (Chapter 3) examined how inter-trial and intra-trial changes could modify performance on the Opposition Task among young adults. The reaction time (RT) data and the trends in accuracy in Experiment B have led to the current Opposition Task format, with three lag lengths being used. The lag of 0 is used as a baseline condition. A lag of 16 was included as a long lag, intended to cause disruption in retrieval in participants. To examine differences in ERP between lagged stimuli at different lengths, a short lag was also included, lag 4. Behaviourally, it is predicted that participants are significantly more likely to label a test-list word as studied if the word is repeated following a lag of 4 or 16 intervening words, as found in previous lag-based Opposition procedures (e.g. Jennings & Jacoby, 1997; Dywan, Segalowitz & Arsenault, 2002).

Therefore we hypothesise that accuracy will decrease as lag length increases, particularly between Lag 0 and the two longer lag lengths. It is also hypothesised that reaction time will increase with increased lag length, again, particularly between Lag 0 and the longer lag length conditions. We hypothesise that words correctly identified as foils or targets will show increased positivity in parietal scalp regions while correctly identified target words will also show increased positivity in frontal regions. Finally, waveforms will be subjected to dipole source analysis procedures in order to identify cortical and sub-cortical generators of the scalp potentials. We hypothesise that correctly recalled words may elicit a larger electrophysiological response in medial temporal regions while correctly recalled targets will also elicit a stronger electrophysiological response in frontal regions, particularly the right prefrontal area. All responses are expected to show parietal activity, particularly at later periods, as evidenced by the parietal activity reported previously.

4.2 Method

4.2.1 Participants

The participants for this study consisted of 22 healthy young adults (age range=18-28, mean=23.4) who volunteered to take part in a study on memory. Of these participants, 4 were removed for excessive EEG/EOG artefacts or head movements in there data and 1 for computer malfunction. Of the remaining 17 participants, 9 were female and 15 were right-handed. English was the primary language of all participants, all reported normal or corrected-to-normal vision. All participants were initially asked to complete a Cognitive Failures Questionnaire as a gross index of memory function (Broadbent, Cooper & Fitzgerald, 1982; See Chapter 2). The experiment conformed to the 1964 Declaration of Helsinki and was approved by the local ethics committee. Participants gave written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information act. The experiment was conducted in accordance with the Code of Ethics of the World Medical Association and the ethical standards of the APA.

4.2.2 Design

The study consisted of a repeated-measures design, with Lag Length as the variable. Lag Length was operationalised on three levels: lag 0, lag 4 and lag 16. Both the behavioural and the electrophysiological results were examined using this same design. Results from the ANOVAs were further examined using Bonferroni-adjusted t-tests.

4.2.3 Apparatus

The task used for the study was a version the Opposition Task developed by Jennings and Jacoby (1997). Alterations were created based on the results found so far in this work, as discussed in Chapter 2 and Chapter 3. As such, the task consisted of 6 separate study and test phases using one of two study lists of 40 words for each of the 6 phases. Each study list included 5 buffers for primacy and recency effects, drawn from the Toronto Noun Pool (Kucera & Francis, 1982), which were not included in the test list. The 30 words from the study list (targets) and an equivalent number of distractor, or “foil” words, were presented twice each during the test phases of the experiment, leading to 128-word test lists, with the 8 being filler words needed in order to include the full amount of lagged words. The high number of presentations was used to reduce signal-to-noise ratio and thereby yield more artefact-free ERP waveforms, again discussed in Chapter 2.

4.2.4 EEG recording and analysis

The EEG set-up for this chapter is described in Chapter 2 (Methods). For this experiment, stimulus-locked ERPs were obtained by averaging the EEG using stimulus presentation as the trigger, and continuing for an epoch of 1200ms post-stimulus, with a 100ms pre-stimulus baseline. Participant EEG was used to create 12 separate conditional ERPs, based on the 12 possible combinations of stimuli and responses (target stimulus at lag 0, 4 or 16 with a correct response, target stimulus at lag 0, 4 or 16 with an incorrect response, distractor stimulus at lag 0, 4 or16 with a correct response and distractor stimulus at lag 0, 4 or 16 with an incorrect response). Table 4.1 shows the minimum, maximum and mean number of trials used to create the different conditional ERPs.

Table 4.1: *Number of valid epochs used for the ERPs analysis of each condition, showing minimum, maximum and mean epochs.*

	Min	**Max**	**Mean**
Correct Target	34	48	41
Incorrect Target	12	26	19
Correct Distractor	41	46	44
Incorrect Distractor	14	19	16

An overall grand-mean waveform was generated for each electrode by collapsing across each group and condition. This allowed the latency of the components of interest to be identified through a simple visual inspection. A posterior P2 component occurred from 80-166ms, peaking at 124ms. A posterior N2 component measured from 166-230ms, peaking at 200ms. A frontal P3 measured from 300-600ms, peaking at 480ms. Finally, a posterior P3 (P3b) measured from 450-750ms, with a peak at 520ms. Using this form of grand-mean analysis in order to identify component latencies has the advantage of reducing the number of analyses undertaken.

These four components were compared across conditions for differences in mean amplitude. For the prefrontal region, the FP2 electrode was chosen for statistical analysis as it represented the peak amplitudes in the area of interest. The parietal electrode used was in the P3 position, chosen for the same reason. Both were compared to the reference electrode. For these analyses, a repeated-measures ANOVA was used, comparing lag length (0, 4, and 16), accuracy (correct, incorrect) and stimulus type (target, distractor) using mean amplitude as the dependent variable. All groups of paired t-tests were subjected to Bonferroni correction prior to reporting.

4.3 Results

4.3.1 Behavioural Analysis

4.3.1.1 CFQ

The participants were examined for their everyday memory lapses by use of the CFQ, which reported a mean score of 33.6 (SEM= 8.12) in the experimental group, allowing them to be considered as having within the normal range of cognitive failures.

4.3.1.2 Accuracy

Overall accuracy was high across lag conditions with participants generally scoring a minimum of 7 out of 10 in every condition. Figure 4.1 shows the mean and standard error for accuracy in each of these conditions. A repeated-measures ANOVA was carried out on the accuracy data in order to test for statistical significance. A main effect of stimulus type (target vs. distractor) was found [F (1, 21) = 11.097, $p<0.05$] as well as a main effect for lag (0 vs. 4 vs. 16) [F (2, 44) = 51.69, $p<0.01$]. Bonferroni corrected t-tests showed that participants were significantly more accurate at recognising target words at lag 0 than at lag 4 [t (21) = 6.544, $p<0.05$]. Participants were also significantly more accurate at recognising target words at lag 0 than at lag 16 [t (21) = 6.942, $p<0.01$]. In terms of distractor stimuli, accuracy was significantly higher for distractor words at lag 0 than at lag 4 [t (21) = 4.506, $p<0.01$] and more accurate at recognising distractor words at lag 0 than at lag 16 [t (21) = 2.665, $p<0.05$].

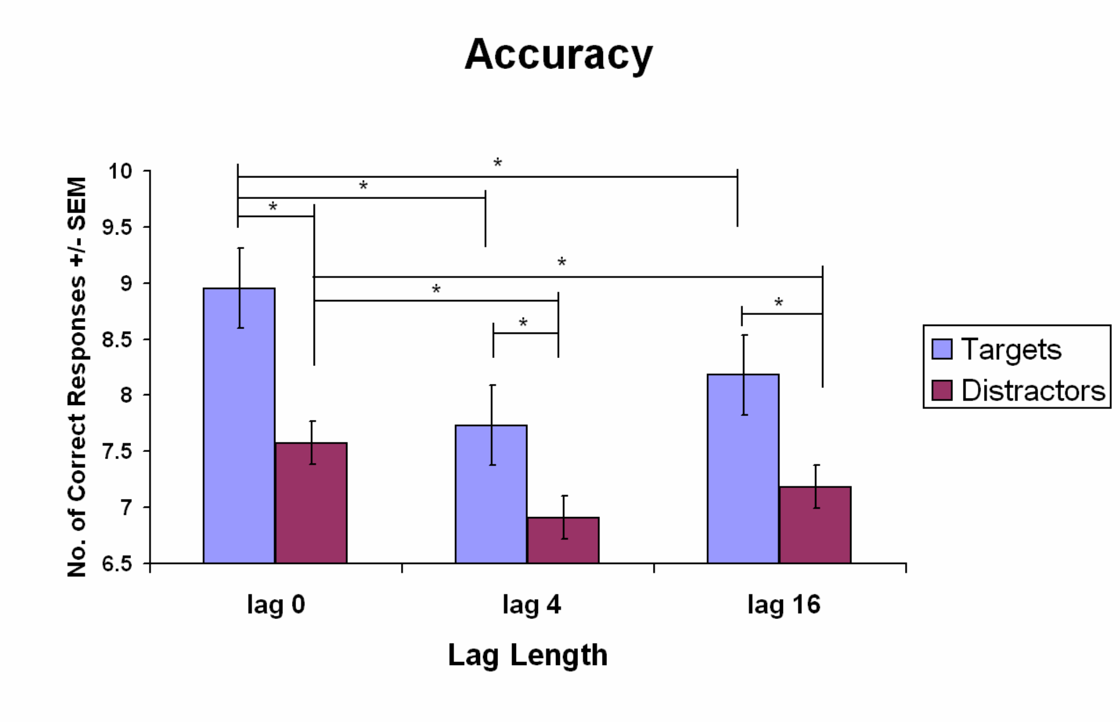


Figure 4.1: *Graph of mean accuracy of responses by participants to both target and distractor stimuli*

4.3.1.3 Reaction Times

Figure 4.2 shows the means and standard errors for the RTs to correct responses. Figure 4.3 shows the means and standard errors for incorrect response RTs. A repeated-measures ANOVA revealed a main effect of lag length [F (1, 22) = 64.496, p=0.0001]. A stimulus*accuracy interaction effect was also found [F (1, 22) = 6.262, p<0.05]. Bonferroni multiple comparisons on correct responses to target stimuli showed that RTs were significantly longer for the lag 4 [t (22) = -10.042, p<0.01] and the lag 16 conditions over the lag 0 condition [t (22) = -9.171, p<0.01]. For correct responses to distractors, RTs were significantly longer for the lag 4 [t (22) = -8.682, p<0.01] and the lag 16 conditions over the lag 0 condition [t (22) = -8.635, p<0.01].

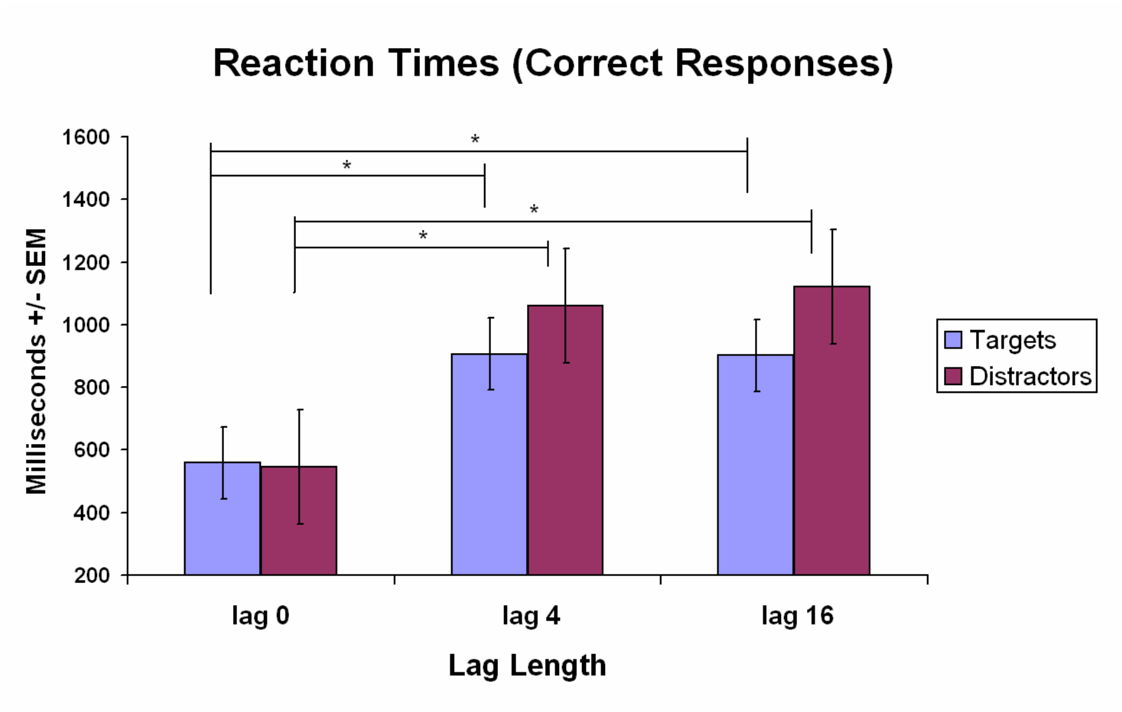


Figure 4.2: *Mean reaction times achieved by participants for correct responses to targets (Hits) and to distractors (Correct Rejections)*

For incorrect responses to target stimuli, RTs were significantly longer for the lag 4 condition over the lag 0 condition [t (22) = -3.268, p<0.05] and for the lag 16 condition over the lag 0 condition [t (22) = -7.804, p<0.01]. The same pattern was evident for incorrect responses to distractors, with significantly longer RTs for lag 4 over lag 0 [t (22) = -5.844, p<0.01] and for lag 16 over lag 0 [t (22) = -8.242, p<0.01]. Correct responses to target trials in the lag 16 condition were also found to be significantly faster than incorrect responses in the same condition [t (22) = -3.390, p<0.05].

Figure 4.3: *Mean reaction times achieved by participants for incorrect responses to targets (Misses) and to distractors (False Alarms)*

4.3.2 ERP Analysis

Separate 3x4 (lag x condition) repeated-measures ANOVAs were carried out for the 4 identified components for mean amplitude data at both FP2 and P3 scalp electrode sites to examine the data for statistically significant differences. The P2 component data at the parietal scalp electrode showed no significant main effects for Lag [F (2, 32) = 0.813, p>0.05] or Condition [F (2, 32) = 0.487, p>0.05], as well as no condition*lag interaction effect [F (2, 32) = 0.765, p>0.05]. The N2 component at the same site showed neither a main effect for lag [F (2, 32) = 0.611, p>0.05] or condition [F (2, 32) = 0.982, p>0.05], or an interaction between the variables [F (2, 32) = 1.31, p>0.05]. This clear pattern of non-significant differences led to no further analysis of these components.

Figure 4.4 shows the comparison between the four conditions at the three lag lengths at the FP2 frontal area scalp electrode, showing the P3 component which exhibits greater positivity in the lag 4 and 16 conditions over the lag 0 condition to some degree in all four conditions, particularly evident for the Hits and False alarms condition; those in which the participant assumes the stimulus is a target. The ANOVA showed a main effect for condition [F (3, 48) = 3.215, p<0.05]. A lag*condition interaction effect was also present [F (6, 96) = 3.886, p<0.05]. The resulting Bonferroni corrected t-tests showed a number of significant results. Mean amplitudes were significantly higher for Hits at lag 4 [t (16) = 3.134, p<0.05] and at lag 16 [t (16) = 2.673, p<0.05] than at lag 0, for Misses at lag 16 than at lag 0 [t (16) = 2.439, p<0.05] and for False Alarms at both lag 4 [t (16) = 2.41, p<0.05] and lag 16 [t (16) = 2.807, p<0.05] compared to lag 0 trials. The Correct Rejections did not show significant differences, nor did any lag 4 vs. lag 16 comparisons in the other conditions.

Between the conditions, at lag 0 the Correct Rejection condition showed higher mean amplitude than the Hits condition [t (16) = 2.165, p<0.05], but no other significant differences were found. At lag 4, Hits were found to be more positive going than Misses [t (16) = 2.028, p<0.05], as were False Alarms [t (16) = 2.731, p<0.05]. No other differences were noted. Finally, for lag 16 trials between conditions, Hits were found to be more positive going than misses [t (16) = 2.933, p<0.05], as were Correct Rejections [t (16) = 2.421, p<0.05] and False Alarms [t (16) = 2.351, p<0.05].

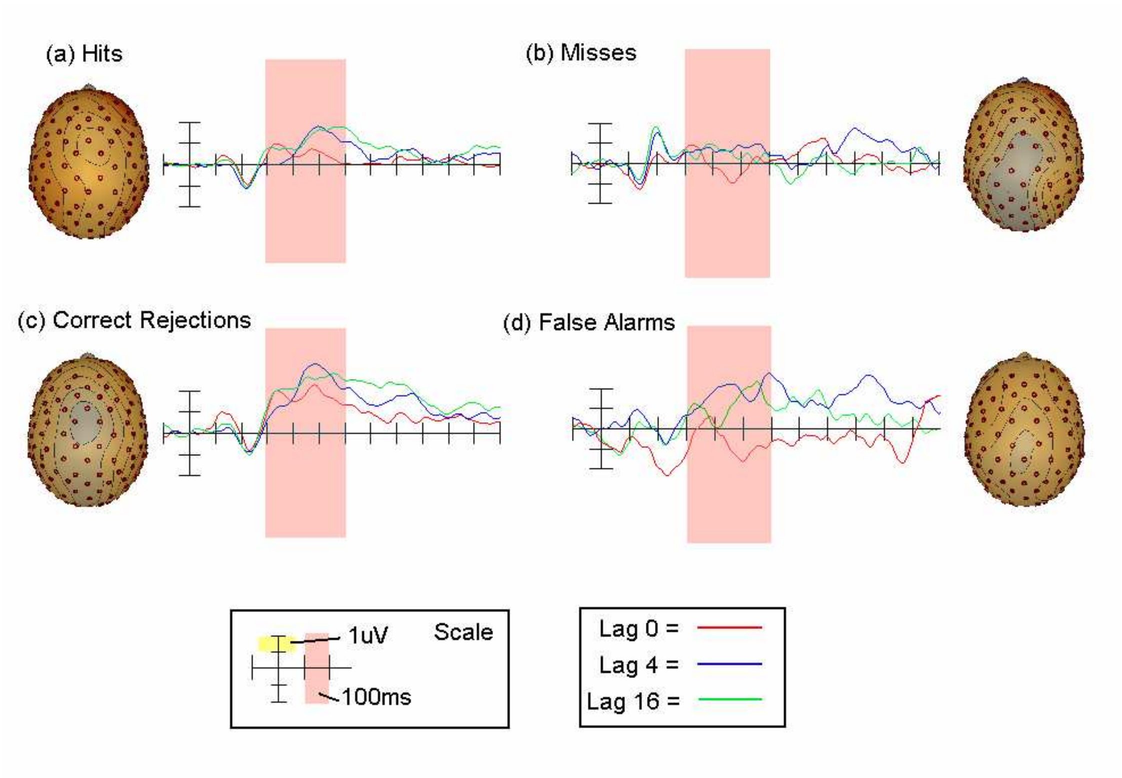


Figure 4.4: *ERPs for Hits, Misses, Correct Rejections and False Alarms at the three lag lengths at the frontal scalp FP2 site showing the majorP3 component to be examined. Scalp topographies represent lag 16 at 450ms for each condition.*

Figure 4.5 compares the four conditions at the three lag lengths at the P3 parietal scalp electrode, showing the P3b component which seems to have a strong negative deflection evident at lag 0 in all conditions that is not evident in the lagged stimuli, although it is not as evident in the False Alarm condition as the three other conditions. The ANOVA found a main effect for lag [F (2, 32) = 4.77, p<0.01] and for condition [F (3, 48) = 5.005, p<0.05]. A lag*condition interaction effect was also recorded [F (6, 96) = 4.519, p<0.05]. This again allowed for further examination through Bonferroni-corrected paired-sample t-tests. Within the conditions, a number of differences were found. For Hits, both lag 4 [t (16) = 2.119, p<0.05] and lag 16 [t (16) = 2.753, p<0.05] components were more positive tending than those at lag 0. For misses, only lag 16 [t (16) = 2.103, p<0.05] showed a difference following Bonferroni corrections. Correct Rejections showed increased positivity compared to lag 0 in both lag 4 [t (16) = 3.095, p<0.05] and lag 16[t (16) = 2.854, p<0.05] ERPs for the duration of the component. No significant differences were found between the False Alarm lag conditions.

Between the four conditions, further significant differences were reported. At lag 0, False Alarms were more positive tending than both Hits [t (16) = 2.801, p<0.05] and Correct Rejections [t (16) = 2.322, p<0.05], though not Misses. No significant differences were recorded between the conditions at lag 4 or lag 16.

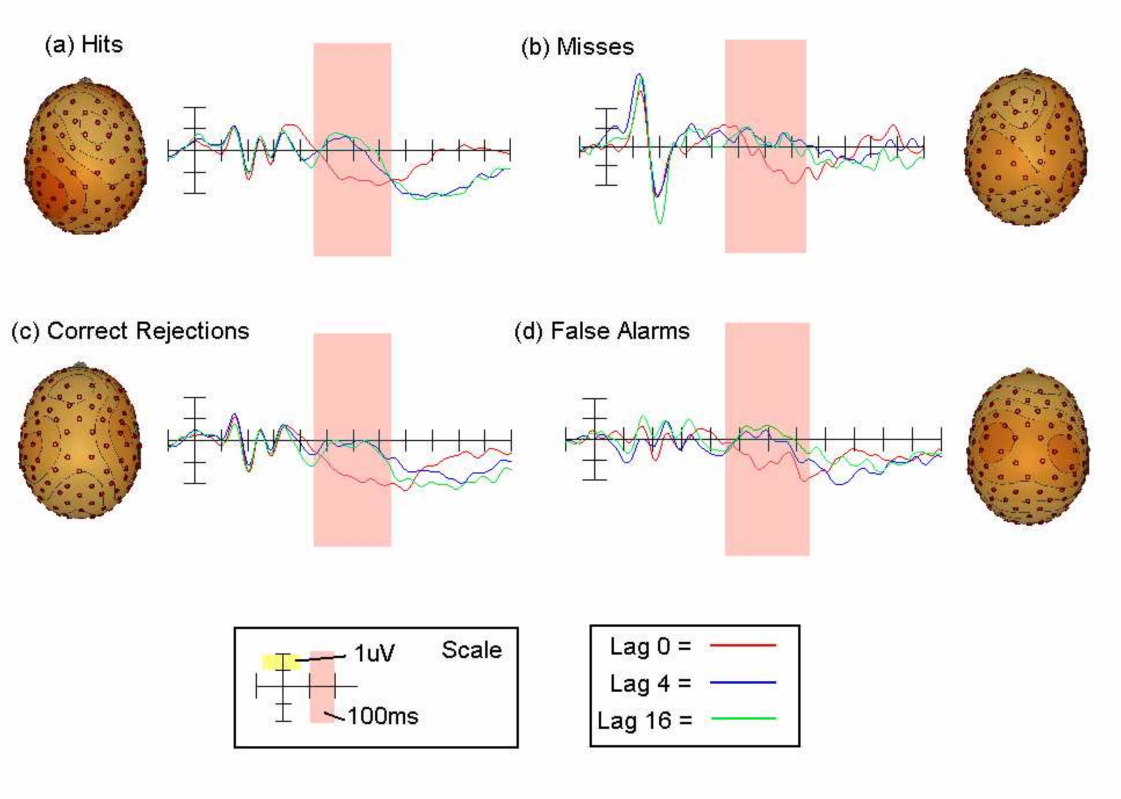


Figure 4.5: *ERPs for Hits, Misses, Correct Rejections and False Alarms at the three lag lengths at the parietal scalp P3 site showing the majorP3b component to be examined. Scalp topographies illustrate lag 16 at 600ms for each condition.*

Overall, this pattern of results shows that at both frontal and parietal sites there was an increase in activity for lagged data over unlagged, and that lag 4 and lag 16 data showed similarities across scalp area and condition. It also shows, at frontal sites, that Hits and False Alarms were more positive-going than Misses at both lags, while the parietal data showed few differences between conditions, apart from at lag 0, where False Alarms exhibited a more positive deflection than Hits or Correct Rejections.

4.3.3 Dipole Analysis

From the amplitude scalp maps shown in Figure 4.8 it is apparent that the scalp distributions visibly differed across the four trial types at lag 16, as seen at 400ms post-stimulus. There was frontal positive-tending activation found at this point for Correct Rejections, Misses and False Alarms, but this was seen to a greater degree in the Hit condition. A general pattern of right prefrontal and right parietal/occipital scalp topography was found across conditions, with only the Hits condition showing greater frontal scalp positivity, and both Hits and Misses showing more left-sided parietal scalp positivity compared to the distractor conditions. This is consistent with the ERP data, which showed greater positivity for Hits at frontal and parietal areas. The Hits condition showed a greater positivity at lag 16 compared to lag 0 at the FP2 electrode, starting from 300ms post-stimulus and continuing. To examine this difference in more depth, a dipole analysis was carried out on these conditions, from 350-400ms post stimulus. The False Alarms condition showed a large parietal scalp area difference between Lag 0 and Lag 16 from 400-700ms with Lag 0 showing significantly greater negativity in the area, and as such was included in the dipole analysis, in this case from 550-600ms post-stimulus. These analyses examine the cortical areas linked to these discrepancies between lag-lengths for Hits, where participants correctly assumed they were responding to a target word, and for False Alarms, where participants incorrectly assumed they were responding to target words.

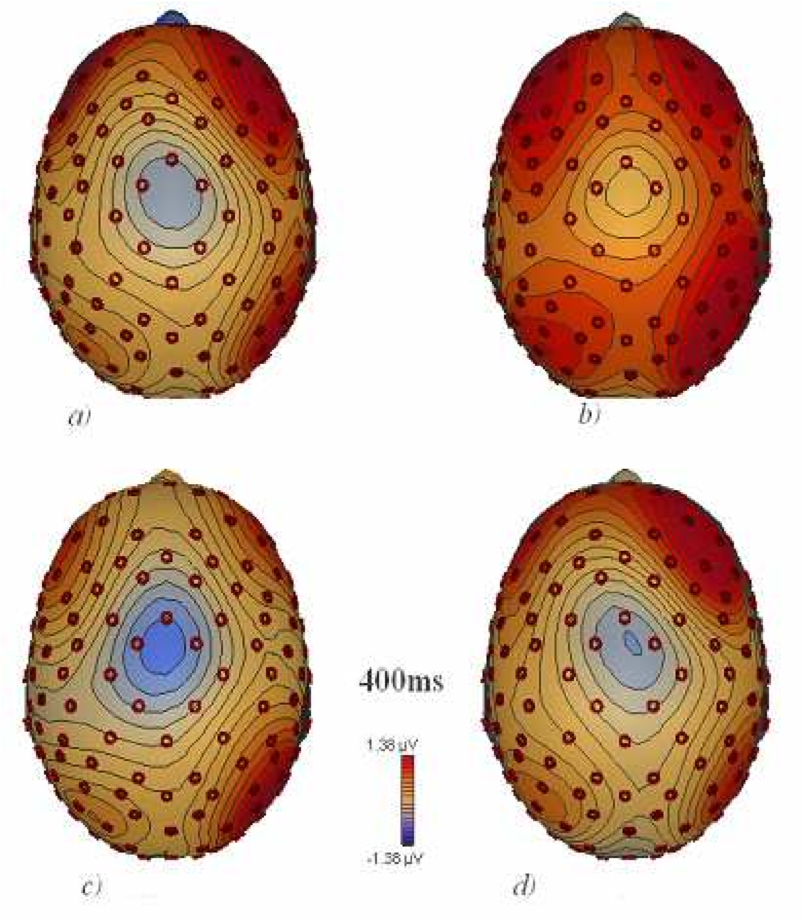


Figure 4.8: *Grand Mean scalp amplitudes for (a) Correct Rejections, (b) Hits, (c) False Alarms and (d) Misses at 400ms post-stimulus at Lag 16.*

In order to examine the neural generators of the scalp-recorded electrophysiological data, the Hits condition from the experiment was subjected to dipole source analysis for both Lag 0 (Residual Variance [RV] = 8.912%) and Lag 16 conditions (RV = 6.024%). Figure 4.9 shows a 4-dipole solution applied to the grand averages for Hits at Lag 0 and Lag 16 for the 350-400 timeframe.

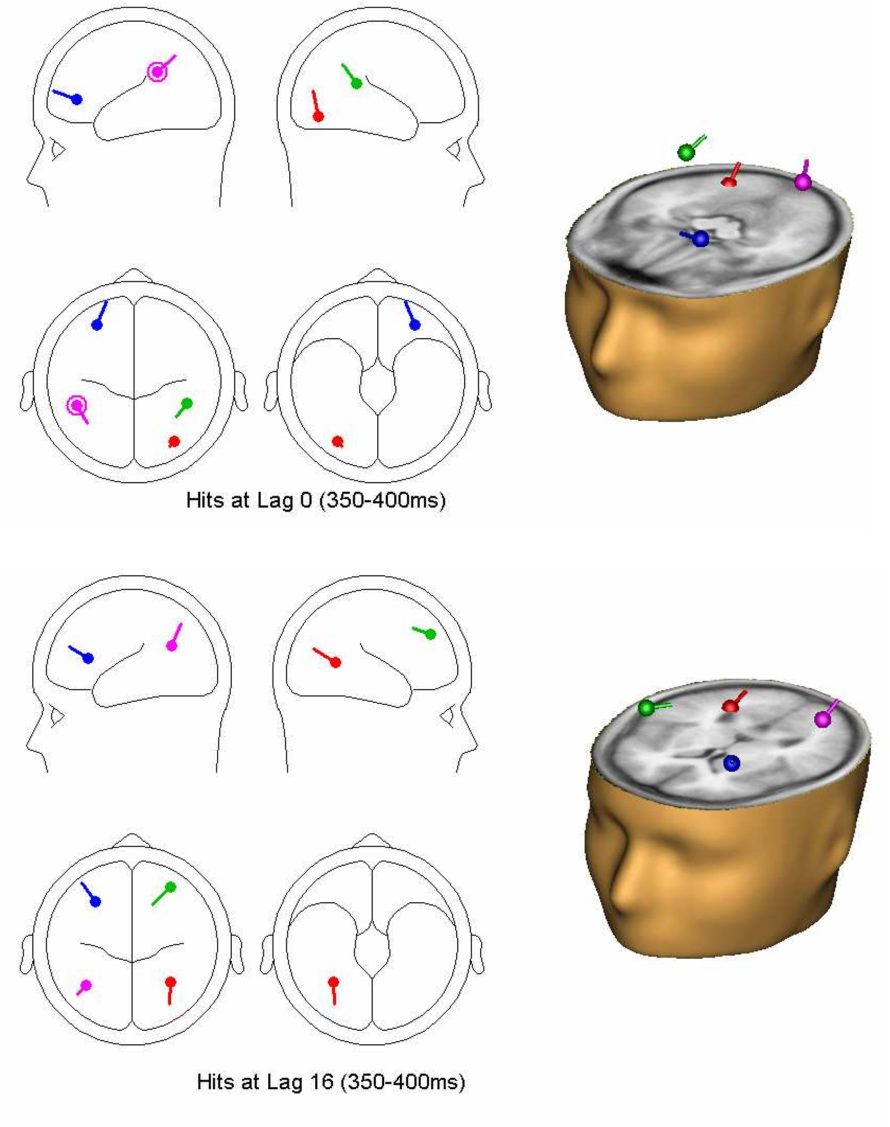
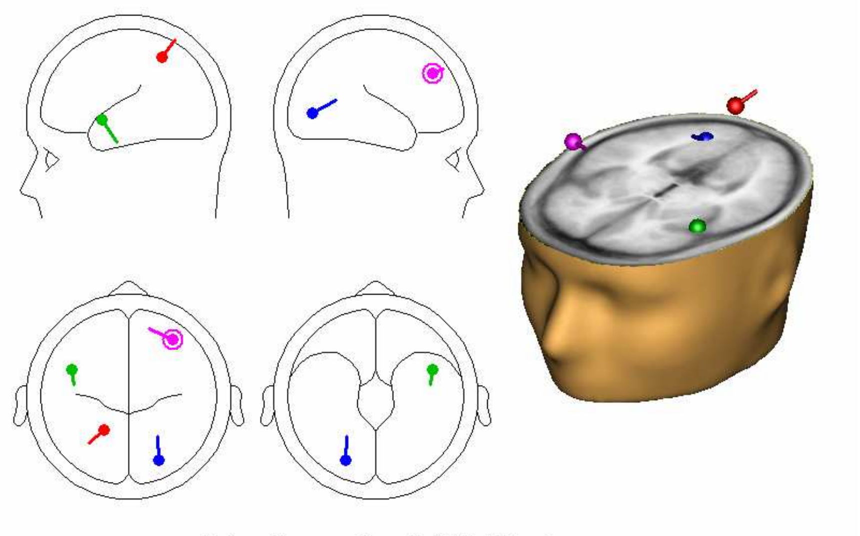


Figure 4.9: *Dipole locations at 350-400 ms for Hits at lag 0 (Top) and lag 16 (Bottom).*

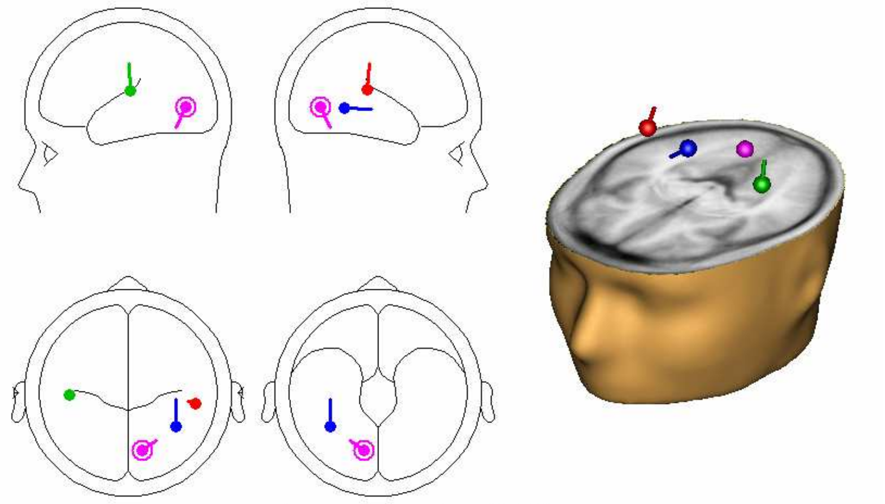
Talairach Daemon software (Lancaster, Summerlin, Rainey, Freitas, & Fox, 1997) was used to find the anatomical locus of each dipole found by the models. The lag 0 condition was shown to have dipoles approximate to the right fusiform gyrus in the occipital lobe (red, Brodmann’s Area [BA] 19), bilateral inferior parietal lobules (pink and green, BA 40) and the left middle frontal gyrus (blue, BA 10). The Lag 16 condition showed a dipole in the region of the right parahippocampal gyrus (red, BA 30), bilateral right middle frontal gyri (blue and green, BA 10) and the left middle temporal gyrus (pink, BA 39).

Figure 4.10 shows a 4-dipole solution applied to the grand averages for False Alarms for the 550-600ms timeframe in both lag 0 (RV = 5.215%) and lag 16 conditions (RV = 7.33%). Again, Talairach software was used to give the anatomical location of the dipoles found by the solution. The lag 0 condition was found to have dipoles located near the left precuneus in the parietal lobe (red, BA7), the right occipital lingual gyrus (blue, BA 18), the left insula (green, BA 13) and the right middle frontal gyrus (pink, BA8). The lag 16 condition showed a different pattern of dipoles, with sources close to the right parahippocampal gyrus (blue, BA 30), bilateral insula (red and green, BA 13) and the right occipital lingual gyrus (pink, BA 18).

These models show a number of interesting results. Both lag 16 conditions (Hits at 350-400ms; False Alarms at 550-600ms) showed MTL activity that was absent in the corresponding lag 0 conditions. The early Hits models show a difference between lag 0 and lag 16, with lag 0 having two parietal dipoles, a frontal dipole and an occipital dipole, while the lag 16 condition shows two frontal and two temporal dipoles. The later False Alarm models also show some differences, with the lag 0 condition having parietal, frontal and occipital dipoles as well as one located near the insula, between the temporal and parietal lobes. The lag 16 model shows bilateral activations near the insula, as well as a MTL dipole and an occipital dipole.



False Alarms at Lag 0 (550-600ms)



False Alarms at Lag 16 (550-600ms)

Figure 4.10: *Dipole Solution for False Alarm responses at Lag 0 and Lag 16 at the 550-600ms epoch*

4.4 Discussion

The purpose of this study was to utilise high-density ERPs to create a realistic model of the brain regions involved in source memory recall, and also to identify ERP componentry at specific scalp sites linked to old/new effects and source memory retrieval. Behaviourally, it was expected that participants would give more accurate and faster responses to the lag 0 condition words than those at lag 4 or lag 16. The data supported these assumptions, showing significantly lower scores and longer reaction times for the lag 4 and 16 conditions over the lag 0 conditions. No significant differences were found between the two longer lag conditions. The behavioural data are in line with those found in other studies in the area, including Jennings and Jacoby (1997), in that it was more difficult for participants to correctly recall the context in which words were learned when a longer lag length was introduced. The increased reaction times mirrored the increased difficulty in recall involved with the longer lags.

Electrophysiologically, it was hypothesised that longer lag lengths will induce greater positivity in frontal and parietal areas over lag 0 condition. For the frontal area P3 component this assumption was found to occur at both lag lengths, with Hits, Misses and False Alarms all showing higher mean amplitudes for lagged stimuli over the lag 0 stimuli. Lagged Hits also had significantly greater positivity than lag 0 Hits at the parietal P3 electrode for the P3b component, as did Misses and Correct Rejections. The False Alarm data did not show comparable differences. Only at lag 0 were there inter-condition differences found at the parietal site.

Wilding, Doyle and Rugg (1995) and more recently Wiese and Daum (2006) found that greater frontal positivity occurs when items are correctly recalled in comparison to incorrect recollection. Wilding and Rugg (1996) used an Old/New paradigm to examine this, and found that greater positivity occurs for correctly recognized words in a word recognition source task at both frontal and parietal sites. The frontal sites in that study showed greater positivity for correctly recalled Hits only above other responses, while the parietal sites showed increased positivity for all correct responses over related incorrect responses. This parietal effect was replicated in the current study, which has many similarities to the old/new paradigm, in that both correctly recalled Hits and distractors showed greater positive parietal deflections than those that were incorrectly recalled. However, no significant differences were found at the frontal site between those Hits and Distractors that were correctly recalled and those that were incorrectly recalled or forgotten. However, the inherent differences in the tasks used (Auditory Memory Exclusion Task vs. visual Opposition Task) could be the cause of these frontal dissimilarities in elicited waveforms. The lack of differences between Hits and Correct Rejections in parietal areas is in agreement with results obtained by Dywan, Segalowitz and Arsenault (2002), who carried out a similar task with young and old adults using one lag length difference reporting that between 400 and 800ms there were no significant differences between any correct responses.

Between lags, the data showed a general trend of lag 4 and 16 ERPs being similar. The differences between the lag 0 ERPs and the lagged ERPs were generally greater than those between the lagged ERPs, perhaps pointing to the possibility that any lag is sufficient to cause an electrophysiological change on the scalp. This mirrors the behavioural data, which showed few differences between the results for lag 4 and lag 16. The pattern of results evident in the current study, when compared to previous similar work, suggests that the parietal area is involved in more general memory processes, while the frontal area aids recognition of the source of the data.

Little experimental data exists for source memory studies using functional or structural brain imaging. However, Swick, Senkfor and Van Petten (2006) conducted an fMRI-based source memory study using a young adult group, a healthy old adult group and a group of patients with frontal area lesions. Their results showed a marked decrease in accuracy across all source judgment calls in the patient group in comparison to the healthy adult control group, as well as a lag in late frontal positivity, particularly in the left PFC in comparison to older adults. They concluded that older adults can use left PFC function to compensate for source-memory deficit, while this compensation is not available to frontal lesion patients. The prevalence of frontal dipoles for correct responses in the young adults in the current study may be comparable to the loss of source memory capacity in those with PFC lesions, especially for the lagged stimuli, which showed more frontal dipoles and scalp activity than the lag 0 condition. Guo, Duan, Li and Paller (2006) used ERPs and sLORETA (Standardized Low Resolution Electromagnetic Tomography) to study source encoding and retrieval, and again equated prefrontal activity with correctly recalled items, as well as some posterior frontal activity, as found in the current study. These results support the current findings. Unfortunately, data for incorrect responses were not recorded in the Guo et al. study, so a comparison of error waveforms and dipole placement is impossible.

The prevalence of dipoles in frontal areas for the longer lag for Hits is matched by the finding of parahippocampal dipoles in both lagged conditions compared to the control lag 0 condition. As discussed previously (See Chapter 1), the hippocampal formation is seen as central to memory processes by many theorists in the area (e.g. Squire & Alvarez, 1995; Nadel & Moscovitch, 1997). The absence of these dipoles at lag 0, and their presence at lag 16 in both conditions, seems to link the area to source memory processes, as other dipoles (insula, occipital dipoles) were consistent between the conditions. The dipole models generated here show a pattern of more frontal and medial temporal activations for longer lag lengths in both Hits and False Alarm conditions. This is consistent with the scalp electrophysiology, with the later parietal area activity seemingly having a neural generator in the area surrounding the insula and parahippocampus.

The results here bear further scrutiny, as they point to a pattern of ERP componentry and underlying neural generators that has not been previously examined in terms of older adults. The next chapter will examine the behavioural differences between young and old adults when attempting the Opposition Task created, as well as examining a middle-aged group, which has thus far been neglected in the literature. This will allow us to investigate whether source memory ability decreases over time from youth, through middle age, to old age, or whether no differences occur between any groups. Following that chapter, an electrophysiological examination of the age groups will be carried out, dependant on the results found in Chapter 5.

Chapter 5

Evidence for late onset of age-related deficits in Source Memory

Abstract

The previous chapters have examined young participants and found some evidence for source memory difficulties stemming from the Opposition procedure. This chapter uses three groups of participants to examine changes in source memory capacity over the life-span. The three groups used were: Young (20-30yrs), Middle Aged (40-50yrs) and Old (60-70yrs). The task used was a modified version of Jennings and Jacoby's (1997) Opposition Task, using three lag lengths during the test phase; Lag 0 (Immediate), Lag 4 and Lag 16, as seen in Chapter 3. The results showed a number of interesting features. In terms of accuracy, the Young and Middle groups scored at similar levels, with both showing decreases at Lag 4 and 16 in comparison to Lag 0. The Old group did not show this pattern, but were uniformly lower in accuracy across the three Lag lengths compared to both the Young and Middle aged groups. In terms of reaction times (RTs), the Young and Middle groups again showed broadly similar results, with RT increasing with lag length generally. The Older group showed slower RTs than both other groups in general, as well as an increase in RT for Lag 4 and 16 trials in comparison to the immediate Lag 0 trials. These results suggest that source memory ability remains stable through young and middle ages but suffers a marked decrease with advancing age.

5.1 Introduction

The last chapter showed strong behavioural effects as well as electrophysiological differences, giving an indication that the lagged design of the Opposition Task creates difficulty in source memory recall, even among a healthy younger group. Those behavioural results form the basis of the hypothesis of this chapter; that older adults will perform more poorly in terms of both accuracy scores and reaction times than a younger group when presented with the Opposition task.

Older adults have demonstrated source deficits across a number of contexts, including that of similarity (Henkel, Johnson & De Leonardis, 1998) and temporal order (Fabiani & Friedman, 1996). Henkel et al. (1998) found that older adults are more influenced by similar items when judging the source of a memory than younger adults, and the features of their memories, whether attributed correctly or incorrectly, show a greater overlap than a younger group, perhaps leading to confusion of source. Fabiani and Friedman (1995) studied young and old participants in an experiment in which trials testing memory for temporal order (Recency memory) and recognition memory were randomly presented with study trials in a sequence. They found that for pictorial stimuli, older adults performed at a higher level for recognition compared to for source judgements. What has yet to be studied in-depth is the nature in which this apparent loss of source memory capacity occurs. Is it a steady decline from young to old adulthood or is there a drop in recall ability among older adults even compared to a middle aged group? To study this, such a group is included in the current chapter.

While studies involving cognitive deficits among middle-aged participants are relatively rare, Park, Smith, Lautenschlager, Earles, Frieske, Zwahr and Gaines (1996) completed a lifespan study of 300 participants aged from 20-90, divided into decades of age, resulting in 40-54 participants for each decade (apart from the oldest, which contained 23 participants). The study involved administering a total of 20 tests, ranging from tests for speed of response, to working memory, episodic memory and object recognition tasks. The experimenters found that working memory, cued recall, free recall and spatial memory had significant negative linear relationships with age, and that speed had a very strongly significant relationship with age, particularly due to a more pronounced decrease in performance in very late adulthood. These data suggest that some types of memory, at least, deteriorate across the lifespan. The study, however, did not measure source memory performance.

While a number of Old/New and Opposition paradigms have been used to examine the source memory differences apparent between younger and older participants, relatively few have examined the process by which this deficit occurs. It has yet to be conclusively found if a gradual decline over the course of a lifetime beginning in young adulthood occurs in source memory, or if the phenomenon is only associated with older populations. In an attempt to answer this question, we again make use of the Opposition Task, and incorporate the alterations mentioned in the Methods (Chapter 2) and Chapter 3 of the current thesis. To test the possibility of source memory ability declining over a lifetime, three sample groups were used, a group aged from 20-30 years of age, another from 40-50 and a third from 60-70. Results from these groups can be compared to conclude whether the middle-aged group has a similar pattern of responses to the younger group, showing that source memory deficit is a larger problem for older participants. Results from the middle group, if significantly lower than the younger group, would show that source memory decline is a life-long problem, starting from an earlier age than was previously thought. The hypotheses are that accuracy in the Opposition Task used will be significantly lower among the older sample compared to the younger and middle-aged samples, while young and middle-aged samples will achieve similar scores, showing source memory deficits to be linked with old age.

5.2 Method

5.2.1 Participants

The sample for the experiment consisted of 36 participants recruited in an *ad-hoc* manner, divided into three separate groups by age range. Group 1 consisted of 12 participants (6 female, 11 right-handed) aged between 20 and 30 years (range=20-28, mean=23.8, SD=2.4). Seven participants were currently in 3rd level education and 5 had completed a 3rd level course. Group 2 consisted of 12 participants (6 female, 9 right-handed) aged between 40 and 50 years (range=41-49, mean=45.6, SD=3.8). For this group, 8 had completed 3rd level education, while 4 had completed 2nd level education. Group 3 consisted of 12 participants (5 female, 11 right-handed) aged between 60 and 70 years (range=60-67, mean=64.4, SD=2.7). This group included 2 participants with 4th level education, 7 that had completed 3rd level education and 3 with 2nd level education. All participants had normal or corrected-to-normal vision, and were self-reported free from psychiatric or serious memory problems. A CFQ was completed by each participant to examine their everyday memory lapses. The experiment conformed to the 1964 Declaration of Helsinki and was approved by the NUI Maynooth ethical committee. Participants gave written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information act (1997). The experiment was conducted in accordance with the Code of Ethics of the World Medical Association and the ethical standards of the APA.

5.2.2 Design

The study consisted of a 3x3 mixed-factorial experimental design, with Age Group and Lag Length being the factors. Age Group was operationalised on 3 levels: young (20-30 years), middle (40-50 years) and old (60-70 years). Lag Length was operationalised on three levels: Lag 0, lag 4 and lag 16. Further analysis was carried out with regards to failures in everyday memory, using scores achieved in the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper & Fitzgerald, 1982) as the factor.

5.2.3 Apparatus

The task used for the study was based on the Opposition Task, with variations and procedural changes as laid out in Chapter 2 (Methods) and Chapter 3. The task was created using the E-Prime experimental presentation program and consisted of a study block of 40 words. Ten of these words were not presented in the test phase; the first 5 were removed to prevent primacy effects, the last 5 removed to prevent recency effects. This led to a test list of 128 words; 60 test words, 60 distractor words and 8 filler words. The filler words were used to allow for the presentation of the different lag lengths smoothly. Scores for filler words were not included in the analysis.

5.2.4 Procedure and Data Analysis

Participants were first asked to sign an informed consent sheet in order to show that they consented to be part of the study, and then to complete the CFQ in order to examine the extent of their everyday memory problems. They were then asked to sit in front of the computer monitor, approx. 100cm from the screen, with their hands on the keyboard in front of them. Participants were requested to study the first block of stimuli, consisting of 40 words, and were told that they were to remember these words for a following test block. Preceding the 128-word test block, another set of instructions was provided. Participants were told that if a word from the study block was presented during the test block, the “S” key on the keyboard should be pressed using the left index finger. If the presented word was new, (i.e. not shown on the study block) the “N” key on the keyboard should be pressed using the right index finger. The session consisted of 6 runs of the task, using separate study and test lists presented quasi-randomly. Following the presentation of the 6 study and test blocks, participants were fully debriefed and informed that all results would be analysed in an anonymous capacity, and reported as grouped means.

Performance accuracy and reaction times were both recorded during the test phase of the experiment. A correct response occurred when the participant pressed “S” when a word from the study list (target) was presented and pressed “N” when a new word (distractor) was presented. Reaction times were measured as the interval between presentation of the stimulus and the response and were recorded for both correct and incorrect trials. These responses and RTs were subjected to mixed factorial ANOVAs (Group [3 levels], Lag [3 levels]) as well as to separate Bonferroni-corrected paired sample t-tests in order to examine the statistical significance of the within-group differences. Finally, an analysis on the differences between first and second presentations of the study-list words was completed using independent and paired-sample t-tests, in order to examine any effects of the repetitions of the stimuli in the data. Hits were defined as a correct response to a target stimulus. Misses were defined as an incorrect response to target stimuli. Correct Rejections were defined as those correct responses to foil words, while False Alarms were defined as incorrect responses to foil words.

5.3 Results

5.3.1 CFQ

The results from the CFQ showed no significant differences between the age groups [F (2, 33) = 5.19, p = 0.14], with all participants scoring within the normal range for the questionnaire, and all groups scoring along a similar spectrum of results. This would seem to show a good level of general memory ability among the groups.

5.3.2 Accuracy

The Young and Middle aged groups showed similar results on completion of the task, with high accuracy scores across lag conditions. The Old group showed lower accuracy scores across conditions. The Young and Middle groups showed higher accuracy for Lag 0 trials than Lag 4 or Lag 16 trials. However, the Old group did not. Figure 5.1 shows accuracy for target words, or Hits, while Figure 5.2 shows accuracy for distractor words, or Correct Rejections. Two separate Group*Lag ANOVAs were completed in order to examine the main conditions: Accuracy of Target responses, or number of Hits, and accuracy of Distractor responses, or number of Correct Rejections.

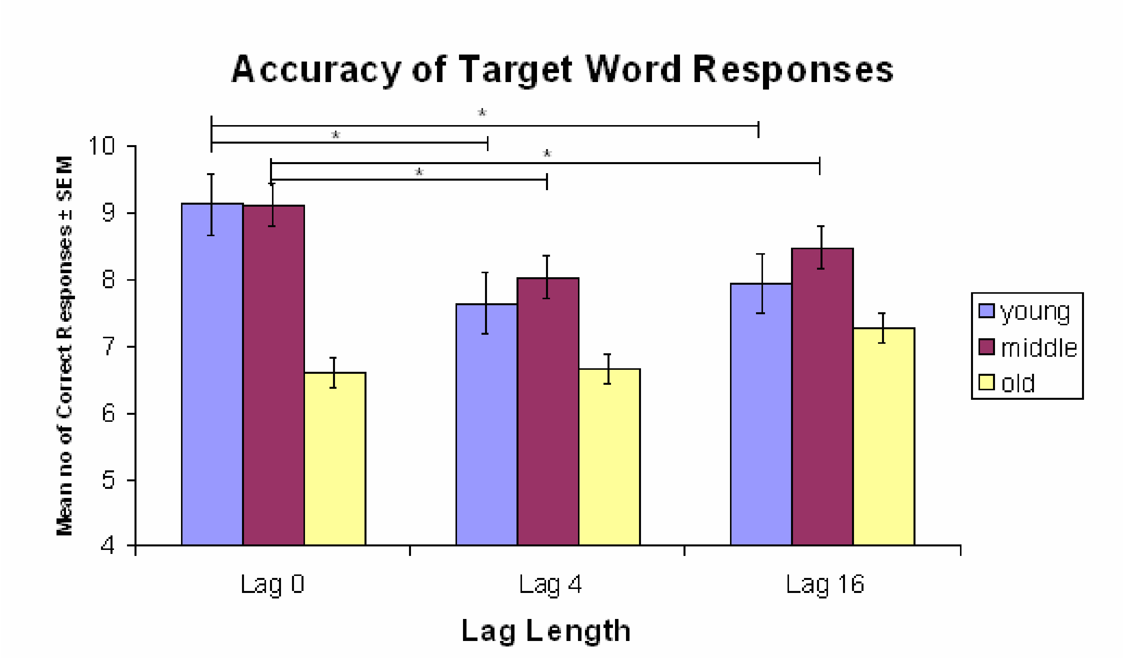


Figure 5.1: *Mean number of correct responses to Target Stimuli achieved by the three groups over the three Lag Lengths.*

In terms of within-group differences for Hits, a main effect for lag was found [F (2, 33) = 9.548, p<0.01)] and for group [F (2, 33) = 11.31, p<0.01] as well as an interaction effect for lag*group [F (4, 66) = 4.744, p<0.01)]. Bonferroni corrected t-tests were used to further analyse these differences, using paired-sample t-tests for within-group differences. For the Young group, lag 0 accuracy for targets was significantly higher than both lag 4 [t (11) = 4.919, p<0.01] and lag 16 accuracy [t (11) = 5.665, p= 0<0.01]. The Middle group also showed significant differences for target word accuracy between lag 0 and lag 4 trials [t (11) = 3.840, p<0.01], as well as a difference between lag 0 and lag 16 trials [t (11) = 2.494, p<0.05]. Lag 4 and lag 16 trials showed no differences. The data from the Old group were analysed for within-subject effects. No statistically significant results were found between any of the lag lengths within this group.

Between young and old groups, a number of significant results were found. For target words at lag 0, the Young group had significantly higher accuracy than the Old group [t (22) = 5.343, p<0.01], as did the Middle group [t (22) = 1.693, p<0.01]. A significant difference in the same direction was found for target words at lag 4 for both Young [t (22) = 2.594, p<0.05] and Middle groups [t (22) = 4.82, p<0.01] compared to the Old group. At lag 16 accuracy for target words also showed a significant difference between both Young and Old groups [t (22) = 2.422, p<0.05] and Middle and Old groups [t (22) = 3.167, p<0.01].

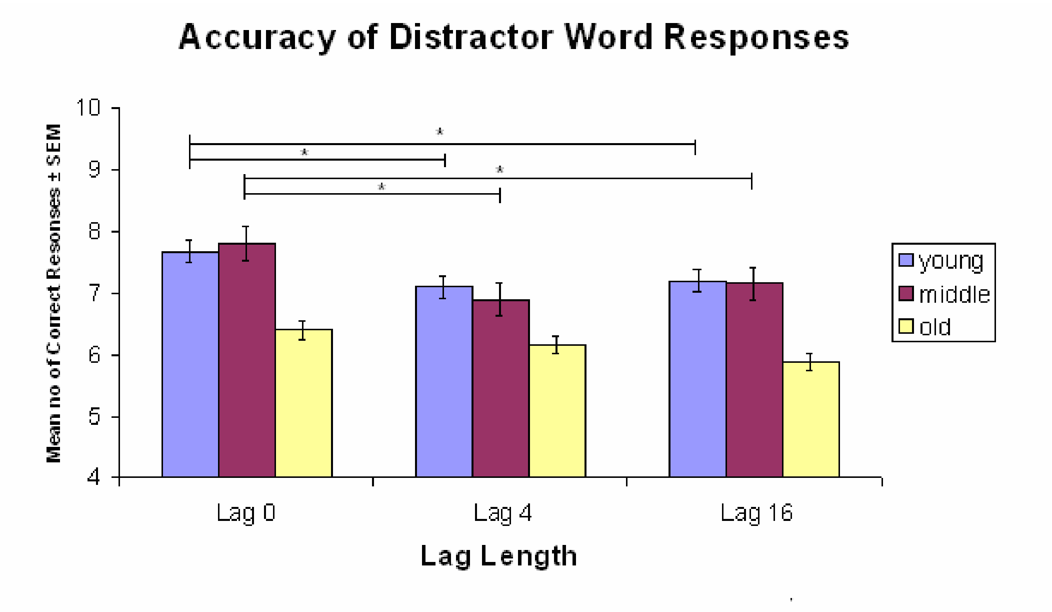


Figure 5.2: *Mean number of correct responses to Distractor Stimuli achieved by the three groups over the three Lag Lengths.*

For distractor word accuracy, a main effect for lag was found [F (2, 33) = 2.796, p<0.05]. Between-group analysis also showed a main effect for group type [F (2, 33) = 14.186, p<0.01]. A lag*group interaction was also reported [F (4, 66) = 4.153, p<0.05].

Lag 0 trials showed significantly higher accuracy scores than lag 4 trials [t (11) = 2.640, $p<0.05$], but not lag 16 trials for the Young group. No differences were found between lag 4 and 16 trials. The Middle group showed a similar pattern for distractor words, between lag 0 trials and lag 4 trials [t (11) = 4.763, $p<0.01$] and between lag 0 and lag 16 trials [t (11) = 2.56, $p<0.05$]. Again, lag 4 and lag 16 trials showed no differences. The Old group showed no significant differences for distractors.

Between the groups, the lag 0 trials showed a significantly higher result for the Young group compared to the Old group [t (22) = 2.504, $p<0.05$]. This pattern was repeated at lag 4 [t (22) = 2.772, $p<0.05$] and lag 16 [t (22) = 3.104, $p<0.05$]. The Middle group showed higher accuracy compared to the Old group at lag 0 [t (22) = 3.643, $p<0.05$], lag 4 [t (22) = 2.414, $p<0.05$] and lag 16 [t (22) = 1.943, $p<0.05$]. No significant differences were found for accuracy of either target or distractor words between the Young and Middle groups, with both showing comparably high accuracy rates across all three lag conditions.

5.3.3 Reaction Times

As with the accuracy scores, the Young and Middle groups showed broadly similar RTs, with the Old group showing generally longer times than either of the other groups. Figure 5.3 shows the RTs for correct responses to target words, or Hits, while Figure 5.4 shows RTs for correct responses to distractor words, or Correct Rejections. Figure 5.5 shows the RTs for incorrect responses to target words, known as Misses, while Figure 5.6 shows RTs for incorrect responses to distractor words, or False Alarms. In order to test the statistical significance of these results, both within- and between-group, repeated-measures ANOVAs were used. Four separate Group*Lag ANOVAs were completed in order to examine the main conditions: RTs for Hits, RTs for Correct Rejections, RTs for Misses and RTs for False Alarms.

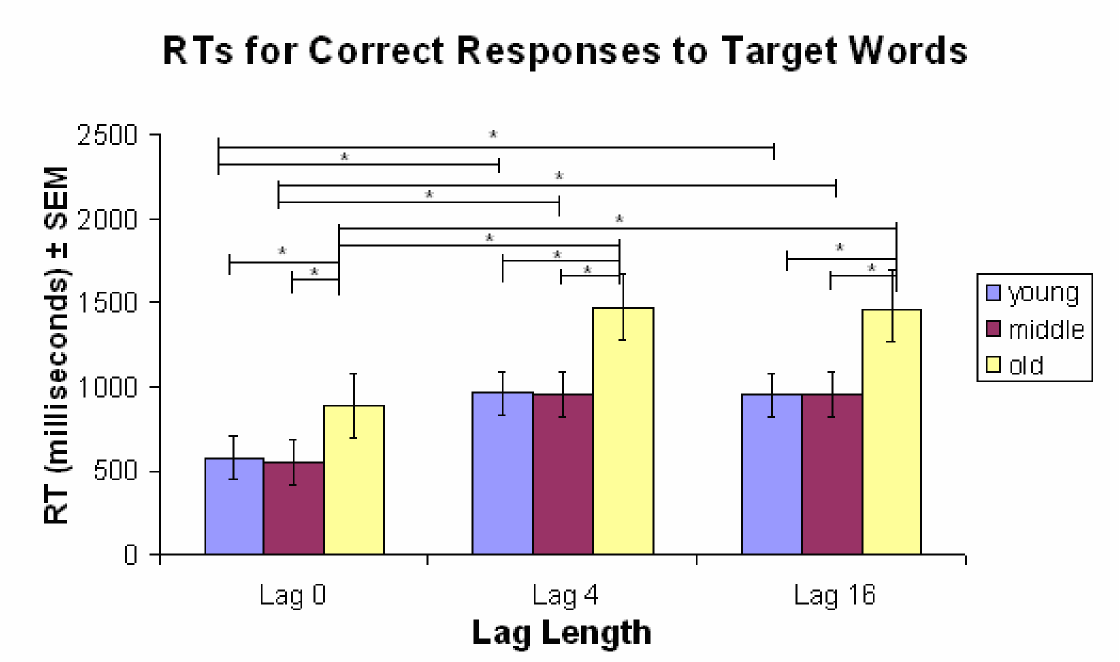


__Figure 5.3:__ Mean Reaction Times for Hit responses achieved by the three groups over the three Lag Lengths.

For the RTs for Hits, a main effect for lag was found [F (2, 32) = 3.772, p<0.05]. A between-subject effect for group was also recorded [F (2, 32) = 12.656, p<0.01], as well as lag*group interaction [F (4, 66) = 4.717, p<0.05]. For the young group, lag 0 Hit responses were significantly faster from those at lag 4 [t (11) = 7.068, p<0.01] and at lag 16 [t (11) = 3.133, p<0.01]. The Middle age group showed lag 0 Hit responses that were significantly faster from those at lag 4 [t (11) = 3.809, p<0.01] and at lag 16 [t (11) =

3.923, p<0.01]. Hits for the Old group at lag 0 were also significantly different from those at lag 4 [t (11) = 3.895, p<0.01] and at lag 16 [t (11) = 3.030, p<0.05].

Between the young and old groups, a large number of significant differences were found to be present. Older adults took significantly longer to achieve Hits at lag 0 [t (22) = 2.84, p<0.05], lag 4 [t (22) = 3.508, p<0.01] and lag 16 [t (22) = 3.641, p<0.01] in comparison to the Young adults. The Middle group showed significantly faster RTs than the Old group at lag 0 [t (22) = 4.812, p<0.05], lag 4 [t (22) = 4.01, p<0.05] and lag 16 [t (22) = 2.751, p<0.05]. As is evident from the graph, there were no significant differences between the Young and Middle groups.

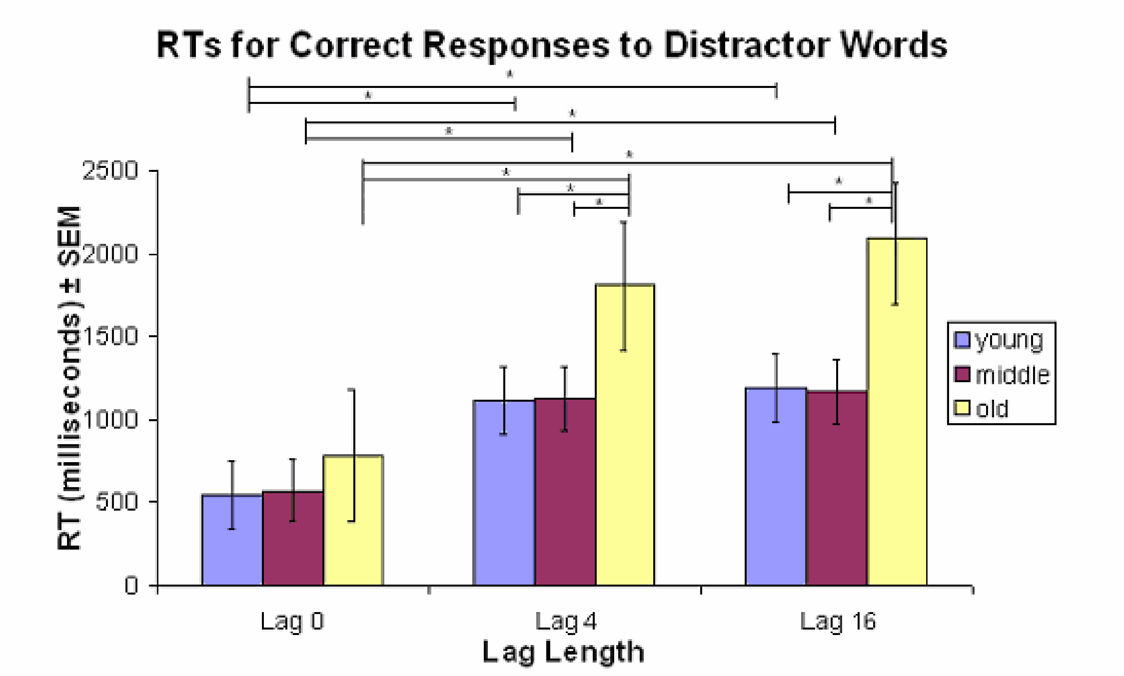


Figure 5.4: *Mean Reaction Times for Correct Rejection responses achieved by the three groups over the three Lag Lengths.*

Correct Rejection RTs showed a main effect within-subjects for lag [F (2, 32) = 6.615, $p<0.01$] and between-subjects for group [F (2, 32) = 9.314, $p<0.01$]. A lag*group interaction effect was also recorded [F (4, 66) = 4.94, $p<0.05$]. The young group showed significantly longer RTs for lag 4 [t (11) = 2.491, $p<0.05$] and lag 16 trials [t (11) = 6.281, $p<0.01$] over lag 0 trials. The Middle group responses showed a similar pattern, with lag 0 responses being significantly quicker than lag 4 [t (11) = 4.91, $p<0.01$] and lag 16 RTs [t (11) = 5.196, $p<0.01$]. The Old group responses showed lag 0 as being significantly quicker than lag 4 [t (11) = 6.292, $p<0.01$] or lag 16 responses [t (11) = 7.203, $p<0.01$].

Significant differences were also found for Correct Rejections between the Young and Old groups for both lag 4 [t (22) = 3.80, $p<0.05$] and lag 16 [t (22) = 4.23, $p<0.01$]. The Middle group were found to be significantly faster at both lag 4 [t (22) = 2.58, $p<0.05$] and lag 16 [t (22) = 1.912, $p<0.01$] in comparison to the Old group. Again, the Young and Middle groups had comparable results.

Figure 5.5: *Mean Reaction Times for Miss responses achieved by the three groups over the three Lag Lengths.*

Data for Misses showed a main effect between-subjects for group [F (2, 32) = 8.53, p<0.01], a main effect for lag [F (2, 32) = 5.144, p<0.05] and an interaction effect between lag and group [F (4, 64) = 4.052, p<0.05]. The young group showed significantly quicker lag 0 responses than lag 4 [t (11) = 5.597, p<0.01] or lag 16 responses [t (11) = 5.75, p<0.01]. The Middle group continued the trend, with lag 4 [t (11) = 3.647, p<0.01] and lag 16 [t (11) = 4.693, p<0.01] showing significantly longer RTs than those for lag 0. The Old group showed similar within-group results, with lag 4 [t (11) = 5.219, p<0.01] and lag 16 [t (11) = 5.392, p<0.01] showing significantly longer RTs than those for lag 0 trials.

Between the three groups, no differences were found at Lag 0. However, at Lag 4, the Young group responded significantly more quickly than the Old group [t (22) =

2.014, p<0.05], as did the Middle group [t (22) = 1.543, p<0.01]. At Lag 16, a similar pattern was evident, with both the Young [t (22) = 3.054, p<0.01] and Middle [t (22) = 2.71, p<0.01] groups showing significantly faster RTs than the Old aged group.

Finally, for False Alarms, a main effect for lag was found to be present [F (2, 32) = 3.811, p<0.05] along with a main effect for group [F (2, 32) = 9.183, p<0.01]. There was no lag*group interaction found for this condition. For the young group, lag 0 trials again showed significantly lower times than lag 4 [t (11) = 5.014, p<0.01] or lag 16 [t (11) = 6.606, p<0.01]. For the Middle group, lag 0 trials again showed significantly faster times than lag 4 [t (11) = 4.471, p<0.01] or lag 16 [t (11) = 7.076, p<0.01]. For the Old group, lag 0 trials again showed significantly lower times than lag 4 [t (11) = 4.868, p< 0.01] or lag 16 [t (11) = 12.699, p<0.01].

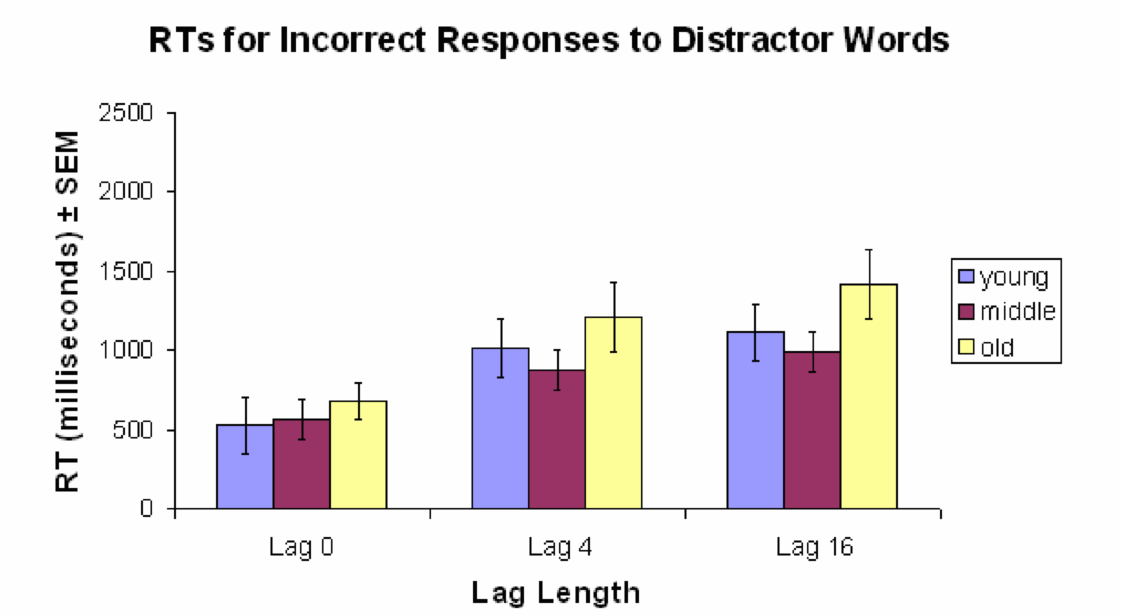


Figure 5.6: *Mean Reaction Times for False Alarm responses achieved by the three groups over the three Lag Lengths.*

No between-group differences were found in the False Alarm condition, with generally comparable results being shown by each age Group. The general finding for RTs therefore is that for all groups, lag 0 seems to take less time to respond to than lag 4 or 16. Also, the findings suggest that the Young and Middle group performed at similar response times, both of which were significantly shorter than the Old group, especially at lag 4 and lag 16 trials. False Alarm responses were the only deviation from this trend.

5.3.4 First Presentations of Stimuli.

Given the low results found in the Old group for accuracy regardless of lag, we compared the three groups for the first presentation of the stimuli, as per the Old/New paradigm, to examine if this pattern would exist for original presentations. The Old group was found to have significantly lower accuracy for first presentations of stimuli than the Young group [t (22) = 2.371, $p<0.01$] and the Middle aged group [t (22) = 2.57, $p<0.01$]. There was no significant difference between the Young and Middle group. For within-group results, the Old group was examined for differences between first and second presentations of stimuli. No significant differences were found [t (11) = 5.231, p= 0.082]. This leads to the conclusion that general recall and recognition in the older group were poor compared to the younger and middle aged groups.

5.4 Discussion

This study is the first to examine the pattern of decline in source memory recall accuracy over the lifespan of healthy participants. The accuracy results reveal that Old, but not Middle, aged groups show deficits relative to the Young group. No significant differences were found between the Young and Middle aged groups. The Old group had significantly lower accuracy scores than the young and middle group across all lags for both target and distractor words. This pattern suggests that a decline in capacity for source memory occurs between the ages of 50 and 70, as no differences were found between the 20-30 year olds and the 40-50 year olds.

The Young versus Old differences mirror those found across a number of source-memory studies including those of Jennings and Jacoby (1997) and Dywan, Segalowitz and Williamson (1994), both of which found significant deficits among older samples compared to younger, as did later studies by Dywan et al. (1998, 2002) and Bridson et al. (2006). The introduction of the middle-aged sample adds a further dimension to these results, suggesting that source memory is preserved intact until at least the age of 50, but declines significantly between then and the ages of 60-70. For the young and middle groups, Lag 0 trials showed significantly higher accuracy than those for Lag 4 and 16, as was hypothesised. The longer lags caused participants from these groups to make errors in recall between target study block words and distractor test block words. This pattern was not replicated in the old adult group. Instead, uniformly low scores were produced across all lags. The lag 0 condition was especially low in comparison to the younger age groups, while the lag 4 and 16 conditions were consistently significantly lower. The low score for lag 0 trials may perhaps be indicative of more general memory processing problems for older adults, in that a result of higher lag 0 trials than lag 4 or 16 trials was expected. Without these expected results, other factors must be considered, including that of a more general loss of memory function among these older adults. However, given the relatively equal scores obtained in the CFQ by the Old group, general everyday memory seems to be unimpaired. The educational levels of the old group consisted mostly of university-educated participants, and were generally similar to those of the other groups. These results do not match with those found in studies such as that of Jennings & Jacoby (1997).

The RT results show a number of interesting significant differences. Across all lag conditions, the old group showed significantly slower RTs than the middle or young group, again as was hypothesised. Some of the RT results showed large differences between young and old participants, with mean RT differences of close to 1000ms being recorded for lag 16 trials. The young and middle groups showed no significant differences, with some mean RTs showing differences of less than 100ms between these groups. This similarity of results adds strength to the hypothesis that source memory deficits are a marker of old age, and that the decline is rapid, with the onset being after the age of 50. The young and middle age groups show significant RT increases at the longer lag conditions compared to lag 0, a pattern replicated in older adults. This consistent pattern of longer lag lengths showing slower RTs is in keeping with previous studies of source memory, regardless of age (Jennings & Jacoby, 1997), and seems to suggest a higher level of functioning is necessary for any lagged words as participants of all ages struggle to recall if this previously presented word is from the study or test block. This RT difference is significantly greater for the older participants, highlighting a particular problem with the recognition of repeated words. While accuracy for lag 4 and 16 words in older participants was not significantly lower than lag 0 words, there was a highly significant increase in RT for the lagged words. Despite the extra time needed to respond to these lag words, accuracy remained unchanged. For young and middle groups, the increased RTs were less noticeable, but were accompanied by a decrease in accuracy. Increased time spent on recall did not increase the chances of correctly recalling a word after a lag as short as 3 intervening words.

It was also seen in the graphical data that for the old group the Miss responses seemed to have slower RTs than False Alarms. This pattern was not evident in either the young or the middle group. Correct responses in the older group showed a similar difference. In both the Miss and False Alarm conditions the participant is incorrect, but processing the word as a distractor takes longer than processing a word incorrectly as a target. This seems to imply that older participants were more certain of their False Alarm responses than their incorrect target responses, or misses. This false certainty phenomenon has been shown in previous studies with increased false alarm responses and decreased RT length (Postma, 1999). The older adults showed both these attributes during the current study, lending strength to the hypothesis that, when incorrect, older participants are more certain that they are correct than younger or middle aged participants. This certainty is at odds with the results, in that the old group is significantly less accurate than the young or middle group.

In general, the results were in keeping with the hypotheses put forward, that older adults are less accurate than younger or middle-aged adults in recalling the context under which words were encoded. Young and middle-aged adults were more accurate at a lag of 0 words than either longer lag, although the longer lags were no different from each other, implying that any gap between first and second presentations of words interferes with source memory in these groups. The old group was uniformly lower for accuracy, but did not show this decrease in accuracy over lag, perhaps due to their poor performance at lag 0 for both target and distractors. Reactions times were significantly longer for the older adults compared to the young and middle-aged participants across both correct response conditions, as well as Misses. Again, the two younger groups showed little in the way of differences. Older adults also seemed to show a false certainty effect for incorrect target responses over False Alarms.

The examination of first presentations showed interesting results. This was completed in order to examine simple recognition in the groups, given the variance in results in the task and for the CFQ. The older group showed markedly lower accuracy for even first presentations of the words from the study list than the young and middle aged groups. This pattern is in keeping with other results found in simple Old/New studies (e.g. Wilding, 2000; Hayama, Johnson & Rugg, 2008), but this examination excludes any influence on recall by lag, and studies only recognition. Regardless of the lag length, the old group scored uniformly low. In order to study the validity of this possible floor effect, it would be necessary to study groups with clinical memory impairments such as Specific Memory Impairments or Alzheimer’s Disease.

The results suggest that source memory decline is a late-life phenomenon, with those participants of young or middle age showing remarkably similar results across accuracy and reaction times. The marked deficit in results between middle-aged and older participants points to a sudden decline between the ages of 50 and 70, rather than a gradual decline from young adulthood. Also, it seems from the results that the introduction of any lag length apart from an immediate re-presentation of words results in a significant decrease in accuracy and an associated increase in RT for young and middle aged groups, although the old group showed a more uniform distribution of data. The striking similarities found between the young and middle-aged groups can lead to the conclusion that the underlying mechanism used by the group for source memory should be similar. As such, the following chapter will deal with the differences between only the young and old groups. The accuracy and RT differences found between these groups demand further examination. The behavioural differences have been found to be profound, but what of the electrophysiological changes? These are examined in the following chapter using 2 groups of participants; young and old adults.

Chapter 6

ERP and Dipole differences may explain age-related behavioural deficits in source memory

Abstract

The previous chapter reported that, compared to both young and middle-aged groups, an old group exhibited lower accuracy and longer reaction times during an Opposition Task. The current chapter compares a young and old group carrying out the task while they have EEG recorded from 128 scalp electrodes. Twelve young and twelve old participants were examined using a three-lag opposition task with lags of 0, 4 and 16, as in previous chapters. Six blocks of the task were used. Behavioural results showed a similar pattern to that of Chapter 5, with young participants scoring higher and reacting faster than old participants across lags and conditions, while the two longer lag lengths showed decreased accuracy from lag 0 for both young and old participants. Electrophysiological data were collated into ERPs, revealing that at the frontal FP2 site, young participants displayed a marked positivity at ~400ms, which was absent in the old group. The old group showed a later parietal area positivity, recorded at the P3 electrode (especially for correct responses), which was absent in the young group. Dipole source analysis attributed a number of frontal dipoles to the young group for the early positivity without later parietal dipoles, which were found only in the old group. These results point to the possibility of a differing mechanism for source memory recall amongst the old group using parietal areas, given their lack of early frontal activity and dipoles.

6.1 Introduction

In Chapter 5, we examined the behavioural changes in source memory recall ability between young, middle aged and old participants. The results indicated marked similarities between the young and middle aged groups, but a number of significant differences between these groups and the old aged group. This chapter will examine the electrophysiological correlates and differences of these behavioural changes between young and old age groups. Evidence supporting a change in electrophysiological activity between young and old participants during source memory tasks has been found using EEG and ERP data, as well as with imaging techniques such as fMRI. Dywan, Segalowitz and Arsenault (2002) showed significantly more positive activity in frontal and parietal areas in a younger group compared to an older group across the ERP latencies for a single-lag procedure. Mathewson, Dywan and Segalowitz (2005) also reported that response conflict during a source memory task, measured as error-related negativity (ERN), was greater among older groups than younger participants. Czernochowski, Fabiani and Friedman (2008) reported that a higher socio-economic status (SES) in an older group seemed to allow for the creation of strategies to compensate for the source memory problems with ageing through the recruitment of additional neural resources not found in the young group. These results show a pattern of changes in source memory recall-related activity that may be attributable to both aging and response accuracy.

Variations of the Opposition Task have examined source memory capacity in a variety of groups using ERP analysis, with Dywan, Segalowitz and Webster (1998), for example, using the task in conjunction with a divided attention paradigm to investigate

ERP data for younger and older adults. Their results suggest that increased age resulted in a higher likelihood in making source monitoring errors and that the younger adult ERPs showed far greater discrimination between target stimuli and non-target foils than that of the older group. Along with making more source error judgments, ERP data showed that older adults produced large amplitude late positivities to distractor words even when these foils were correctly rejected. Dywan, Segalowitz, Webster, Hendry and Harding (2001) again used an Opposition-type design, this time to examine lagged repetitions in new, distractor, words. Their results again showed that the younger participants were less likely to make source memory recall errors. Their ERP data for correct response trials indicated that younger adults produced late positivities of greatest amplitude in response to whichever word type was designated as a target, irrespective of its familiarity, meaning that both Hits and False Alarms elicited higher positivity over Misses and Correct Rejections, which participants respond to as distractors, either correctly or incorrectly. Older adults had generally less differentiated ERPs between the conditions and showed late positivities for recently repeated words irrespective of target designation (target or foil), perhaps showing a more general familiarity effect. Bridson, Fraser, Herron and Wilding (2006) studied a young group of participants using a lag that varied between 7 and 9 words between trials. Their results showed that ERPs from the Miss trials were more positively deflected generally than those ERPs that were elicited by Correct Rejections, especially at frontal areas. They did not compare these results to an older group however.

The experiment reported in the current chapter uses a high density, 128-channel ERP array in order to investigate scalp-recorded waveform componentry and behavioural responses in a task designed to measure source memory ability in adults. Here we examine source memory capacity in healthy young and older adults using the Opposition Task (as described in previous chapters). Behaviourally, it is predicted that participants of both age-groups are significantly more likely to label a test-list word as studied if the word is repeated following a lag of 4 or 16 intervening words. Therefore we hypothesise that accuracy will decrease as lag length increases, particularly between Lag 0 and the two longer lag lengths, in both the young and old groups (see Chapter 5). It is also hypothesised that reaction time will increase with increased lag length for both age groups, particularly between Lag 0 and the longer lag length conditions (see Chapter 5). Finally, we anticipate that the older group will make significantly more errors than the younger group, and will display significantly longer reaction times across conditions, as shown in previous research (e.g. Jennings & Jacoby, 1997; Dywan et al., 2001).

Our task will use repeated presentations of new test items, as employed by Jennings & Jacoby (1997), as well as repeating the studied words at the same lag intervals, in order to examine if ERP waveforms for the correct responses to study-list words (Hits) and incorrect responses to test-list words (False Alarms) are similar, as both are viewed as words from the study list by participants. This has as yet not been reported in the literature. Dywan et al. (1998) and others have recorded ERPs for a single lag length compared to a base-line, and so have not examined if differences exist between lag length ERPs in an older group. Chapter 4 reported that there was little difference between lags in a young group, but the behavioural differences evident between the age groups means that this finding has not been generalized to an older group. Here we use a lag of 0 as a baseline and study this in comparison to two further lag lengths, those of 4 and 16 intervening stimuli. We hypothesise that words correctly identified as foils or targets will elicit increased positivity in parietal scalp regions, while correctly identified target words will also show increased positivity in frontal regions, as shown by Wilding and Rugg (1998). Finally, the younger group is expected to show greater positivity to targets regardless of response in comparison to the old group, which is predicted to show less differentiated ERPs within-group, as found by Dywan et al. (2001).

6.2 Method

6.2.1 Participants

The participants for this study consisted of 12 healthy young adults (6 male, age range 20-30, mean = 24.1) and 12 healthy older adults (7 male, age range 60-70, mean = 63.4). For the young group, 10 were currently in 3rd level education, while 2 had completed a 3rd level course. The old group included 6 participants with 2nd level education completed and 6 with 3rd level completed. English was the primary language of all participants and all reported normal or corrected-to-normal vision. All participants were initially asked to complete a Cognitive Failures Questionnaire as a gross index of everyday memory function (Broadbent, Cooper & Fitzgerald, 1982; see Chapter 2). The experiment conformed to the 1964 Declaration of Helsinki and was approved by the local ethics committee. Participants gave written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information act. The experiment was conducted in accordance with the Code of Ethics of the World Medical Association and the ethical standards of the APA.

6.2.2 Design

The study consisted of a 2x3 mixed-factorial experimental design, with Age Group (2) and Lag Length (3) being the factors. Age Group was operationalised on 2 levels: young (20-30 years) and old (60-70 years). Lag Length was operationalised on three levels: lag 0, lag 4 and lag 16. Both the behavioural and the electrophysiological data were examined using this same design. Results from the ANOVAs were further examined using Bonferroni-adjusted paired-samples t-tests for post-hoc comparisons.

6.2.3 Apparatus

The task used for the study was the Opposition Task developed by Jennings and Jacoby (1997) with the alterations created based on the results found so far in this work, as discussed in Chapter 2 and Chapter 3. As such, the task consisted of 6 separate study and test phases using two study lists of 40 words, including 5 buffers for primacy and recency effects, drawn from the Toronto Noun Pool (Kucera & Francis, 1982). These words and an equivalent number of distractor, or "foil" words, were presented twice each during the test phases of the experiment, leading to 128-word test lists. The high number of presentations was used to reduce signal-to-noise ratio and thereby yield more artefact-free ERP waveforms (See Chapter 2 for a discussion).

6.2.4 EEG recording and analysis

The EEG set-up for this chapter is described in Chapter 2 (Methods). For this experiment, stimulus-locked ERPs were obtained by averaging the EEG using stimulus presentation as the starting trigger, beginning at 100ms pre-stimulus and continuing for an epoch of 1200ms post-stimulus. Participant EEG was used to create 12 separate conditional ERPs, based on the 12 possible combinations of stimuli and responses (target stimulus at lag 0, 4 or 16 with a correct response, target stimulus at lag 0, 4 or 16 with an incorrect response, distractor stimulus at lag 0, 4 or16 with a correct response and distractor stimulus at lag 0, 4 or 16 with an incorrect response).

Component structure was defined without knowledge of the pattern of effects the data may present. An overall grand-mean waveform was generated for each electrode by collapsing across each group and condition. This allowed the latency of the components of interest (anterior P3, posterior P3b) to be identified through a visual inspection. These frontal and parietal components have been found repeatedly in the ERP data for source memory tasks, and Chapter 4 in the current thesis also exhibited the presence of these two components. For this current Chapter, the frontal P3 measured from 300-500ms, peaking at 418ms. The posterior P3 (P3b) measured from 500-700ms, with a peak at 585ms. Using this form of grand-mean analysis in order to identify component latencies has the advantage of reducing the number of analyses undertaken.

These two components were compared across conditions for differences in mean amplitude. The two areas of interest for the study were the prefrontal area, consisting of 13 electrodes, and the central parietal area, consisting of 20 electrodes (See Fig 6.1). These two areas were examined in detail, and the electrodes showing consistent peak amplitudes were chosen from each for statistical analysis. The prefrontal electrode used was in the FP2 position, and the parietal electrode used was in the P3 position. Both were compared to the reference electrode. For these analyses, a repeated-measures ANOVA was used, comparing lag length (0, 4, and 16), accuracy (correct, incorrect) and stimulus type (target, distractor) using mean amplitude as the dependent variable. All groups of paired t-tests were subjected to Bonferroni correction prior to reporting.

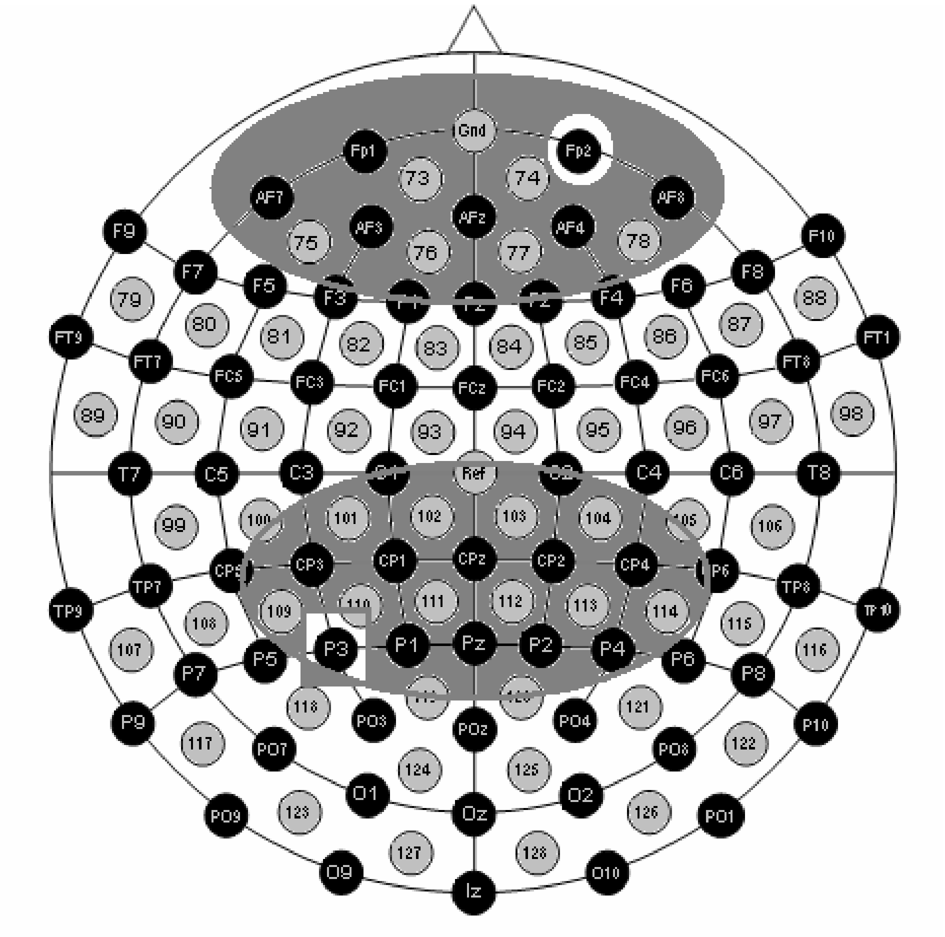


Figure 6.1: *Electrode Montage of the 128-channel 10-20 system showing areas of interest for the current study and electrodes chosen for further examination based on mean amplitude results; Fp2 in the right prefrontal scalp region and P3 in the left parietal scalp region.*

6.3 Results

6.3.1 Behavioural Results

6.3.1.1 CFQ

Both groups completed a Cognitive Failures Questionnaire in order to examine behavioural differences in everyday memory between the groups. The young group scored a mean of 40.4 (SEM 6.1), while the old group scored a mean of 44.7 (SEM 5.32). The results showed no significant differences between the groups in terms of cognitive failures and everyday memory using a paired-sample t-test [t (22) = 1.021, p>0.05], allowing for the assumption that neither group suffered from obvious memory-related problems.

6.3.1.2 Accuracy

We initially compared the young and old groups in terms of mean accuracy score to target words (Fig 6.2) and to distractor words (Fig 6.3). The old group showed lower accuracy scores than the young group across conditions, while performance at longer lags showed lower accuracy than lag 0 for both age groups. Both groups showed greater levels of accuracy for Lag 0 trials than Lag 4 or Lag 16 trials. Two 3x2 mixed factorial ANOVAs were conducted with lag as the within-group factor and age as the between group factor. The first ANOVA examined responses for targets, and the second for distractors.

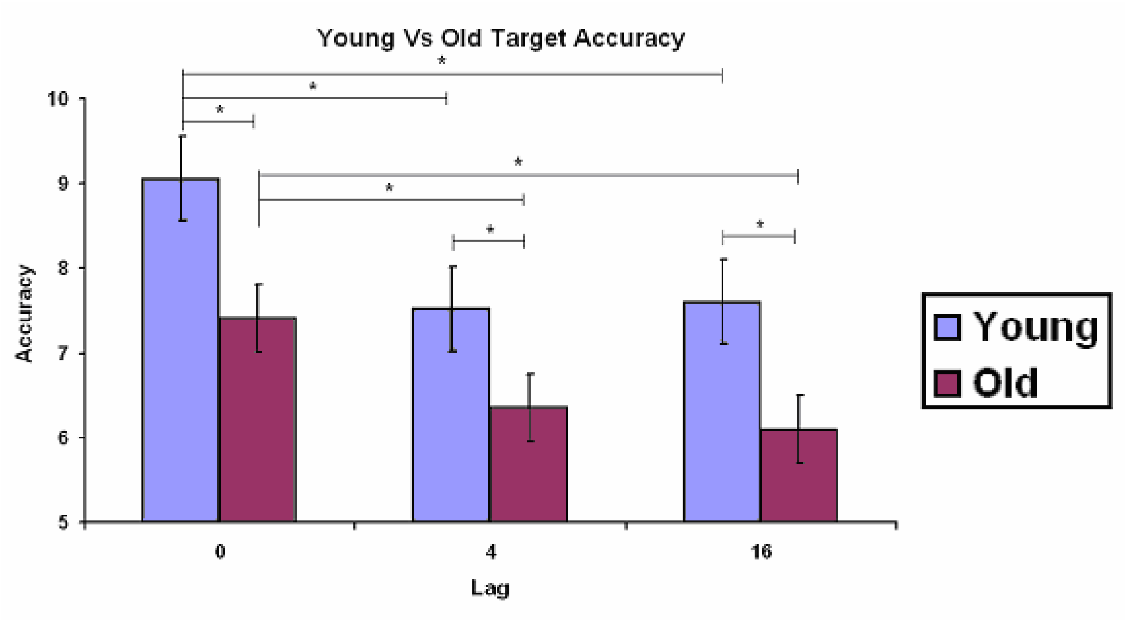


Figure 6.2: Comparison of accuracy of responses to Target stimuli by both groups (Means +/- SEM).

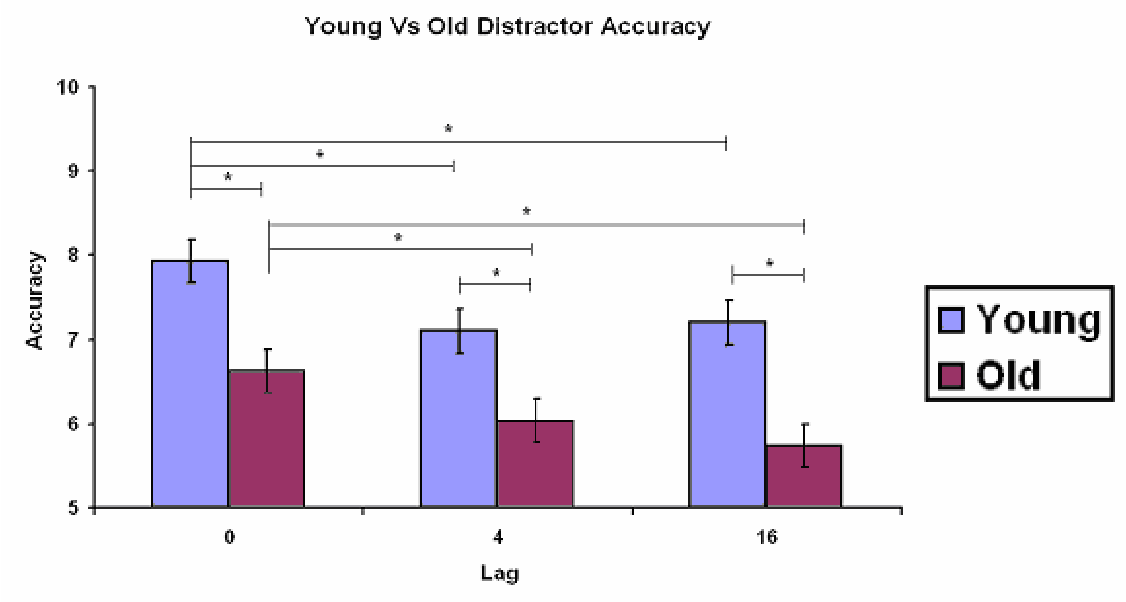


Figure 6.3: Comparison of accuracy of responses to Distractor stimuli by both groups (Means+/- SEM).

In terms of target words, a main effect for Lag was found [F (2, 44) = 9.548, p<0.01) as well as a main effect for age [F (1, 22) = 5.044, p<0.05] and an interaction effect for Lag*Age [F (2, 44) = 4.744, $p<0.01$). Bonferroni corrected t-tests were used to further analyse these differences, using paired-sample t-tests for within-group differences. The within-group comparisons showed a number of significant results. For the young group, lag 0 accuracy for targets was significantly higher than both lag 4 [t (11) = 4.919, $p<0.05$] and lag 16 accuracy [t (11) = 5.665, $p<0.05$]. It was found that lag 0 accuracy for targets in the old group was significantly higher than both lag 4 [t (11) = 5.19, $p<0.05$] and lag 16 accuracy [t (11) = 6.22, $p<0.01$]. Between the young and old groups, a main effect was recorded [F (1, 22) = 8.017, $p<0.01$]. For target words at lag 0, the young group had significantly higher accuracy than the old group [t (22) = 2.37, $p<0.01$]. A similar significant difference was found for target words at lag 4 [t (22) = 5.194, $p<0.05$]. At lag 16 accuracy for target words also showed a significant difference [t (22) = 2.12, $p<0.05$].

The ANOVA for distractor words (see Fig 6.3) showed a main effect for Lag [F (2, 44) = 10.101, $p<0.01$], a main effect for Age [F (1, 22) = 7.316, $p<0.01$] and a Lag*Age interaction [F (3, 22) = 5.877, $p<0.05$]. Lag 0 trials for the young group showed significantly higher accuracy scores than lag 4 trials [t (11) = 2.64, $p<0.05$], and for lag 16 trials [t (11) = 2.115, $p<0.05$]. No differences were found between lag 4 and 16 trials for the young group. The data from the old group were also analysed for within-subject effects. Lag 0 trials showed significantly higher accuracy scores than lag 4 trials [t (11) = 4.706, $p<0.05$] and for lag 16 trials [t (11) = 8.221, $p<0.05$]. For the distractor words, the young group had significantly higher accuracy than the old group at lag 0 [t (22) = 4.537, $p<0.01$]. A significant difference was also found for target words at lag 4 [t (22) = 3.641, p<0.05]. Data for lag 16 accuracy for target words also showed a significant difference between the groups [t (22) = 2.12, p<0.005].

6.3.1.3 Reaction Times

The reaction time data were similar to those recorded by the young and old participants in Chapter 5. The young group showed generally faster RTs than the old group at the different lag lengths, while both groups showed generally longer RTs at lag 4 and 16 compared to lag 0. Four 3x2 mixed factorial ANOVAs were conducted with Lag as the within-group factor and Age as the between group factor. The first ANOVA examined responses for Hits, the second for Misses, the third for Correct Rejections and the fourth for False Alarms.

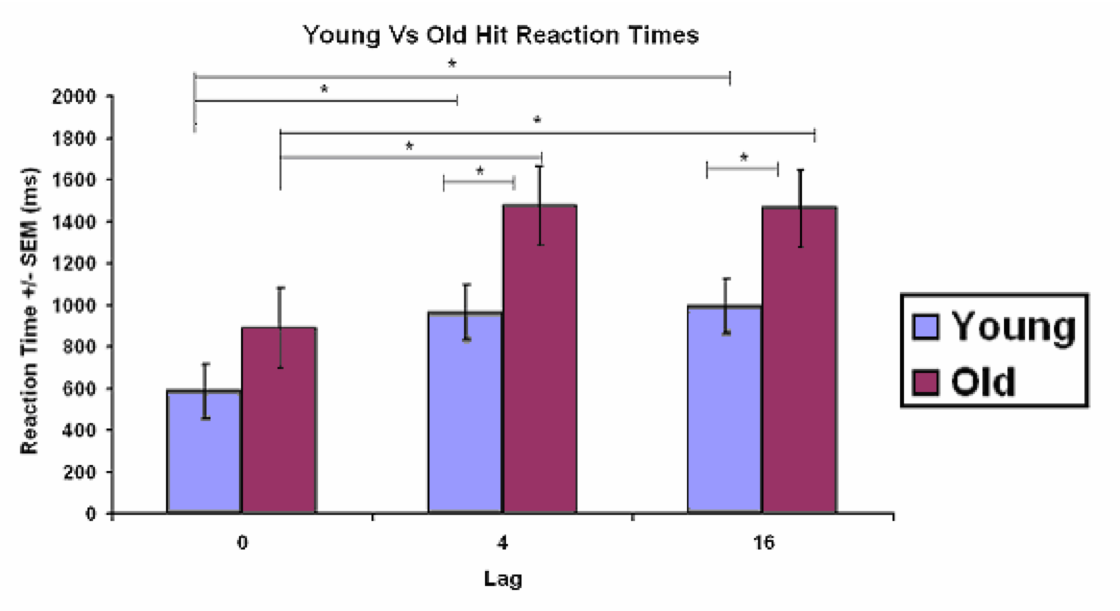


Figure 6.4: *Reaction times for young and old groups for correct responses to Target stimuli (Hits)*

Figure 6.4 shows the RTs for correct responses to target words, known as Hits. A main effect for Lag was found for this group [F (2, 44) = 3.772, p<0.05]. A between-subject effect for Age was also recorded [F (1, 22) = 12.656, p<0.01]. An interaction effect between Age and Lag was found [F (2, 44) = 8.737, p<0.05]. For the young age group, lag 0 Hit responses were significantly faster from those at lag 4 [t (11) = 7.068, p<0.05] and at lag 16 [t (11) = 6.133, p<0.05]. For the old group, Hits at lag 0 were significantly faster than those at lag 4 [t (11) = 3.895, p<0.05] and at lag 16 [t (11) = 3.030, p<0.05]. Between groups, older adults took significantly longer than younger adults to react at lag 4 [t (22) = 3.508, p<0.05] and lag 16 [t (22) = 3.641, p<0.05] in comparison to younger adults, though following Bonferroni correction, the difference failed to reach significance at lag 0.

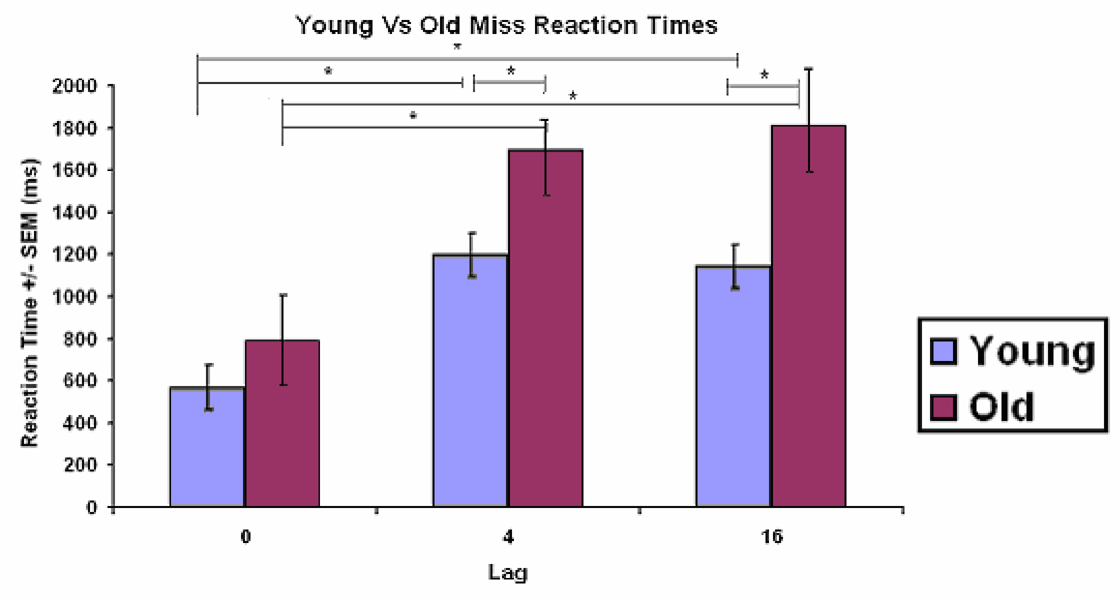


Figure 6.5: *Reaction times for young and old groups for incorrect responses to Target stimuli (Misses)*

Data for Misses showed a main effect for lag [F (2, 44) = 3.052, p<0.05] as well as a main effect between-subjects for age [F (1, 22) = 8.53, p<0.01] and an interaction effect between age and lag [F (2, 44) = 6.933, p<0.05]. T-tests with Bonferroni-corrected again, found that lag 4 [t (11) = 2.491, p<0.05] and lag 16 [t (11) = 6.281, p<0.05] showing significantly longer RTs than those for lag 0 trials among the young group. The old group showed similar results, with lag 4 [t (11) = 5.219, p<0.01] and lag 16 [t (11) = 5.392, p<0.01] showing significantly longer RTs than those for lag 0 trials. There was a significant difference between the old and young groups for RTs to Misses at lag 4 [t (22) = 2.238, p<0.05] and lag 16[t (22) = 3.529, p<0.05].

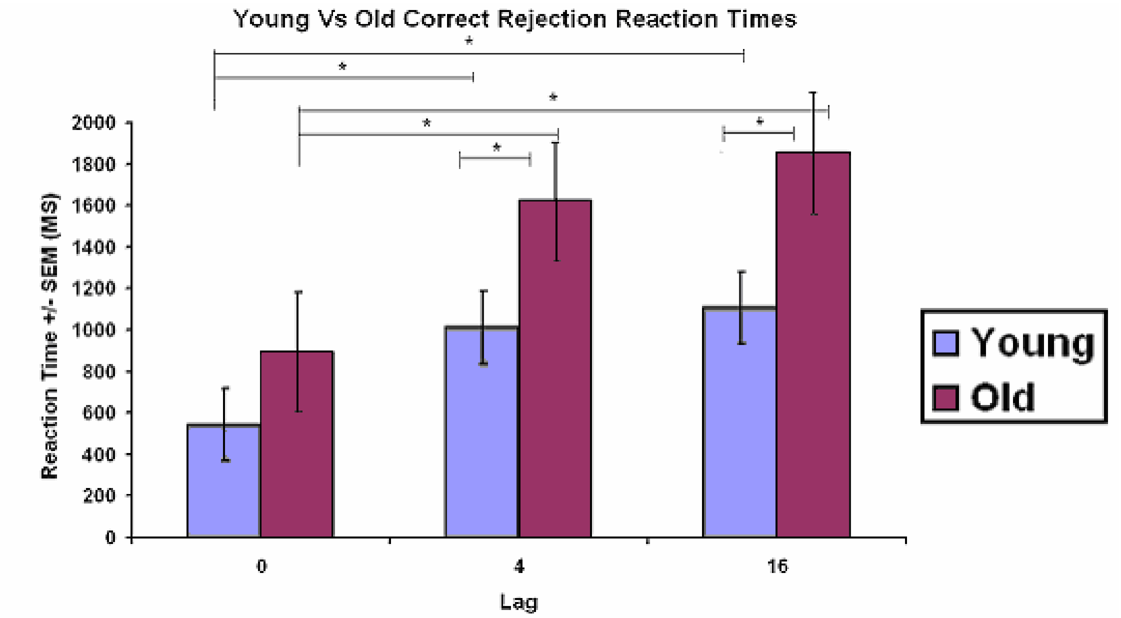


Figure 6.6: *Reaction times for young and old groups for correct responses to Distractor stimuli (Correct Rejections)*

Correct Rejection RTs followed a similar patter, with a main effect within-subjects for lag [F (2, 44) = 6.615, p<0.01] and between-subjects for age [F (1, 22) =

19.314, $p<0.01$]. A lag*group interaction effect was also recorded [F (2, 44) = 4.94, $p<0.05$]. Lag 0 responses were significantly quicker than lag 4 [t (11) = 5.597, $p<0.05$] or lag 16 responses [t (11) = 5.75, $p<0.05$] for the young group. Correct Rejection responses in the old group showed lag 0 responses as being significantly quicker than lag 4 [t (11) = 6.292, $p<0.05$] or lag 16 responses [t (11) = 7.203, $p<0.01$]. Between the groups, a difference was recorded at lag 4 [t (22) = 5.265, $p<0.05$] and lag 16 [t (22) = 4.993, $p<0.05$] though not at lag 0.

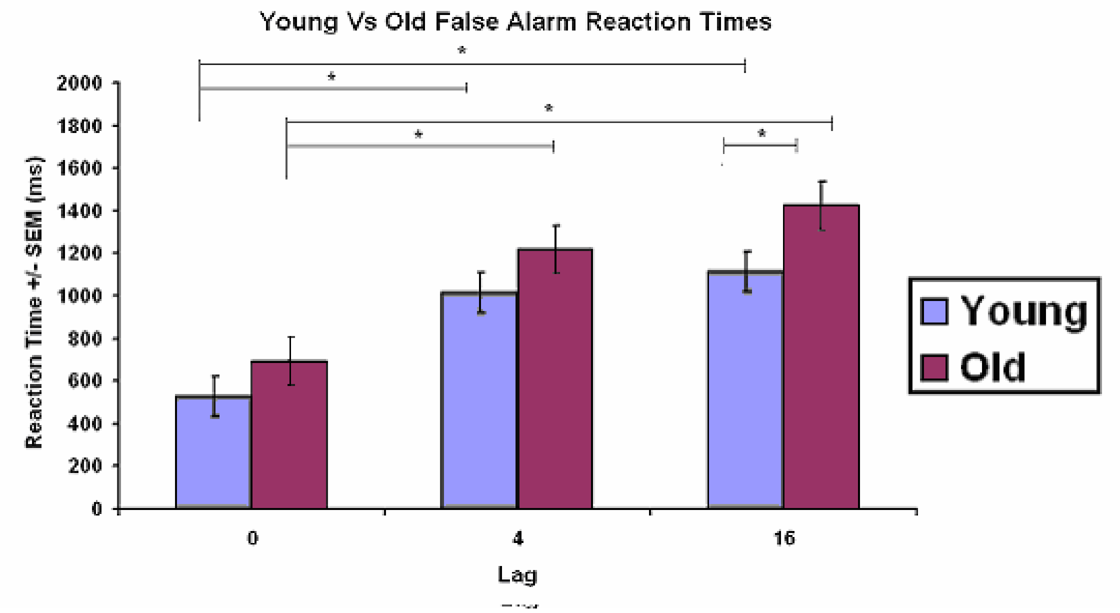


Figure 6.7: *Reaction times for young and old groups for incorrect responses to Distractor stimuli (False Alarms)*

Finally, for False Alarms, a main effect for lag was found to be present [F (2, 44) = 13.811, $p<0.01$] along with a main effect for age [F (1, 22) = 9.183, $p<0.01$]. There was a lag*age interaction found for this condition [F (2, 44) = 7.916, $p<0.01$]. For the young group, lag 0 trials again showed significantly lower times than lag 4 [t (11) = 8.014,

$p<0.01$] or lag 16[$t(11) = 6.606$, $p<0.01$]. The pattern of RTs for the old group adhered to the same pattern as the young group for False Alarms, with lag 0 trials again showing significantly lower times than lag 4 [$t(11) = 7.868$, $p<0.01$] or lag 16 [$t(11) = 12.699$, $p<0.01$]. Incorrect responses to distractors yielded one between group difference, at lag 16 [$t(22) = 3.148$, $p<0.05$].

6.3.2 Electrophysiological Results

6.3.2.1 Grand Means

The Grand Average waveforms for both the young and old groups were subjected to a mean amplitude analysis in order to examine the differences between the groups and to ascertain the latencies and peaks of each component. The two main areas of interest were the prefrontal region and the parietal region of the scalp, based on the findings of previous research groups (e.g. Dywan et al., 2002), as well as Chapter 4 in the current work. In the frontal region (consisting of 13 electrodes) the FP2 electrode was found to have the largest mean amplitudes for the componentry being analysed. The P3 electrode in the parietal scalp area (consisting of 20 electrodes) showed the highest mean peak amplitudes. For the young group, a frontal P3 was evident from 300-500ms, peaking at 418ms. A posterior P3 (P3b) was observed from 500-700ms, with a peak at 585ms. The corresponding latencies for the old group showed frontal negativity in the same 300-500ms epoch, peaking at 435ms, and posterior positivity for the later 500-700ms epoch, peaking at 579ms.

These latencies and peaks were then examined for each of the 12 experimental conditions for both age groups; both correct and incorrect responses in target words at lag 0, lag 4 and lag 16 latencies, and distractor words at lag 0, lag 4 and lag 16 latencies among all participants, resulting in a number of separate possible comparisons. The mean amplitudes at the FP2 right frontal electrode and the P3 left parietal electrode were subjected to separate 3x4x2 mixed-factorial ANOVAs and Bonferroni-corrected t-tests to examine for statistically significant differences between conditions.

6.3.2.2 Frontal Scalp Area

For the first component, the frontal P3 evident from 300-500ms in the frontal group and the corresponding epoch in the older group, a 3x4x2 mixed factorial ANOVA was carried out at the FP2 scalp electrode site to examine any statistically significant differences using mean amplitude comparisons between the four conditions, three lags and two age groups. Figure 6.8 shows the grand mean ERPs of the 4 experimental conditions at the FP2 electrode for both groups. The ANOVA found a main effect of Lag [F (2, 44) =16.650, $p<0.01$], as well as a main effect of Condition [F (3, 66) = 14.915, $p<0.01$] and for age [F (1, 22) = 11.663, $p<0.1$]. A Condition*Lag interaction was also found to occur [F (6, 132) =6.193, $p=0<0.05$], as well as an effect of Condition*Age [F (3, 66) = 10.016, $p<0.01$].

The resulting t-tests revealed that mean amplitudes were significantly larger in the young group for Hits at lag 16 over lag 0 [t (11) =6.673, $p<0.05$] and for lag 4 over lag 0 [t (11) =4.121, $p<0.05$]. For Misses, lag 0 responses were significantly different from both lag 4 [t (11) =7.532, $p<0.05$] and lag 16 responses [t (11) =10.416, $p<0.05$]. For Correct Rejections, a significant difference was found between lag 16 and lag 0 [t (11) =2.439, $p<0.05$], though not at lag 4. False Alarm results showed significantly greater positivity at lag 4 over lag 0 [t (11) = 6.798, $p<0.05$). Between conditions, lag 0 for Hits was found to be significantly less positive tending than those for Misses [t (11) = 7.643, $p<0.05$] or Correct Rejections [t (11) = 8.016, $p<0.05$], though not for False Alarms. Hits at lag 4 were significantly more positive-tending than Misses [t (11) = 4.741, $p<0.05$], False Alarms [t (11) = 4.188, $p<0.05$] and Correct Rejections [t (11) = 9.035, $p<0.05$].

Lag 16 Hits showed more positivity than those for False Alarms [t (11) = 6.487, p<0.05], though not those for Misses or Correct Rejections.

For the old group, Bonferroni-corrected t-tests found no significant difference between lags for the Hit condition. For the Miss condition, lag 16 responses were significantly less positive-going than those for lag 0 [t (11) = 4.956, p<0.05), though no other significant differences were found. Correct Rejections showed a significant difference between lag 0 and lag 16 [t (11) =5.35, p<0.05] and for lag 0 compared to lag 4 [t (11) =5.195, p<0.05], though not between lag 4 and lag 16. The False Alarm results showed a significant difference between lag 16 and both lag 0 [t (11) = 8.143, p<0.01] and lag 4 [t (11) = 7.011, p<0.01]. Between conditions, Hits at lag 16 were found to be significantly less negative tending than False Alarms at lag 16 [t (11) =2.843, p=0.044]. No other significant effects were found were found between the conditions.

The two age groups were then compared with each other through further paired-sample t-tests to examine which conditions and lags differed at the frontal scalp area of interest. Twelve t-tests were carried out, finding 11 significant results following Bonferroni adjusting. These results are tabulated in Table 1. As it shows, the frontal area showed many differences between the age groups. The younger age group exhibited higher mean amplitudes for all ERP waveforms measured.

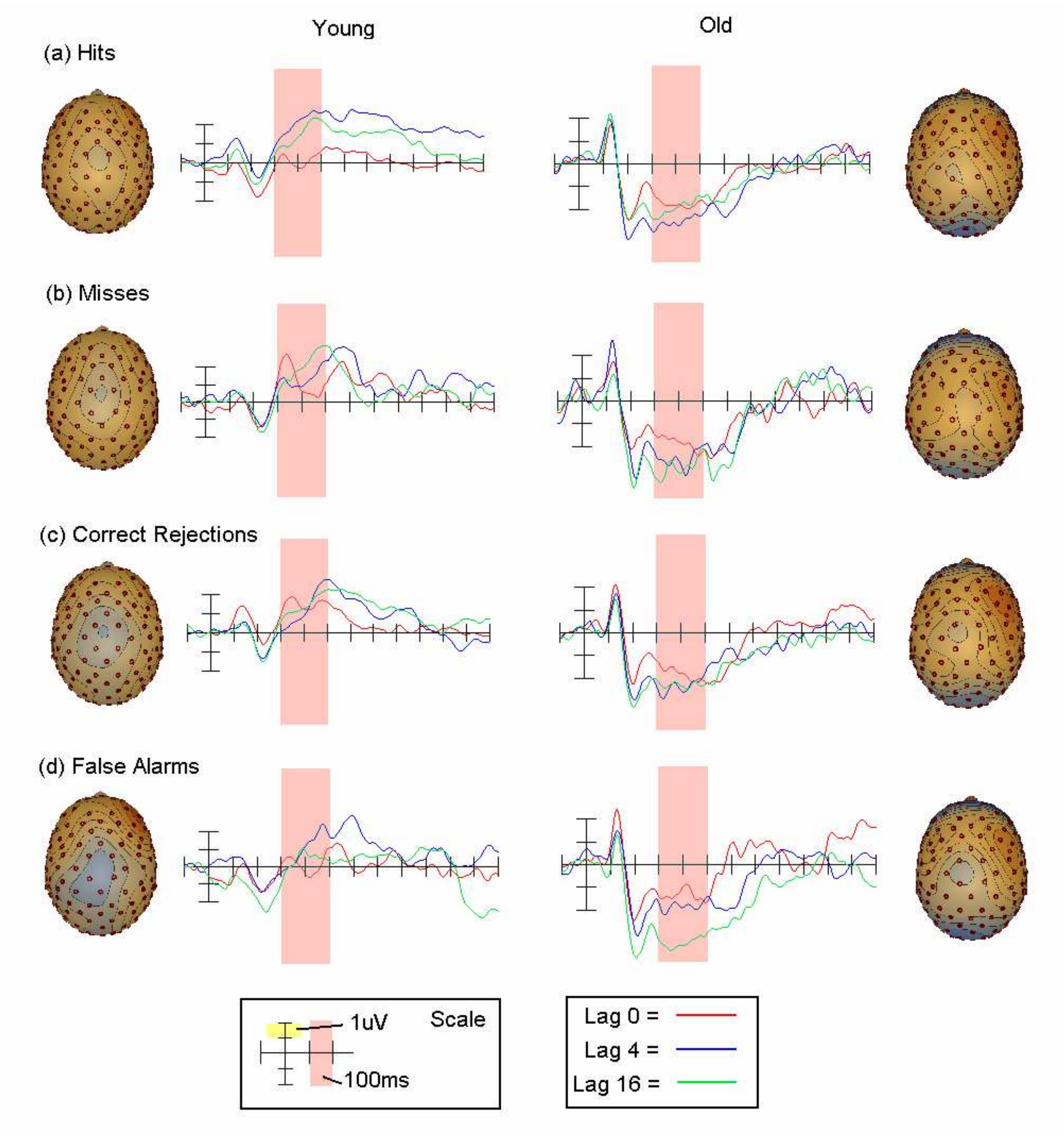


Figure 6.8: *Grand mean ERPs of the 4 experimental conditions at the FP2 electrode for both groups; (a)Hits, (b) Misses, (c) Correct Rejections and (d) False Alarms and sample topographical maps showing scalp areas active for lag 16 data at 400ms for both groups in all conditions*

Table 1: *T-tests carried out to examine between-group differences in Mean Amplitude at the FP2 site for the 300-500ms epoch for young and old groups. The asterisk denotes a significant difference.*

Condition	**Lag**	**t**	**DF**	**p<0.05 * p<0.01****	**Young Mean**	**Old Mean**
Hits	0	4.342	22	*	0.26±0.15	-1.86±0.21
	4	4.756	22	**	1.62±0.31	-2.24±0.37
	16	5.861	22	**	2.42±0.22	-2.39±0.29
Misses	0	4.013	22	*	1.45±0.36	-1.58±0.16
	4	4.153	22	**	1.77±0.41	-2.17±0.25
	16	3.709	22	**	1.91±0.53	-2.34±0.31
C.R.	0	3.941	22	**	0.74±0.28	-1.65±0.36
	4	5.106	22	*	1.83±0.35	-2.36±0.19
	16	5.608	22	**	2.03±0.28	-2.39±0.27
False Alarms	0	0.757	22	-	0.51±0.28	-1.18±0.60
	4	2.642	22	**	1.28±0.51	-2.07±0.44
	16	5.91	22	*	1.71±0.30	-3.42±0.62

6.3.2.3 Parietal Scalp Area

Figure 6.9 shows the grand mean ERPs at the P3 electrode for the 500-700ms epoch for the 2 experimental groups across the 4 conditions and 3 lags. A 3x4x2 ANOVA, as used for the frontal component, found a main effect for Lag [F (2, 44) =13.061, p<0.01], as well as a main effect for Condition [F (3, 66) = 10.964, p<0.01] and for Age [F (1, 22) = 12.408, p<0.1]. A Condition*Lag interaction was reported [F (6, 132) =4.973, p<0.05], along with an effect for Condition*Age [$F (3, 66) = 8.18$, $p<0.01$] and for Lag*Condition*Age [$F (6, 132) = 6.745$, $p<0.05$].

For the young group, Bonferroni corrected t-tests were used to compare the lags and conditions. Mean amplitudes were significantly lower for the young group for Hits at lag 0 compared to lag 16 [$t (11) = 4.806$, $p<0.05$] and lag 4 [$t (11) = 3.589$, $p<0.05$]. The Miss condition showed significant differences between lag 0 responses and both lag 4 [t (11) =8.414, $p<0.05$] and lag 16 responses [$t (11) =6.093$, $p<0.05$] in the Miss condition. For Correct Rejections, a significant difference was again reported between lag 0 and both lag 4 [$t (11) = 3.755$, $p<0.05$] and lag 16 [$t (11) =2.439$, $p<0.05$]4. False Alarm results followed this trend, showing significantly greater positivity at lag 4 [$t (11) = 6.798$, $p<0.05$] and lag 16 [$t (11) = 5.541$, $p<0.05$] and lag 0. Between the four conditions, lag 0 amplitudes were found not to vary significantly, while those at lag 4 showed a difference between Hits and False Alarms [$t (11) = 4.864$, $p<0.05$] and Misses and False Alarms [$t (11) = 6.122$, $p<0.05$]. Lag 16 Hits showed more positivity than those for Correct Rejections [$t (11) = 5.856$, $p<0.05$]].

Examining the old group, mean amplitudes for Hits were significantly lower at lag 0 compared to lag 4 [$t (11) = 3.974$, $p<0.05$] and lag 16 [$t (11) = 5.143$, $p<0.05$] For the Miss condition, again both lag 4 [$t (11) = 7.686$, $p<0.05$] and lag 16 responses [$t (11) = 8.214$, $p<0.05$] were significantly more positive-going than those for lag 0. Correct Rejections showed a significant difference between lag 0 and lag 16 [$t (11) =3.772$, $p<0.05$] though not lag 4. The False Alarm results showed no significant difference between the three lag lengths. Between the conditions, lag 0 results showed no differences, while at lag 4, Misses were found to be more positive going than both Correct Rejections [t (11) = 6.962, p<0.01] and False Alarms [t (11) = 4.57, p<0.05] .

As with the frontal area data, the two age groups were then compared to examine differences across lag and condition. Twelve Bonferroni corrected t-tests were carried out, finding 10 significant results. These results are shown in Table 6.2. The parietal results showed many differences between the age groups, although in this case the older age group exhibited more positive-tending mean amplitudes for most ERP waveforms measured, excepting Hits at lag 4 and Misses at lag 16.

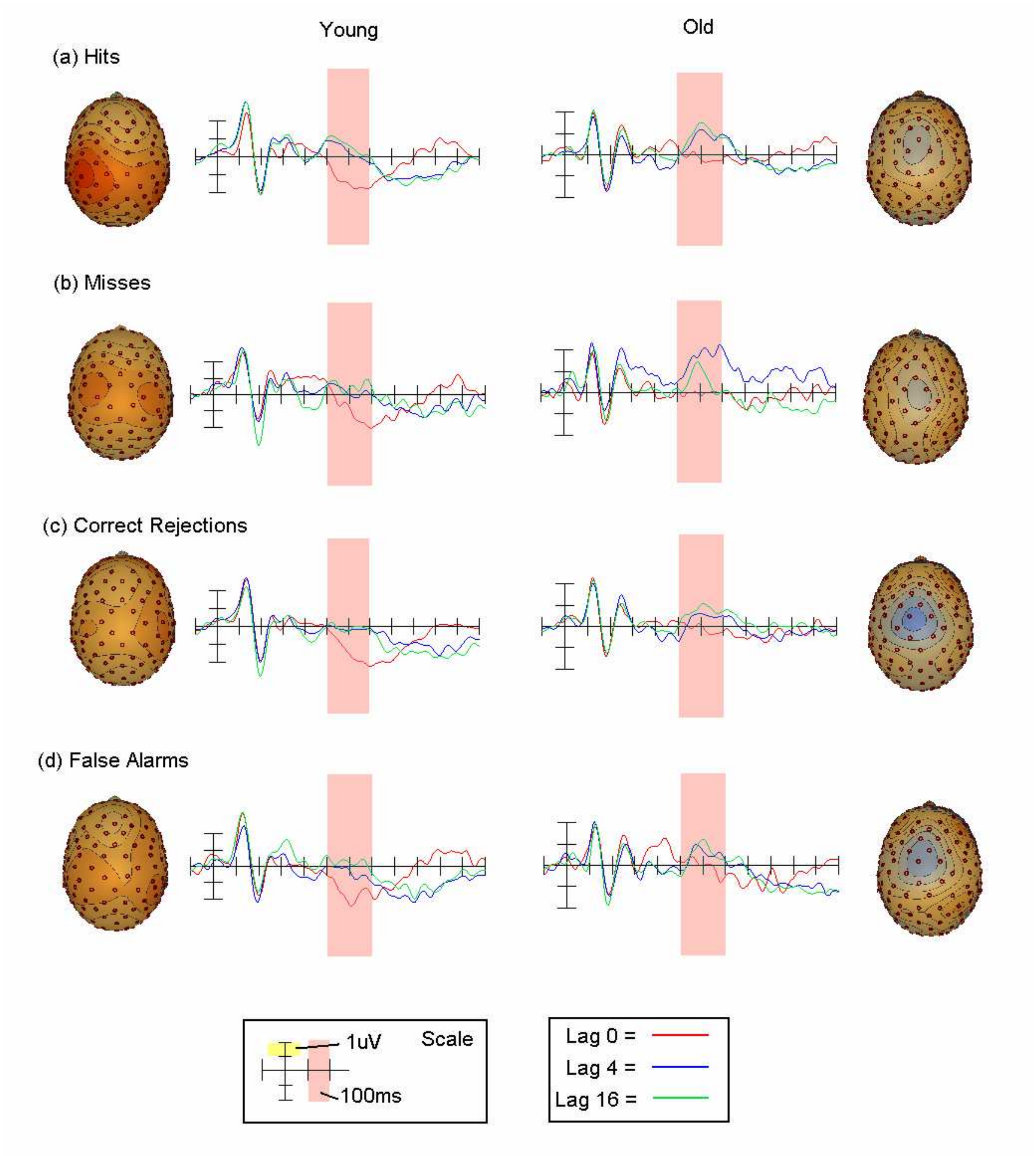


Figure 6.9: *Grand mean ERPs of the 4 experimental conditions at the P3 electrode for both groups, with (a) showing Hits, (b) showing Misses, (c) showing Correct Rejections and (d) showing False Alarms and sample topographical maps showing scalp areas active for the young and old groups for each condition at lag 16 at 400ms post-stimulus*

Table 2: *T-tests carried out to examine between-group differences in Mean Amplitude at the P3scalp electrode site for the 300-500ms epoch for young and old groups. The asterisk denotes a significant difference.*

Condition	**Lag**	**t**	**DF**	**p<0.05 * p<0.01****	**Young Mean**	**Old Mean**
Hits	0	10.421	22	**	-1.63±0.75	-0.16±0.21
	4	7.652	22	-	0.52±0.31	1.24±0.35
	16	5.417	22	*	0.59±0.26	1.39±0.52
Misses	0	4.91	22	**	-1.45±0.36	-0.02±0.01
	4	6.037	22	*	0.27±0.18	1.17±0.29
	16	11.154	22	-	0.31±0.12	1.40±0.16
C.R.	0	4.059	22	**	-1.74±0.28	-0.09±0.01
	4	2.116	22	*	-0.03±0.03	0.36±0.19
	16	7.834	22	*	-0.09±0.01	0.39±0.27
False Alarms	0	8.001	22	*	-1.51±0.82	-0.41±0.33
	4	9.144	22	*	-0.28±0.14	0.07±0.44
	16	3.086	22	*	0.18±0.09	0.42±0.62

6.3.2.4 Dipole Source Analysis

ERP data were subjected to dipole analysis using BESA software. Due to the high number of separate analyses completed, it was necessary to choose those with the greatest differences to subject to further study. The primary point of this chapter is to examine the differences between the age groups, as Chapter 4 has previously examined the within-group differences of a young group. As such, this section will be limited to the differences found between the groups. Further to this, the general similarities found between the lag 4 and 16 results across the groups allows for fewer examinations to be carried out.

Due to the large number of comparisons possible, two response types were subjected to dipole source analysis. The first examination compares neural correlates of Hit responses at lag 16 for both groups and for both major components, the early frontal P3 component examined at the FP2 electrode, and the later parietal P3b component examined at the P3 electrode. The second comparison is between young and old participants for False Alarms at lag 16 for both components. Both of the above response types are present when a participant recognises a stimulus as from the study block, either correctly (Hit) or incorrectly (False Alarm), meaning comparisons should provide useful information about the brain areas used to correctly respond by the different age groups. The components were narrowed from the original 200ms each to shorter timeframes, allowing for more accurate depictions of the sources of the components and lower residual variances (RVs). The FP2 component peaked at 418ms, and was examined for an epoch of 50ms around this peak, from 393-443ms. The P3 component peaked at 585ms, and is examined from 560-610ms, also a 50ms epoch. For all solutions, a 4-dipole model was attempted, in order to allow for more direct comparisons.

The first comparison, the frontal P3, was between the young and old groups Hit responses at lag 16. Figure 6.10 shows the dipole models of the two groups for the first component, the frontal P3 found in the young group. Both groups yielded 4 dipole solutions that remained within the head-model used, resulting in an RV of 9.121% for the young group and 11.314% for the old group. All the dipoles were localized using Talairach Daemon software, giving an anatomical (X, Y, Z) location and Brodmann's area for each dipole. The young group had dipoles in the region of the left superior frontal gyrus (BA 6), the right superior temporal gyrus (BA 22), the right precuneus (BA 19) and the left middle frontal gyrus (BA 10). The older group had dipoles reported near the left precentral gyrus (BA 6), the right middle temporal gyrus (BA 21), the right precuneus (BA 19) and the left inferior temporal gyrus (BA 35). Therefore, both groups were fond to have precuneus, temporal and frontal activity, though the young group had bilateral frontal activations compared to the left frontal dipole in the old group.

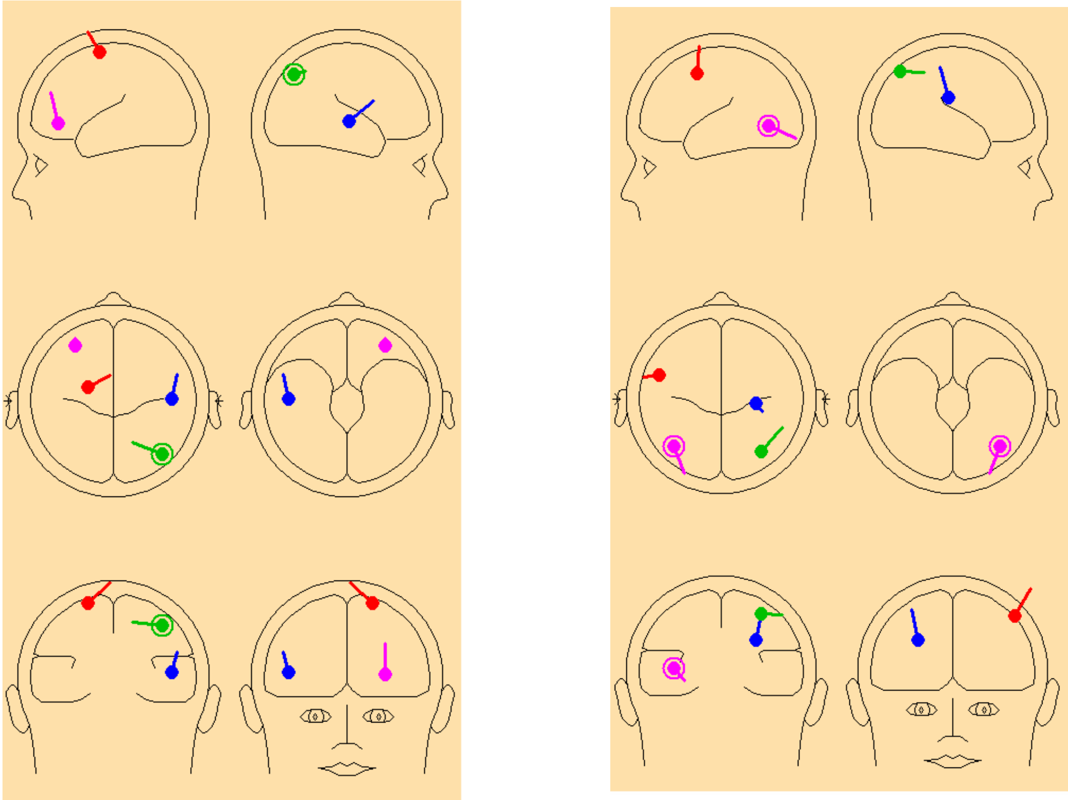


Figure 6.10: *Young (left) and old dipole maps for the Hit condition at lag 16 from 393-443 milliseconds.*

The second of the four analyses undertaken examined the False Alarm responses of both age groups for the earlier component, from 393-443 milliseconds. Figure 6.12 gives a graphical representation of the dipole models created. The 4-dipole solutions resulted in an RV of 6.92% for the young group and 5.408% for the old group. The Talairach software again provided anatomical data for both sets of results. The young group was reported to have dipoles near the right precuneus (BA 19), bilateral middle frontal gyri (BA 10) and the right medial frontal gyrus (BA 6). The old group was found to have dipole sources at locations close to the left middle temporal gyrus (BA 21), the right middle frontal gyrus (BA 9), the right superior temporal gyrus (BA 22) and the right precuneus (BA 19). Both groups therefore had a right frontal source and a right precuneus source, while the young group alone showed further frontal dipoles, with the older group instead showing bilateral temporal activations.

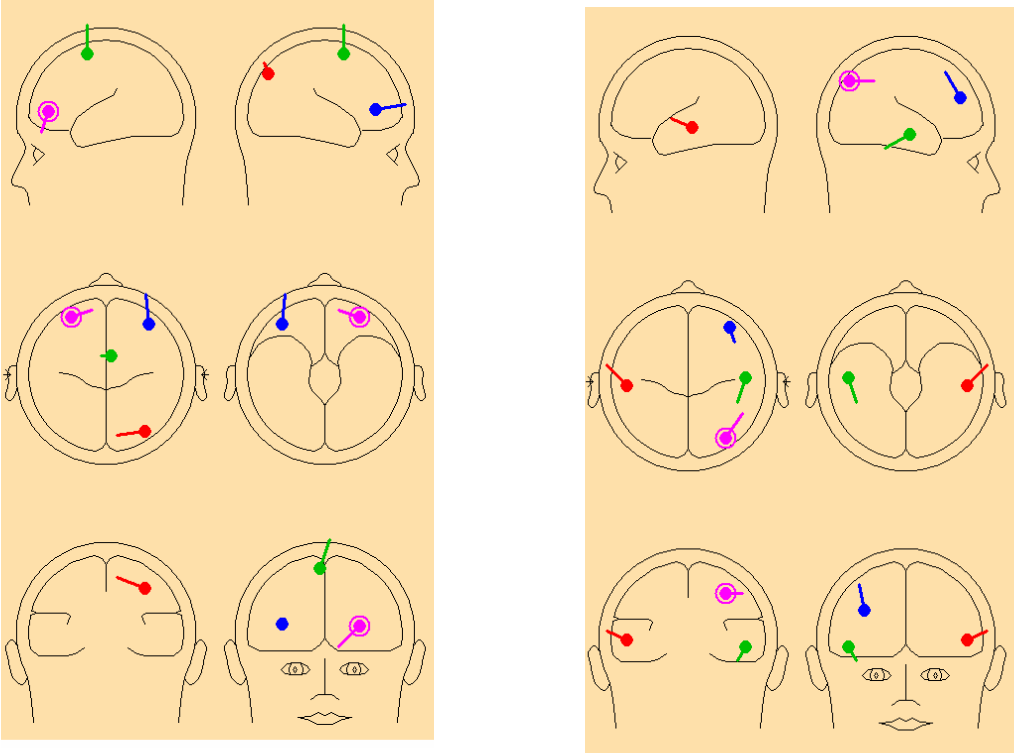


Figure 6.11: *Young (left) and old dipole maps for the False Alarm condition at lag 16 from 393-443 milliseconds*

The third comparison was also for Hits condition at lag 16, this time focusing on the second major component, the parietal P3b. Again, a 4 dipole solution was sufficient to create models of the dipole sources, with an RV of 9.86% reported for the young group, and 7.117% reported for the old group. Figure 6.11 shows the comparison between the young and old group for this component. The Talairach Daemon software localised the dipoles to anatomical correlates. The young group was found to have dipoles close to the left middle temporal gyrus (BA 19), the left superior temporal gyrus (BA 22), the right middle occipital gyrus (BA 19) and the right superior temporal gyrus

(BA 22). The old group was found to have dipoles in the region of the left sub-lobar caudate nucleus, the right sub-lobar thalamus, the left precuneus (BA 19) and the right superior parietal lobule (BA 7). For this comparison, the young group showed activation bilaterally throughout the middle temporal lobes, while the older group showed a pattern of parietal and sub-lobar dipole sources.

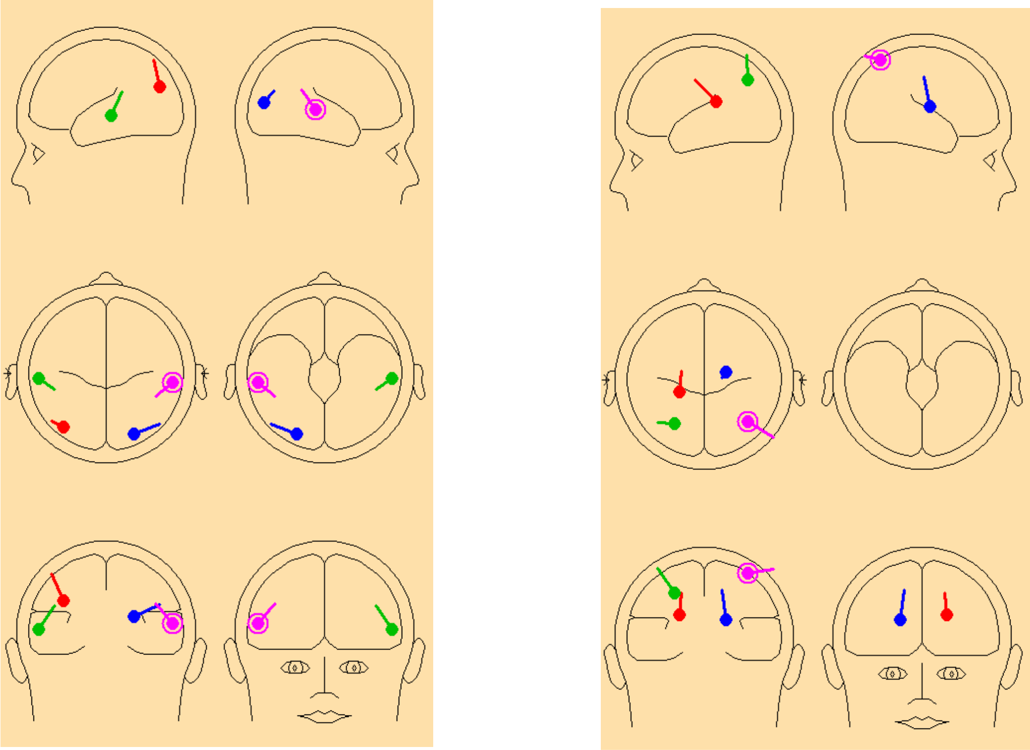


Figure 6.12: *Young (left) and old dipole maps for the Hit condition at lag 16 from 560-610 milliseconds.*

The fourth and final comparison of dipole sources that was examined was that between the young and old groups at lag 16 for False Alarms for the later parietal component. The RV for the young group was found to be 4.55%, while the old group had an RV of 6.875%. Figure 6.13 shows the two groups compared. Using the Talairach software, the young group was found to have dipoles near the right precentral gyrus (BA

4), the inferior temporal lobe (BA 20), the left supramarginal gyrus of the temporal lobe (BA 40) and the left inferior frontal gyrus (BA 9). The old group had dipoles in the region of the left precuneus (BA 19), the left precentral gyrus (BA 6), the right middle frontal gyrus (BA 46) and the left parahippocampal gyrus (BA 19). For these conditions, the young group exhibited a pattern of bilateral temporal and frontal area dipoles, while the old group pattern was less distributed through the cortex, instead showing three right parieto-temporal dipoles and a single frontal dipole.

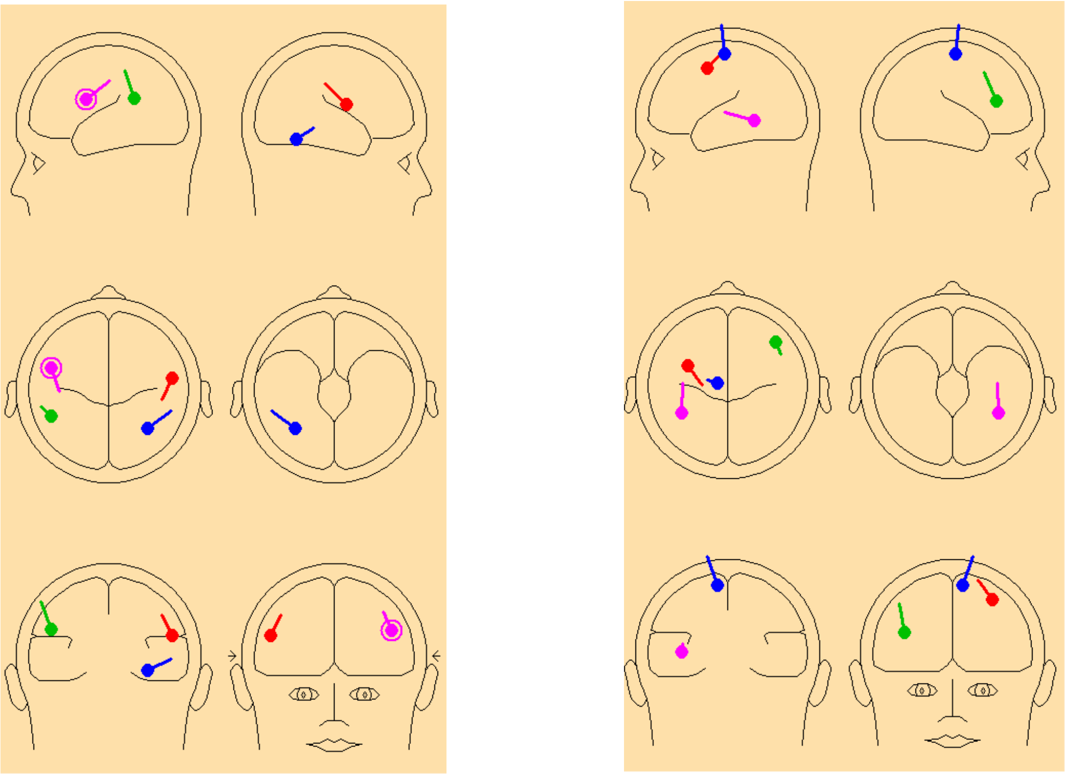


Figure 6.13: *Young (left) and old dipole maps for the False Alarm condition at lag 16 from 560-610 milliseconds*

These BESA analyses seem to reveal a number of interesting patterns. For the young group, the early component for both response types has two or more frontal dipoles, linking the results to those found by the ERP analysis. The old group does show some frontal activity, but not to the same extent as those of the young group, with one frontal dipole present in each P3 analysis. Likewise, the later component for the older group shows a cluster of dipoles around MTL and parietal areas, especially evident in the Correct Rejection condition, but also present for Hits. The younger group show a more even distribution of dipoles for this timeframe for both conditions, with frontal, temporal and parietal sources being shown. The implications of these findings are discussed below.

6.4 Discussion

These results provide a picture of the behavioural and electrophysiological differences involved with retrieving source memory information between the two groups being studied. Although the old group showed similar scores in a measure for everyday lapses in memory and cognition to the young group, their scores at the Opposition Task were uniformly lower than those achieved by the young group. These young vs. old differences mirror those found across a number of source-memory studies including those of Jennings and Jacoby (1997), Dywan, Segalowitz and Williamson (1994) and Chapter 5, all of which found significant deficits among older samples compared to younger. The lag differences within-group were also shown clearly, with lag 4 and 16 accuracy being significantly poorer across conditions for both age-groups than lag 0 results. Lag 0 trials showed significantly greater accuracy than those for Lag 4 and 16, as was hypothesised. The longer lags caused participants from these groups to make errors in recall between target words that were studied prior to the test block, and distractor words, that were presented only in the test block, but on more than one occasion. This pattern of within-group results was not found in the old group in the previous chapter, though it was reported in the aforementioned studies. Due to these conflicting results given the same task and similar groups of old participants in terms of CFQ scores and level of education achieved, further study is necessary to examine which result typifies this form of the Opposition Task.

A number of differences are evident from the reaction time results. As predicted cross all lag conditions, the old group showed significantly slower RTs than the young group. Both the young age group and the old age group showed significant RT increases at the longer lag conditions compared to lag 0. This pattern of longer lag lengths associated with slower RTs across age-groups is similar to results reported in previous studies of source memory (e.g. Jennings & Jacoby, 1997; Dywan et al., 2001) and in previous chapters of the current work. It seems that participants, regardless of age, take longer to react to a word after a lag is imposed, regardless of the length of lag. The older group seem especially susceptible to this, with large RT differences found between lag 0 stimuli and any of the lagged stimuli across conditions.

As with the previous chapter, Miss responses show slower RTs than False Alarms among older participants. The young group did not show this pattern. In both Miss and False Alarm conditions the participant is incorrect, but the action of recognizing a word as a distractor despite being a target seems to take a toll on the RT of the older participants, though not the younger. As Postma (1999) posited, this *false certainty* is not matched by the accuracy of responses, and the older group scored significantly lower for accuracy in these conditions than the younger group. Postma (1999) discusses this in terms of the instructions used in experiments, stating that conservative instructions ("Read the words aloud"), as used here, will increase the false certainty level in participants, compared to liberal instructions ("Try and remember the words in any way possible").

The ERP data revealed further interesting results, both between and within the groups. The young group showed greater frontal positivity for lag 4 and lag 16 as opposed to lag 0 for target words, regardless of their response to those words. For the parietal area of interest, lag 0 words showed little deviation from the baseline, but lag 4 and 16 words showed pronounced negativity in parietal scalp areas for all conditions. The

ERP data from the P3 electrode showed marked similarities across the response types, with few significant differences found when comparing the conditions. This apparent sensitivity only to lag differences has not been previously reported. The young and old groups have topographically dissimilar P3 components, but the old group also shows significant differences between lag 0 and longer lags across all four conditions in the parietal scalp areas. The old group has strong positive deflections for the lag 4 and 16 trials, especially for False Alarms, but the lag 0 trials show little such deviation. This lag-only sensitivity may reveal the specific capacity in which the lag-based Opposition Task differs from the normal old/new paradigm, which tends to show central-parietal amplitude changes in relation to correct versus incorrect responses (e.g. Wilding & Rugg, 1997). These differences were not noted in the current experiment, perhaps due to the lag-sensitive components elicited.

Comparing between the groups, a number of obvious differences emerged. The most prominent was at the frontal site, where pronounced positive-going waveforms in the young group were shown, while the old group had pronounced negative-going waveforms. This mirrors the data found by Swick, Senkfor and Van Petten (2006), who examined age-related differences in a source memory task, finding early positives absent in their old group, which also showed marked negative deflections at frontal sites (although these were later in the epoch in the Swick et al. (2006) study, from 600ms as opposed to 300ms). Swick et al. (2006) showed a pattern of generally longer RTs in their study than in the current work, perhaps explaining this difference in the timing of the deflections. Anderer et al. (2001) also reported reduced positivity for the P300 component among older participants in a study of auditory source memory. The parietal activity also differed substantially between the groups, though not to the same extent as the frontal differences. The old group showed positive deflections in the 500-700ms latency, as opposed to the young group, whose ERP data showed a negative deflection in these later stages, despite similar early componentry for the groups. These positive deflections may be a compensatory effect, due to the lack of early positivity found at frontal scalp sites. Functional MRI Studies such as that by Dennis et al. (2008) have shown that the prefrontal area produces less activity during source memory procedures in older adults even without behavioural deficits in tasks, which, coupled with the lack of positive deflections in frontal scalp areas as reported in the current study, could account for the poor scores achieved in the task, linking the ability to differentiate between sources to the frontal lobe.

However, behaviourally the old group scored above chance for their responses, suggesting that there is some mechanism in place to compensate for this reduced frontal activity, which perhaps this activation in parietal sites not present in the young group can explain. The later activity in the parietal areas compared to a lack of similar activity in younger adults and longer reaction times for the old group could point towards a secondary function for the parietal area in older adults. While it seems that both groups have lag-related activity in the parietal scalp area, the old group also has generally larger positivities in this region. Czernochowski et al. (2008) posited that older may use alternate strategies to compensate for the adverse effects of aging in source memory tasks by recruiting additional brain areas not required by the young. Their study was examined in terms of SES, with those older participants scored as “High SES” achieving higher scores than older adults with lower SES. The SES of participants in the current study was not recorded, and a future study to examine this effect in detail would be beneficial.

The dipole source models generated could be seen to lend strength to this theory of alternate mechanisms as compensation. The lack of prefrontal or anterior-frontal dipoles in the old group at earlier latency examined is in line with the fMRI findings of Dennis et al. (2008), who also found reduced prefrontal activity in older adults. The later peak in central scalp areas over the parietal region was found to have putative neural correlates in the posterior frontal lobe, precuneus, temporal lobes and parahippocampal areas, which could point to the use of these areas by the old group to compensate for the lack of prefrontal activity, which is very evident in the young group. The longer reaction times achieved by the old group could also be represented by these findings, as the compensatory effect seems to be less efficient than the use of the anterior frontal lobe demonstrated in the young group. Areas such as the parahippocampal gyrus and the precuneus have been strongly linked to memory in a large number of past studies, as mentioned in the introductory chapter (e.g. Gold et al., 2006; Uncapher et al., 2006, Lundstrom et al., 2006). Therefore, it would not be surprising to find increased activations in those areas to compensate for diminished activation of the prefrontal areas.

The data reported here are in line with that found by previous researchers that attempted to map the differences between young and old participants in source memory tasks, and also may shed new light into the activity promoted in the older participants to allow them to compensate for the hypothesised lower frontal activation levels. The next chapter will examine the young and old groups further in an attempt to expand upon the results found among the old participants without radically changing the design of the experiment or the procedure. Instead, we will use a simple change of instruction based around the depth of encoding framework of Craik and Lockhart (1972).

Chapter 7

A Comparison of Deep and Shallow Encoding Strategies for Young and Old Adults using the Opposition Task

The Experimenter would like to thank Ms Katherine Still for her aid in initial data collection

Abstract

The experiments carried out so far have indicated that both age and lag length can have a detrimental effect on accuracy of response in an Opposition Task. The current chapter attempts to utilise the levels of-processing framework of Craik and Lockhart (1972, 1977, 2002) to lessen the impact of these two factors on the accuracy of results using the same Opposition procedure as used thus far. To do so, both young and old participants were divided into two groups; shallow encoding and deep encoding. The shallow encoding groups were asked to simply read the words presented in the study phase, while those in the deep encoding group were asked to put each in a sentence of their own devising. According to the levels-of-processing theory, those in the deep group should show increased accuracy during recognition. Our results showed that regardless of lag or age, performance was improved in the deep conditions in comparison to their age-matched shallow controls. However, reaction time was generally longer in the deep processing groups. These results indicate a greater level of processing being used among the deep groups which seems to lessen the effects of both lag and age on results, while increasing their reaction times, possibly due to the more complex recall of sentences over words.

7.1 Introduction

The previous chapters have shown the efficacy of the opposition task in measuring age-related changes in source memory, and investigating the neural correlates underpinning the process, with replicated results showing many similarities. Although the task allows for a simple analysis of source memory decline and allows us to track deficits across lags and age, it has not been shown to improve the participants' source memory capacity. Indeed, this was never the intention of the test. This chapter will employ a modified version of the Opposition Task designed to improve participants' ability to recall the source of their memories, using a modification based on the Levels-of-Processing framework put forward by Craik (e.g. 1972, 2002).

A number of theorists in the 1960s established the idea that perception involved the rapid analysis of stimuli at a number of levels or stages (Selfridge & Neisser, 1960; Sutherland, 1968). Treisman (1964) first proposed a hierarchical "*levels of analysis*" theory for perceptual processing. In his theory, semantic information (e.g. word identification and meaning) is processed during a later stage of perceptual analysis than the surface features (e.g. number of letters in the word) (see Figure 7.1). As such, preliminary stages of perception concern only the physical and sensory features such as angles and clarity, and later stages involve matching the stimulus with stored semantic meaning. Treisman's theory strongly influenced Craik and Lockhart (1972), who proposed that shallow *maintenance rehearsal* is equal to the repetition of previous analyses (such as phonemic or graphemic) whereas deep *elaborative rehearsal* involves a further level of semantic analysis (see Figure 7.2). In essence, reading and understanding the meaning of a word will improve memories for that word over merely seeing the structure of word without attributing a meaning or context.

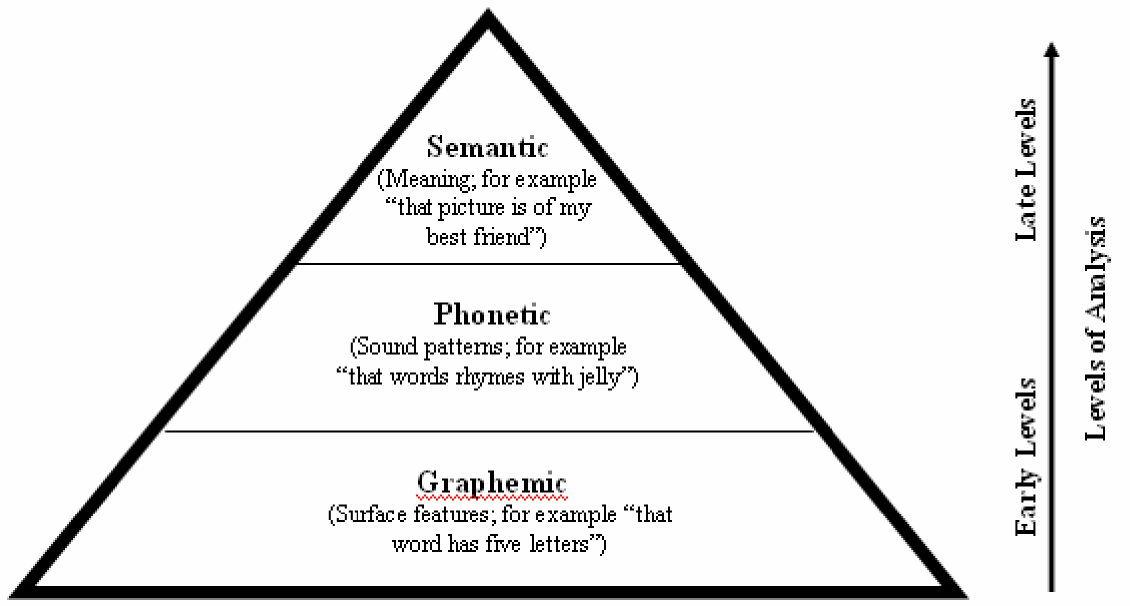


Fig 7.1: *Diagrammatic representation of Treisman's (1964) Levels of Analysis Theory*

The original definition of *Depth*, as given by Craik and Lockhart (1972) was "a greater degree of semantic or cognitive analysis". This was found to be too vague and open to interpretation, leaving the theory exposed to major criticism. Craik later developed this idea on deep encoding further, referring to it as the qualitative processing carried out on the stimulus, in comparison to shallow processing. More recently, Craik (2002) issued a revised and more comprehensive definition of deep encoding, suggesting that it "refers to the analysis of meaning, inference, and implication, in contrast to shallow analyses such as surface form, colour, loudness, and brightness". The latest definition allows for a stronger description of the process being examined, although the definition remains still relatively vague.

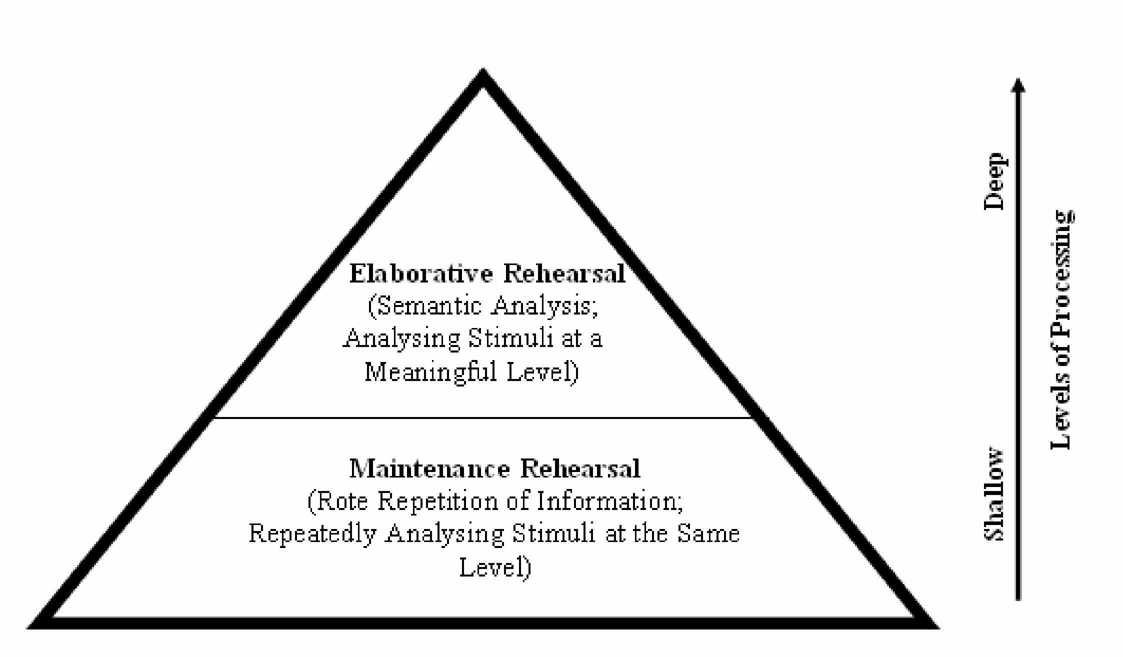


Fig. 7.2: *Diagrammatic Representation of Craik and Lockhart's (1972) Levels of Processing Theory*

To explore the levels-of-processing framework for memory research proposed by Craik and Lockhart, Craik and Tulving (1975) conducted a number of important experiments. The experiments involved an encoding phase where experimenters asked participants various types of questions about the words (to be remembered), with the type of question being asked reflecting an attempt to process the words at different depths. Shallow encoding was obtained by asking questions about typescript; intermediate levels of encoding were achieved by asking questions about the sound of a word; deep levels were accomplished by asking whether a word would fit into a given sentence. After the encoding phase, some participants were given an unexpected recall or recognition test for the words; whilst in other experiments participants were alerted to the memory test prior to the encoding phase. In general, these experiments found that deeper levels of encoding were associated with higher levels of accuracy and longer reaction times on subsequent memory tests.

The results of these studies showed that participants performed best on a memory test when they were asked to make judgements about the meaning of words at the encoding stage. Further work by Craik and Tulving (1975) demonstrated that when encoding level is the same for positive and negative decisions about words, they are equally well recalled. Also, they found that the depth of processing effects were robust across complex sentences for negative responses but not positive ones and that the strong superiority effect for deep encoding participants was robust across the isolation effect (Cermak, 1972) because although the shorter word list led to better retention, there were still significantly higher accuracy scores for deep encoding participants. In addition, the superiority effect of deeper encoding was found to be robust across both slow and fast presentation rates and even when the recognition of shallow encoded words was rewarded and the recognition of deep encoded words was not. These results confirmed and extended the findings of previous levels-of-processing research (Hyde & Jenkins, 1973; Till & Jenkins, 1973; Schulman, 1971; 1974).

Memory decline has also been studied in relation to the levels-of-processing framework discussed above and, in general, early studies found that the strong deep encoding effect was not lost in older adults (e.g. Eysenck, 1974). Craik (1977), for example, examined the effects of deeper encoding on recognition capacity in different age groups, finding that older participants performed as well as young participants in the deep and shallow encoding groups. Craik therefore theorised that the recall of older adults was not affected by the level of processing, so their capacity to process information (which is crucial to the efficacy of retrieval) may not have degenerated naturally with aging. Recent studies have found some similar results with elderly participants, although for the deep processing groups only, therefore putting an element of doubt into the theory of Craik (1977).

In a recent study, Jacoby, Shimizu, Velanova and Rhodes (2005) completed an experiment in which young and older participants were asked to either judge the pleasantness of a study word (deep encoding) or to make an O or U vowel judgement about the word (shallow encoding). Participants were asked to study both shallow and deep encoding lists, and to determine which word was from either list in the test phase. Results showed higher accuracy for the deep encoding words regardless of the age of participants, with accuracy rising from 50% in for shallow encoding to 80% for deep encoding, scoring higher than the shallow scores achieved by the younger group. Studies have also examined the level-of-processing effect on source memory in schizophrenic patients. Failure to use semantic information to structure encoding, i.e. to use the features of a stimulus to memorise it, is thought to contribute to severe verbal episodic memory deficits often found in schizophrenia (Saykin et al., 1991). Ragland, Valdez, Loughead, Gur & Gur (2006) contrasted the accuracy scores of schizophrenic patients with healthy controls and found that there was a significant “level of processing effect” (i.e. the deeper the level of processing, the higher the accuracy scores were) on word recognition but not on source memory in schizophrenic patients. In contrast, Ragland et al. found a level-of-processing effect for source memory with the healthy participants.

While a number of Old/New paradigms have been used to investigate the source memory differences apparent between younger and older participants, as discussed in Chapter 1, relatively few have examined the effect of depth of processing on source memory. Jacoby et al. (2005) found a depth-of-encoding effect in source memory with a group of healthy older participants, but did not examine the findings using a lag-based procedure. The current study will examine the effects using the lag-based Opposition Task to increase the difficulty of Old-New judgements, and allowing an examination of the effects of the lags on the accuracy scores of the deep encoding groups. To examine the possibility, deep encoding groups, both old and young, were asked to put each word from the study list into a short sentence spoken aloud, and the shallow encoding groups were asked to simply read each word aloud. Results from these groups were compared to observe whether deep encoding participants have divergent patterns of accuracy scores to the shallow group, which would show the effect of depth of processing on source memory. Also, the groups' reaction times were compared as the seminal studies in the area report that deeper encoding leads to slower reaction times, which was not found in the Jacoby et al. (2005) study. The main hypotheses are that accuracy will be significantly higher in the deep encoding groups compared to the shallow groups, regardless of age. The effect of depth of encoding on accuracy over lags does not seem to be examined in the literature, but we expect that the deep encoding groups will show less sensitivity to longer lag lengths as the words will be recalled more readily due to deeper encoding.

7.2 Method

7.2.1 Participants

The sample for the experiment consisted of 60 participants recruited in an *ad-hoc* manner, divided into 4 separate groups by age range and Depth-of-Processing group; Deep or Shallow. Group 1 (young, shallow) consisted of 15 participants (9 female, 13 right-handed) aged between 18 and 30 years (range=18-28, mean=23.8, SD=2.4). Eleven were currently in 3rd level education, 2 had completed a 3rd level course while 2 had completed a 4th level course. Group 2 (young, deep) consisted of 15 participants (7 female, 12 right-handed) aged between 18 and 30 years (range=18-27, mean=23.1, SD=2.7). For this group, 8 were currently in 3rd level education, 6 had completed a 3rd level course and 1 had completed a 4th level course. Group 3 (old, shallow) consisted of 15 participants (8 female, 11 right-handed) aged between 60 and 70 years (range=61-69, mean=65.6, SD=3.8). Within this group, 5 had completed 2nd level education, 9 had completed 3rd level education and 1 had completed a 4th level course. Group 4 (old, deep) consisted of 15 participants (6 female, 11 right-handed) aged between 60 and 70 years (range=62-70, mean=66.1, SD=2.2). Six of this group had completed 2nd level education and 9 had completed 3rd level education. All participants had normal or corrected to normal vision, and were self-reported free from psychiatric or serious memory problems. All participants fell within the normal range of the CFQ. The experiment conformed to the 1964 Declaration of Helsinki and was approved by the NUI Maynooth ethical committee. Participants gave written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information act (1997). The experiment was conducted in accordance with the Code of Ethics of the World Medical Association and the ethical standards of the APA.

7.2.2 Design

The study consisted of a 2x2x3 mixed-factorial experimental design, with Age Range, Depth of Encoding Group and Lag Length being the factors. Age Range was operationalised on 2 levels: young (20-30 years) and old (60-70 years). The Group factor was also operationalised on 2 levels: Deep and Shallow. Lag Length was operationalised on three levels: Lag 0, lag 4 and lag 16.

7.2.3 Apparatus

This experiment made use of the Opposition Task discussed earlier (Chapter 2) with a number of methodological and procedural changes added. The task consisted of a single study and test-block with 60 study words as well as 5 buffers for primacy effects and 5 for recency effects. The longer list was included as participants were subjected to a single study and test list rather than the 6 phases from previous chapters. Participants in the Shallow Encoding groups were instructed to read each word in the study list aloud. Participants in the Deep Encoding groups were instructed to put each word in the study list in a short sentence of their own devising as they appeared. To allow for both this additional task and the increase in words on the list, a 3-second inter-stimulus interval was used for all participants as opposed to the 2-second ISI used in the previous chapters. Each of the 60 study words were presented twice during the test phase, and were presented in a pseudo-random order. Sixty distractor words were also included in the test phase, with two repetitions of each. In order to examine the effects of differing lags on participants' source accuracy, the target words were presented for the second time at lags of 0, 4, and 16 in the test phase. All foil words were also presented using these three lag lengths. All other details were as set down in Chapter 2.

7.2.4 Procedure and Data Analysis

Participants were first asked to sign an informed consent sheet in order to show that they consented to be part of the study, and then to complete the CFQ in order to examine the extent of their everyday memory problems. They were then asked to sit in front of the computer monitor, approx. 100cm from the screen, with their hands on the keyboard in front of them. Participants were requested to study the first block of words, consisting of 70 words, and were told that they were to remember these words for a following test block. Preceding the test block, another set of instructions were provided. Participants were told that if a word from the study block was presented during the test block, the "S" key on the keyboard should be pressed. If the presented word was new, (i.e. not shown on the study block) the "N" key on the keyboard should be pressed. Following the presentation of the study and test blocks, participants were fully debriefed and informed that all results would be analysed in an anonymous capacity.

Performance accuracy and reaction times were both recorded during the test phase of the experiment. A correct response occurred when the participant pressed "S" when a word from the study list (target) was presented and pressed "N" when a new word (distractor) was presented. Reaction times were measured as the interval between presentation of the stimulus and the response and were recorded for both correct and incorrect trials. These responses and RTs were subjected to mixed factorial ANOVAs (Age [2 levels], Depth [2 levels], Lag [3 levels]) as well as to separate Bonferroni-corrected paired sample t-tests in order to examine the statistical significance of the within-group differences.

7.3 Results

7.3.1 CFQ

All groups of participants were examined for everyday lapses in memory through the completion of a CFQ. The young shallow group showed a mean of 41.3 (SD = 6.17), the young deep group had a mean of 36.2 (SD = 8.94), the old shallow group had a mean of 44.7 (SD = 9.01) and the old deep group had a mean of 39.7 (SD = 5.33). No significant difference was reported between the groups [F (3, 56) = 1.012, $p>0.05$], allowing for the assumption that all groups were at a similar level for everyday memory problems.

7.3.2 Accuracy

We initially compared the Young Shallow, Young Deep, Old Shallow and Old Deep groups in terms of mean accuracy score to target words (Fig 7.3) and to distractor words (Fig 7.4). The old shallow group showed lower accuracy scores than the young shallow group across lags, while the young deep group showed higher scores than the old deep group. However, the young shallow group did not show greater scores than the old deep group. The deep encoding groups showed higher accuracy scores than those in the Shallow encoding groups of the same age. Both shallow encoding groups showed higher accuracy for Lag 0 trials than Lag 4 or Lag 16 trials. The deep encoding groups did not show these lag-related declines. Two 3x2x2 mixed factorial ANOVAs were conducted with lag as the within group factor and Age and Encoding group as between group factors.

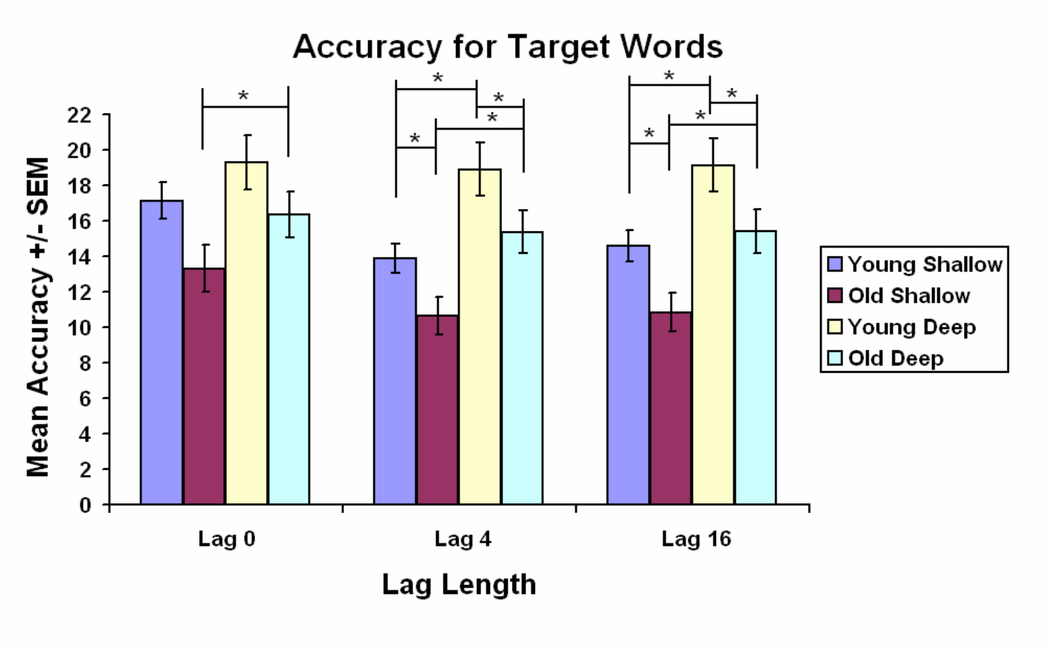


Figure 7.3: *Comparison of accuracy of responses to Target stimuli by all groups*

In terms of target words, a main effect for lag was found [F (2, 56) = 9.548, p< 0.01] with lag 0 scoring significantly higher than 4 or 16. Main effects for age [F (1, 56) =10.622, p<0.01], with young scoring higher than old, and for depth [F (1, 56) =6.103, p<0.01], with deep groups outscoring shallow groups, were also reported. There was also an interaction effect for lag*group [F (5, 56) = 4.744, p<0.01] and for lag*age [F (3, 56) = 8.124, p<0.01]. Bonferroni corrected t-tests were used to further analyse these differences, using paired-sample t-tests for within-group differences. The within-group comparisons showed a number of significant results. For the Young Shallow group (blue bars, Fig 3.7), lag 0 accuracy for targets was significantly higher than both lag 4 [t (14) = 4.919, p<0.05] and lag 16 accuracy [t (14) = 5.665, p<0.05]. It was found that lag 0 accuracy for targets in the Old Shallow group (purple bars, Fig 3.7) was significantly higher than both lag 4 [t (14) = 5.19, p<0.05] and lag 16 accuracy [t (14) = 6.227,

$p<0.05$]. However, the Young Deep Group (yellow bars, Fig 3.7) and Old Deep group (green bars, Fig 3.7) did not show statistically significant within-group changes dependent on lag length.

Between the young and old shallow encoding groups, a number of significant differences were recorded using Bonferroni-adjusted t-tests. For target words at lag 0, the young group had significantly higher accuracy than the old group [$t(28) = 2.37$, $p<0.05$]. A similar significant difference was found for target words at lag 4 [$t(28) = 5.194$, $p<0.05$]. At lag 16 accuracy for target words also showed a significant difference [$t(28) = 2.12$, $p<0.05$]. Between the young and old deep encoding groups, significant results were also found. At lag 16 accuracy for target words a significant difference was found [$t(28) = 2.827$, $p<0.05$], as well as at lag 4 [$t(28) = 3.211$, $p<0.05$]. Comparing the deep encoding groups to the shallow encoding groups of the same age also found significant differences. At lag 0, the old deep group scored significantly higher than the old shallow group [$t(28) = 3.784$, $p<0.05$], as they did at lag 4 [$t(28) = 3.012$, $p<0.05$] and lag 16 [$t(28) = 5.206$, $p<0.05$]. The young deep group scored significantly better than the young shallow group at lag 4 [$t(28) = 3.953$, $p<0.05$] and at lag 16 [$t(28) = 4.114$, $p<0.05$].

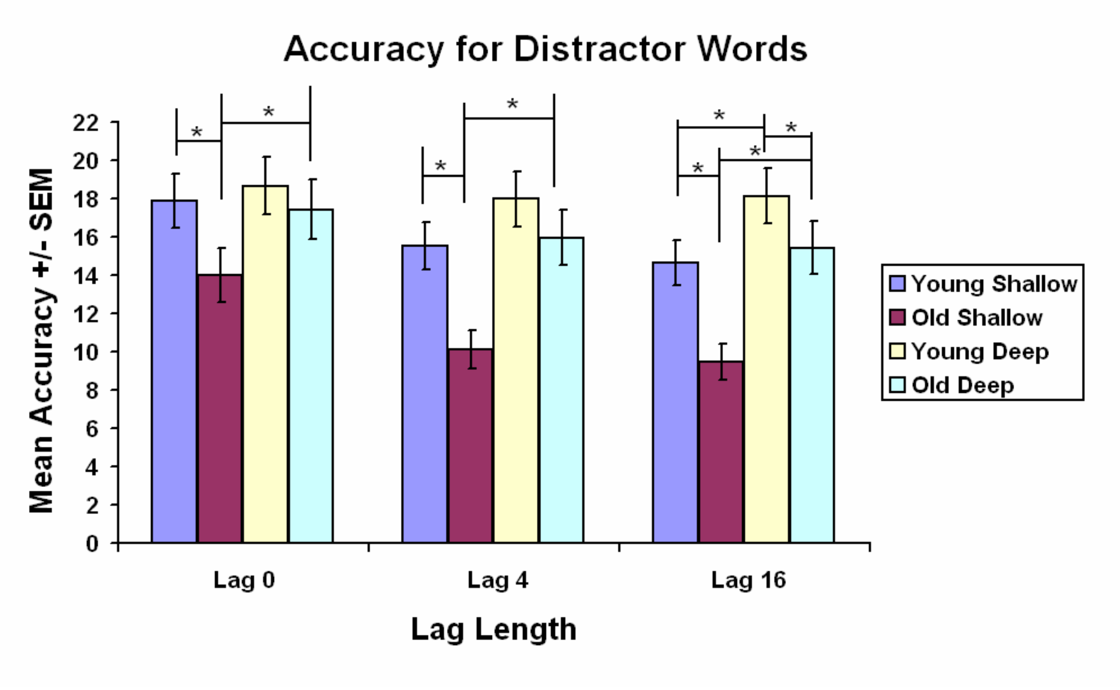


Figure 7.4: *Comparison of accuracy of responses to Distractor stimuli by all groups*

For distractor words, a main effect for lag was found [F (2, 56) = 6.319, p<0.05] with lag 0 scoring significantly higher than lag 4 or 16 stimuli. A main effect for age [F (1, 56) =8.243, p<0.05], with young scoring higher than old, was reported, while a main effect for depth [F (1, 56) =7.913, p<0.05], with deep groups outscoring shallow groups, was also reported. There was also an interaction effect for lag*group [F (5, 56) = 3.969, p<0.05] and for lag*age [F (3, 56) = 4.728, p<0.05].

As with the target words, the deep encoding groups showed no significant within-group differences based on lag. However, lag 0 trials for the young shallow encoding group showed significantly higher accuracy scores than lag 4 trials [t (14) = 2.644, p<0.05], and lag 16 trials [t (14) = 5.081, p<0.05]. No differences were found between lag 4 and 16 trials for the young group. The data from the old shallow encoding group were also analysed for within-subject effects. Lag 0 trials showed significantly higher accuracy scores than lag 4 trials [$t (14) = 2.702$, $p<0.05$] and for lag 16 trials [$t (14) = 4.221$, $p<0.05$]. Between the age groups, the young shallow encoding group also showed significantly higher accuracy than the old shallow encoding group at lag 0 [$t (28) = 5.37$, $p<0.05$], lag 4 [$t (28) = 4.121$, $p<0.01$] and lag 16 [$t (28) = 3.41$, $p<0.01$]. However, the deep encoding groups did not show age-related differences in accuracy for any of the three lag lengths. Comparing shallow to deep encoding groups, it was found that at lag 0, the old deep group scored significantly higher than the old shallow group [$t (28) = 3.178$, $p<0.05$], but this was not reported in the young group. At lag 4, the results were similar, with the old groups showing a significant difference in favour of deep encoding [$t (28) = 5.911$, $p<0.05$], but not the young group. For lag 16, both the old deep group [$t (28) = 4.219$, $p<0.05$] and the young deep group [$t (28) = 5.006$, $p<0.05$] outscored the shallow groups of the same age.

7.3.3 Reaction Times

Reaction time data was collected and analysed for all groups, and compared both between and within the groups, as with the accuracy results. Figure 7.5 shows the RTs for Hits, showing that the shallow encoding groups showed increases in RT for longer lags regardless of age, while the deep encoding groups show a less varied RT, although longer than the shallow encoding groups at lag 0. Figure 7.6 displays the RTs for Misses, with the general trend mirroring that of the Hit results. The results in Figure 7.7 are those for Correct Rejections, again showing RT increases with lag in the shallow processing groups that are absent in the deep processing groups. Finally, Figure 7.8 shows the RTs for false alarms, with a similar pattern, although the lag 16 RTs for the old deep processing group are longer than the shorter lags. Four 3x2x2 mixed factorial ANOVAs were conducted with lag as the within group factor and Age and Encoding group as between group factors.

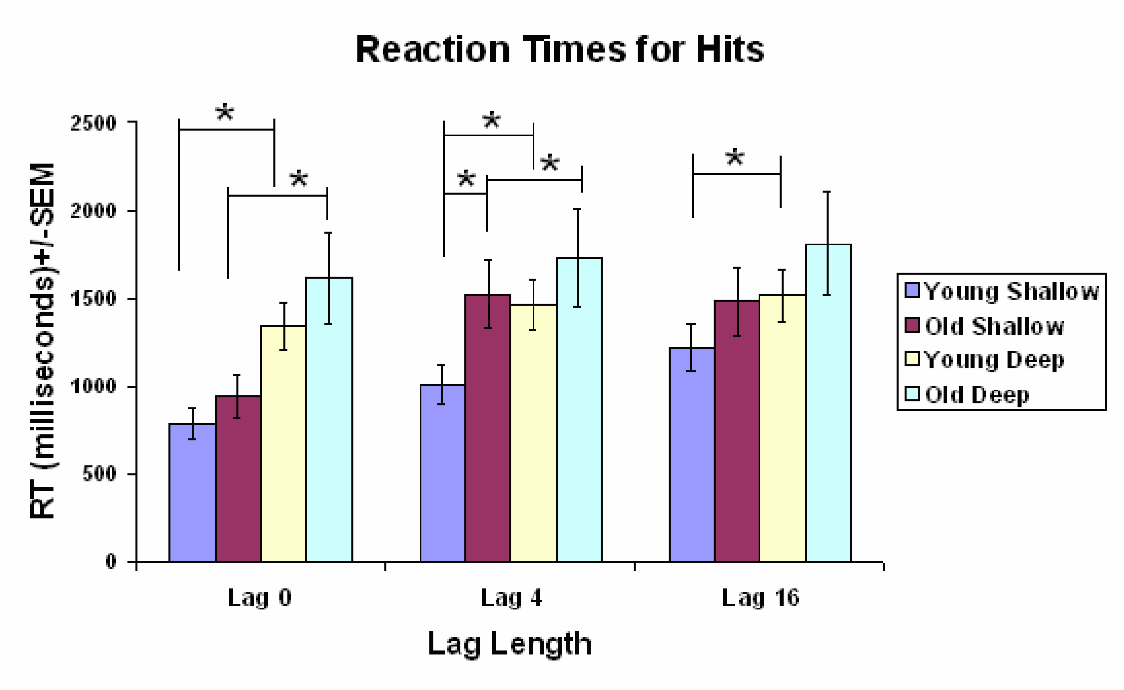


Figure 7.5: *Comparison of RTs of correct responses to Target stimuli by all groups*

For the RTs for Hits, a main effect for lag was found [F (2, 56) = 7.772, p<0.05]. An effect for depth was also recorded [F (1, 56) = 12.656, p<0.01], as well as a main effect for age [F (1, 56) = 8.155, p<0.05] Interaction effects between lag* group [F (5, 56) = 6.013, p<0.05] and lag*age [F (3, 56) = 4.863, p<0.05] were also reported. Bonferroni-corrected paired-sample t-tests were used for the RT data to examine within and between group differences. For the young shallow age group, lag 0 Hit responses were significantly faster from those at lag 4 [t (14) = 7.068, p<0.05] and at lag 16 [t (14) = 6.133, p<0.05]. For the old shallow group, hits at lag 0 were significantly different from those at lag 4 [t (14) = 3.895, p<0.05] and at lag 16 [t (14) = 3.030, p<0.05]. The young deep and old deep groups showed no significant differences with regards to lag.

Comparing the shallow to deep groups at the two ages found further significant result at different lag lengths. At lag 0, both the young deep [t (28) = 4.112, p<0.05] and old deep [t (28) = 6.013, p<0.05] groups were significantly slower at reacting than the comparable shallow groups. At lag 4 [t (28) = 3.755, p<0.05] and at lag 16 [t (28) = 4.328, p<0.05] this pattern was repeated among the young groups, but not the old group. Finally, the young and old groups of each depth were compared to each other at each lag. At lag 0, no significant differences were reported between the age groups regardless of depth of encoding. At lag 4, the young shallow group had significantly faster RTs than the old shallow group [t (28) = 4.693, p<0.05] while this did not occur in the deep groups. At lag 16, no significant differences were recorded following Bonferroni adjustments.

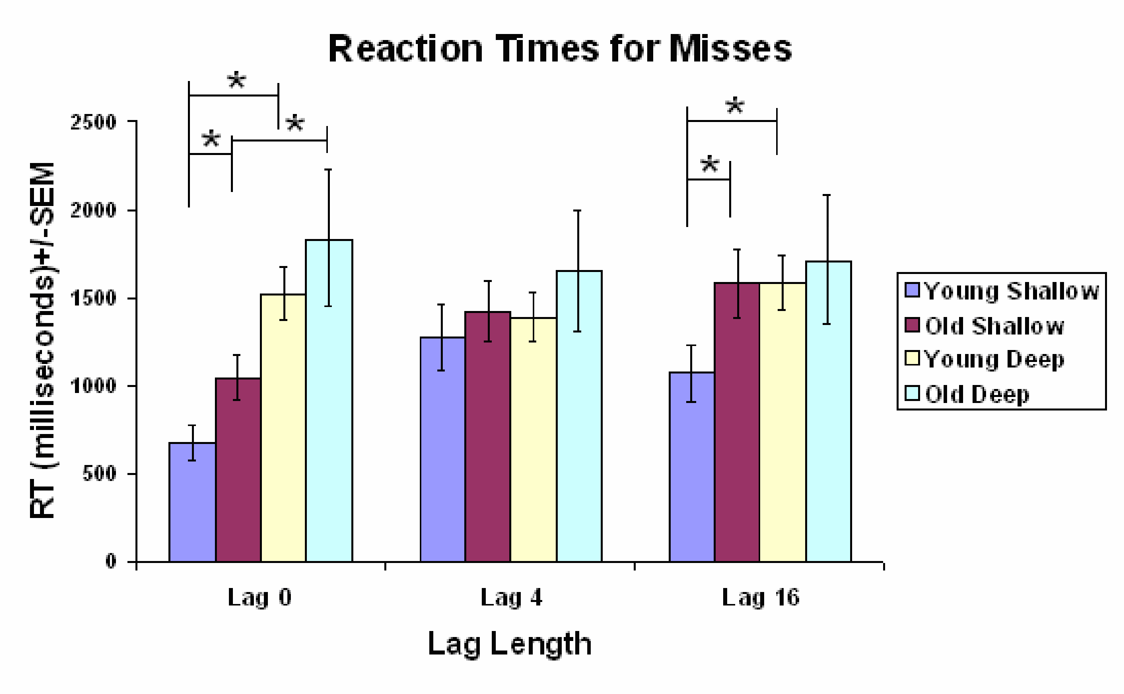


__Figure 7.6:__ Comparison of RTs of incorrect responses to Target stimuli by all groups

Data for Misses showed a main effect for lag [F (2, 56) = 9.915, p<0.05] and for group [F (1, 56) = 11.609, p<0.01] as well as a main effect for age [F (1, 56) = 8.536, p<0.01]. A lag*group interaction was also reported [F (3, 56) = 6.944, p<0.05], as was a lag*age interaction [F (5, 56) = 5.86, p<0.05]. Bonferroni corrected t-tests for the young shallow encoding group found that lag 4 [t (14) = 2.491, p<0.05] and lag 16 [t (14) = 6.281, p<0.05] showing significantly longer RTs than those for lag 0 trials. The old shallow encoding group showed similar results, with lag 4 [t (14) = 5.219, p<0.05] and lag 16 [t (14) = 5.392, p<0.01] showing significantly longer RTs than those for lag 0 trials. Again, the results for the two deep encoding groups showed no significant within-group differences.

Between the groups, the young shallow group was found to react significantly faster at lag 0 [t (28) = 6.142, p<0.05] and 16 [t (28) = 4.631, p<0.05] than the old shallow group. However, the deep groups showed similar RTs regardless of age. The young shallow group was also significantly faster to react than the young deep group at lag 0 [t (28) = 2.947, p<0.05] and lag 16 [t (28) = 3.866, p<0.05]. The old shallow group had significantly faster RTs at lag 0 over the old deep group [t (28) = 4.593, p<0.05], though not at the longer lags.

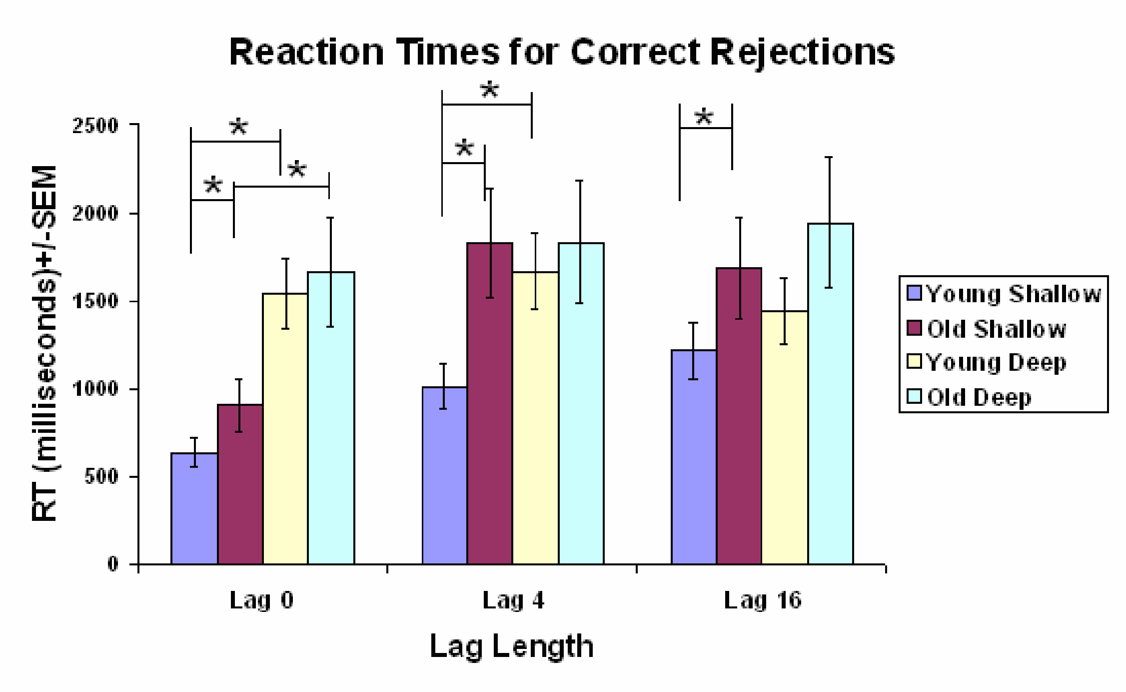


Figure 7.7: *Comparison of RTs of correct responses to Distractor stimuli by all groups*

Correct Rejection RTs showed a main effect for lag [F (2, 56) = 6.615, p<0.01], for depth [F (1, 56) = 9.314, p<0.01] and for age [F (1, 56) = 7.933, p<0.01]. A lag*age interaction effect was also recorded [F (5, 56) = 4.94, p<0.05] as was a lag*group interaction [F (3, 56) = 4.215, p<0.05]. Bonferroni adjusted t-tests fond that lag 0 responses were significantly quicker than lag 4 [t (14) = 5.597, p<0.05] or lag 16 responses [t (14) = 4.975, p<0.05] for the young shallow encoding group. Correct Rejection responses in the old shallow group showed lag 0 responses as being significantly quicker than lag 4 [t (14) = 6.292, p<0.05] or lag 16 responses [t (14) = 7.203, p<0.01]. The young and old deep encoding groups again showed no results of statistical significance for lags.

Between-groups analyses found that for lag 0 [t (28) = 5.022, p<0.05], lag 4 [t (28) = 4.165, p<0.05] and 16 [t (28) = 3.768, p<0.05], the old shallow group showed significantly slower RTs than the young shallow group, while the young and old deep encoding groups did not show significant differences. Comparing the age groups for differences between shallow and deep encoding found that amongst the two young groups at lag 0, the shallow group were significantly faster than the deep group [t (28) = 5.517, p<0.05]. This patter was replicated at lag 4 [t (28) = 6.223, p<0.05] though not lag 16. The old shallow and old deep groups were significantly different in favour of the shallow group at lag 0 [t (28) = 3.549, p<0.05].

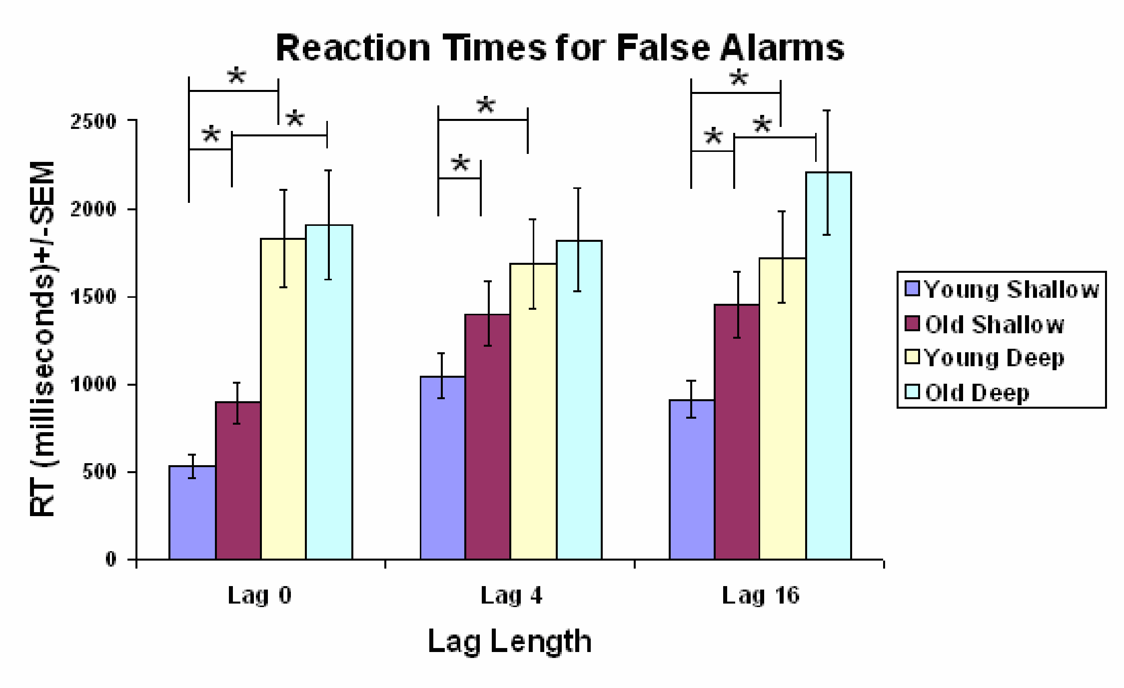


Figure 7.8: *Comparison of RTs of incorrect responses to Distractor stimuli by all groups*

Finally, for False Alarms, a main effect for lag was found to be present [F (2, 56) = 7.811, p<0.01] along with a main effect for depth [F (1, 56) = 9.183, p<0.01] and for age [F (1, 56) = 10.057, p<0.05]. A lag*age interaction effect was also found [F (5, 56) = 4.94, p<0.05] along with a lag*group interaction [F (3, 56) = 5.045, p<0.05]. Following a series of Bonferroni corrected t-tests, it was found that in the young shallow encoding group, lag 0 trials again showed significantly lower times than lag 4 [t (14) = 5.014, $p<0.05$] or lag 16 [t (14) = 6.606, $p<0.05$]. The pattern of RTs for the old shallow group adhered to the same pattern as the young group for False Alarms, with lag 0 trials again showing significantly lower times than lag 4 [t (14) = 4.868, $p<0.05$] or lag 16 [t (14) = 7.699, $p<0.05$]. The young and old deep encoding groups again showed no statistically significant results.

Comparing the young to old groups based on encoding depth, the deep groups were not found to have any significant differences, while the young shallow group showed lower RTs than the old shallow group at lag 0 [t (28) = 6.718, $p<0.05$], lag 4 [t (28) = 5.934, $p<0.05$] and lag 16 [t (28) = 3.726, $p<0.05$]. The young shallow group was also found to respond significantly faster than the young deep group at lag 0 [t (28) = 5.207, $p<0.05$], lag 4 [t (28) = 4.166, $p<0.05$] and lag 16 [t (28) = 7.223, $p<0.05$]. For the corresponding old groups, differences were found at lag 0 [t (28) = 4.685, $p<0.05$] and lag 16 [t (28) = 3.598, $p<0.05$].

The accuracy results for the shallow groups show a similar pattern to the previous findings, with lag 4 and lag 16 results for both age groups being significantly lower than those at lag 0. The deep encoding groups scored generally higher than their shallow counterparts, but while the young group outscored the old group, the lag effect seems to have been lessened considerably. For RTs, the shallow results again mirrored our earlier findings, but the deep groups showed some interesting differences, with generally longer RTs than the shallow groups, and a loss of lag-based differences.

7.4 Discussion

The results for the current chapter show strong evidence for a depth-of-processing effect using the Opposition task, Regardless of age. The shallow processing groups replicated the findings of the previous chapters, with lag 0 scores for both accuracy and reaction times being significantly better than those at lag 4 or lag 16, regardless of the age of the participants. Also, the differences between the young and old shallow processing groups mirrored the results found previously, with the older group consistently showing lower accuracy and higher RTs than the comparative younger group. Within the shallow-processing older group, a lag effect was found to be present, as in Chapter 6 of the current work, though absent in Chapter 5, using a broadly similar group of healthy older adults. This seems to suggest that results for the task conform to those found in earlier experiments such as Jennings and Jacoby (1997) and Dywan, Segalowitz and Webster (2001). The results for the groups requested to process the study list more deeply showed profound differences in the pattern and accuracy of scores than those in the shallow processing groups. Firstly, any lag-based differences seemed to disappear, with greater accuracy and longer RTs demonstrated with no significant differences between lags. Further, the age effect found within the shallow groups was diminished, especially at lag 0, with large increases in accuracy demonstrated by the old deep encoding group over the shallow encoding group.

The use of a simple method of increasing the level of encoding by participants seems to allow for a significant increase in accuracy levels. While this result has been shown using a number of paradigms, it has not been examined with old participants using an opposition-based source memory task. The most similar study to the current chapter is that of Jacoby et al. (2005), who carried out a source memory Old/New style task on young and old participants, with participants divided into a Deep and Shallow condition. In the deep condition, participants were asked to rate study words on a pleasant – unpleasant scale, while the shallow condition merely requested topographical information on the word; whether it contained an O or U. The results found by Jacoby et al. are generally similar to those reported in this chapter. The major difference between the two studies is the inclusion of lags in the current chapter, in an attempt to examine if the repetition of target and distractor words would decrease the effect of deeper encoding. Therefore, the lag 0 results found herein would be roughly analogous to those results found by Jacoby et al. (2005).

In our experiment, the young deep processing group scored the highest results, with accuracy levels of ~90% for targets. The Old deep processing group showed accuracy levels of ~80% for targets. The Jacoby et al. study gave results of ~60% for the young shallow processing group, significantly lower than the old deep group, which was not replicated here. In both the current study and the Jacoby et al. study, the old group with shallow processing scored lowest, with ~50% accuracy reported by Jacoby et al., compared to ~55% in the current study for lag 0 responses. The results of the Jacoby et al. (2005) study closely resemble those found in the lag 0 condition in the current study, although are generally lower. This would be expected, as the lag 0 condition is the second presentation of the word, directly following the first presentation, which may act as a primer, thereby increasing the accuracy for the second presentation. However, the results are broadly similar.

Jacoby et al. (2005) found no differences between the RT data of the two young groups, which differs from the current study, with RT data for lag 0 trials showing significantly longer for the deep processing group. Those experimenters did not report the RTs for the old groups, so a comparison cannot be made. However, the studies by Craik & Tulving (1975) found a trend for longer RTs in groups involved with deeper processing over shallow processing. Our results may be interpreted as the participants repeating the sentence the word was placed in during the study phase. While accuracy and RT is not generally inversely graphed in memory tests, the processing involved with the deeper encoding over the shallow encoding, i.e. recalling the sentence rather than merely a word, can account for the longer RTs for the Hits and False Alarm conditions. For the two conditions where words are recognised as distractors, either correctly (Correct Rejections) or incorrectly (Misses), the longer RTs could be linked to a similar trend in searching sentences rather than words to reject the stimulus as a target.

Another comparison comes from Ragland et al. (2006), who examined the source memory capacity of young healthy participants and compared them to a frontal lobectomy patient group with schizophrenia. These authors found a similar pattern of results to those shown by the young group in the current study. That is, a higher rate of correct source judgements for target words encoded deeply than those that were encoded in a shallower manner. The schizophrenic group showed no significant differences between deep and shallow encoding, pointing to a frontal-lobe oriented process, according to the authors. Our findings, that the older participants showed ameliorated performance based on deeper encoding, suggest that they have retained the functions related to encoding specificity, or, as in the previous chapter, the longer RTs over the shallow encoding group, combined with higher accuracy, may be linked to the use of a compensatory mechanism to make up for any loss in frontal processing.

The results for the differences between lags in the deep processing groups were as hypothesised, with those participants showing significantly less susceptibility to the effects of the longer lags than the shallow processing groups. While the reaction times were longer, possibly due to internal repetition of the encoded sentence, the accuracy results were higher than the shallow processing groups and showed a plateau effect across both deep processing groups. Both old and young participants showed no significant effect for lag. This may be due to the ameliorating effect of deeper encoding, with participants recalling words as studied or new regardless of repetition or lag length as a sentence was either recalled or not. The sentences recalled may have given context to the word, allowing for simpler differentiation between the old and new words.

The results show a large increase in accuracy for old participants over the control group and the previous chapters, based on a simple principle. It seems that, as Craik and Lockhart (1972, 1977, 2002) put forward, concentrating on a stimulus and giving it context or an additional point of reference, beyond colour, font or capitalisation, allows participants to greatly increase their memory ability, regardless of the difficulty of the task. The use of a simple method involving only placing a word in a sentence is enough to significantly increase accuracy. While this is a finding replicated many times previously, using such a method to combat the confusion of reported source memory deficits (e.g. Jennings & Jacoby, 1997) has yet been examined beyond simple Old/New paradigms. The current results allow for the expansion of the depth-of-encoding framework into a new area; that of repetition-based source memory deficits in older populations. Therefore, the next step forward would be to examine similar groups using the same paradigm while recording from scalp EEG. Such a study could examine whether parietal or other areas are active at later stages in the older population as was found in Chapter 6, or if the introduction of the deeper encoding level causes a more profound change to EEG, including increased frontal activation over a shallow encoding group. fMRI could also be used to examine the phenomena reported in the current chapter, as by examining the changes in blood oxygen in different areas between the groups would give a valuable insight into which areas are differentially recruited by the shallow and deep encoding groups of different ages.

Chapter 8

General Discussion

8.1 Overview of results

The thesis examined the behavioural, electrophysiological and neural differences found between young and old adults in terms of their ability to recall the context of an encoded memory, known as source memory, and to investigate whether the use of simple memory strategies based on the depth-of-processing theory (Craik, 1972, 1977, 1992) would facilitate performance in either or both groups. Further, we wished to study whether a middle-aged group would differ significantly from the young groups or if they would show some decrease in source memory recall ability, similar to the old group. To begin these analyses it was necessary investigate the parameters of the task itself, which has been used by many research groups since it was originally devised. As such, in Chapter 2 we examined the effect of a number of differing lag lengths. The accuracy results varied while RT data showed increases that corresponded to lag length. These RT results led to the design of the second part of the chapter, which examined whether increasing the time between the study and test blocks would change the ability of participants to recall the study words accurately and quickly. For this task, a long lag of 16 was included to compare with lag 0, along with the inclusion of a lag 4 condition, as an intermediate between the immediate and long lags. The results of this experiment showed no difference in accuracy between groups that were immediately tested following the study block, and those that were tested either an hour or 24 hours later. Again, the RT data showed increases for the lagged stimuli over the unlagged, while in terms of accuracy, a trend of decreasing accuracy was found for target words, though it was not significant.

These results allowed for the creation of a three-lag format for Chapter 4, with lag 0 as the immediate (control) lag and lag 4 and 16 as those to be compared. The lag 4 condition was included to determine if there was a gradual change in EEG data between an unlagged stimulus and a long lag, or if both lagged stimuli showed similar topographies. Behaviourally, the lagged conditions showed significant decreases in accuracy compared to lag 0, and showed little difference between lag 4 and 16 while RTs showed a significant increase for lag 4 and 16 compared to lag 0, with similar results found again for the lag 4 and 16 conditions. The EEG data showed a general trend of frontal activity from ~300ms onwards, with greater mean amplitudes for the lagged trials over lag 0 in the four experimental conditions. The parietal data showed a later component, from ~450-750ms; lag 4 and 16 trials showed significantly less negative deflections to those trials at lag 0. The dipole analysis carried out following this gave two dipole in frontal areas at lag 16 for hits compared to one at lag 0, and a parahippocampal area dipole for the longer lag that was absent in the immediate lag at the 350-400ms epoch. At the later 550-600ms epoch, False Alarm trials showed parahippocampal area activity at lag 16 though not at lag 0, as well as further parietal/temporal activity around the insula.

Chapter 5 used the same Opposition Task as Chapter 4 to examine how source memory recall ability changes over the lifespan through a behavioural experiment comparing groups of healthy young (20-30), middle-aged (40-50) and older (60-70) adults. The data showed that young adults produced results similar to those from Chapter 4. The middle-aged group scored a similar pattern of results to the young group, with no between-group differences reported in accuracy or reaction time. The general pattern of results within the old group did not mirror this, with lag 4 and 16 stimuli showing no significant decreases in accuracy and increases in RT over the lag 0 trials. However, between the groups, the old participants had significantly decreased accuracy compared to both the young and middle-aged groups, as well as showing significant increases in RT compared to the two younger groups, especially for lagged stimuli.

Due to the similarity in the behavioural results found between the young and middle-aged group, Chapter 6 examined the electrophysiological correlates of source memory in young and old adults. Again, the Opposition Task was used, and behavioural results for both groups were functionally similar to those found by the analogous groups in Chapter 5, apart from finding the lag effect to be present in both young and old groups, as had been expected. The ERPs for the young group were again similar to those found in Chapter 4, showing frontal area positivity and parietal variations between the lags. The old group showed a pattern of early frontal negativity in comparison to the positive deflections in the young group, followed by later (~500ms+) parietal scalp area positive deflections. Again these were different from the mainly negative deflections shown by the young group during the same epoch. Source analysis was carried out to compare the two groups at lag 16, revealing that the older group showed fewer frontal dipoles at the early epoch, instead showing generally temporal and parietal sources. The later epoch showed a distributed pattern of dipole sources for the young group, with temporal, parietal and frontal areas showing activation, compared to a more clustered model for the older adults, bilaterally around the parietal lobe and posterior areas of the frontal lobe.

The final chapter examined the behavioural changes found when a group of young and old participants were asked to engage a deeper level of encoding of the study list through placing the stimuli in sentences rather than reading them aloud. The young deep-encoding group scored higher than the young shallow-encoding group at lag 4 and 16, although with longer RTs. The old group exhibited similar data, with those who encoded more deeply showing results comparable to the shallow-encoding young group, although again with longer RTs. As in Chapter 6, a lag effect was present in both young and old shallow processing groups, which echoes the findings of earlier studies in the area. This seems to point to the results of Chapter 5 as being anomalous, as no lag effect was found in the old group therein. It is possible that this group was misrepresentative of a healthy older population despite the similarities found in CFQ scores and educational level achieved. Further studies in the area might benefit from a deeper analysis of participants' cognitive ability beforehand. Although this would create a longer study for elderly participants, it would aid in creating a more representative sample of the population being studied. While the experimenters used education and everyday memory as a broad index of normal cognitive ability, the introduction of further assessors of memory, such as the Everyday Memory Questionnaire (EMQ) could lead to a more fully characterised sample, and thus, more replicable and reliable results.

8.2 Context of the results in the literature

The behavioural results reported herein can be seen to generally mirror those reported by a number of previous studies in the area. The original Opposition Task study by Jennings and Jacoby (1997) exhibited that lagged repetitions of distractor, or foil, words caused a detrimental effect on recognition of the context in which the word was encountered. This conclusion was the basis of the research of Dywan et al. (1997, 2001, 2002), Mathewson et al. (2005) and Bridson et al. (2006) all of whom report that, behaviourally, a new stimulus repeated at a lag may be mistaken for a stimulus from a study list, and that this problem was more prevalent in an older population. Also, this decrease in accuracy was usually found to have an associated increase in reaction time, again exacerbated by old age. Despite Jennings and Jacoby (1997) examining the effects of a number of lags and pointing to this as one of the strengths of the paradigm, the general trend in other studies has been to use a control ("lag 0" condition) and one further lag. The behavioural nature of this original study means that an electrophysiological examination of differing lag lengths has not occurred in the literature to date.

Chapter 4 examined this using a short lag of 4 and a long lag of 16. As evidenced by the ERPs recorded from the young adult participants, the lag 4 and lag 16 waveforms show a great deal of similarity, despite their obvious differences with the lag 0 trials. This suggests that, as found behaviourally by Jennings and Jacoby (1997), regardless of the length of lag or the correctness of response the introduction of any lag in a test phase causes a neural pattern distinct from unlagged trials. However, while this lag-based pattern is present for all conditions, it differs topographically between correct and incorrect conditions. The dipole source analysis carried out in Chapter 4 supports this, showing frontal and medial temporal dipoles in the lagged trials at both lengths, though not in the lag 0 trial. This seems to link these areas of the cortex with the more difficult task of recognising the source of a lagged trial, compared to the simple recognition necessary to correctly identify an unlagged stimulus. Given the importance given to the parahippocampal area in memory processing (e.g. Nadel & Moscovitch, 1997), it is unsurprising that the area is implicated in the retrieval of source memory, especially those more remote from the first representation. Gold et al. (2006), for example, implicated the parahippocampal region in source memory retrieval using fMRI with brain injured patients. Findings by Dennis et al. (2008) also suggest the recruitment of prefrontal areas and hippocampal connections during source retrieval, and Slotnick, Moo, Segal and Hart Jr. (2003) found activation in frontal areas for a source task based on shape information rather than words. The electrophysiological results obtained from the two lags in Chapter 4 show a number of other similarities with established results, with frontal activations greater for the lagged stimuli over the unlagged and for Hits over other conditions, showing greater activity for correct recognition of targets, as found by Dywan et al. (2001). Event-Related Potential data from Old/New studies (e.g. Wilding & Rugg, 1996, 1997) have shown frontal and parietal areas as most active for the process used for distinguishing between previously presented words and those that are presented for the first time. The results found here showed greater positivity for the P3 in frontal areas for lag 16 responses (both targets and distractors). Hits also elicited greater positivity for the parietal P3b at lag 16 than at lag 0. This can be interpreted hand-in-hand with the Old/New data, in that the frontal bias for correct responses becomes more pronounced as lag length increases. ERP and dipole sources elicited by short and long lags in Chapter 4 is similar to those reported previously, and to each other, pointing to both recruiting the same source-memory recall processes absent in the unlagged trials.

Source memory studies, as mentioned repeatedly through the thesis, have clearly reported interesting and important findings, but a flaw in the designs is evident. While young and old adults are frequently compared (e.g. Mathewson et al., 2005) there is little evidence of an examination of source memory in relation to lifetime deterioration, while other memory types have been so studied (e.g. Park et al. 1996), finding that healthy middle-aged participants tend to be free of memory deficits compared to older participants. Jennings and Jacoby's (1997) conclusion that source memory may be a useful method of examining early deficits had not been studied previously in this regard. The differences between young and old groups have been widely reported, but the addition of a middle-aged group matched to the other groups by CFQ scores in Chapter 5 represents new ground in the study of source memory. The results reported are informative. The older group exhibits a clear deficiency in comparison to the young group in both accuracy and reaction time, as expected due to the wealth of studies in the area. The results of the middle-aged group show no behavioural differences from those of the young group, with near-identical accuracy and reaction time scores. These data point to the onset of deterioration in source memory recall ability occurring after the age of 50 but before the age of 70 a result as yet unreported in the literature. The absence of a deficit in the middle-aged group shows that while source memory may be susceptible to ageing even among healthy older adults, it is not necessarily useful to study it as a sign of early-onset memory problems in normal ageing. The inclusion of a middle-aged group with pathological memory problems could allow further examination of this decline, and conclude whether examining source memory changes could be useful in indexing such pathologies.

The electrophysiological examination of older adults during the Opposition Task was central to the thesis, and Chapter 6 compared this group to a group of younger adults, again examining ERPs and dipole models. Parietal scalp area recordings showed an increase in positive deflections for the old group over the young group at an epoch of ~500ms onwards, which is similar to the results reported by Dywan, Segalowitz and Webster (2002). However, the frontal scalp data shows a lack of positivity in older adults that is evident in the young group, and in the data of Dywan et al. (2002). While Mathewson et al. (2005) found higher positivity among a young group following lagged stimuli compared to an older group, their use of a response-locked analysis makes it difficult to compare with the results reported herein. Swick, Senkfor, and Van Petten (2006) found that older adults showed left frontal negativity in the 600-1200 ms in a source memory task that was absent in young adults and suggested that this reflected the use of alternate strategies in older adults that were not needed by young adults. This may be the case, as while there were clear behavioural deficits in the old group compared to the young group in Chapter 6, the lags still showed a decrease in accuracy compared to the unlagged controls. This suggests that while older adults may have source memory problems, they are not scoring at a behavioural floor level, indicating that an alternate neural correlate may exist for older adults compared to that of the young group in PFC and MTL areas. While later than the negativity found in the current thesis, the similarity is present. The late parietal positivity, known as a late positive component (LPC) has been linked to familiarity (e.g. Rugg & Doyle, 1992) and to effortful recollection (e.g. Wilding & Rugg, 1996). Rugg and Doyle (1992) used an old/new study of lexical decision making, finding greater positivity was present over parietal areas when words were correctly recognised as seen previously. Wilding and Rugg (1996) examined the difference between a simple old/new recognition and more difficult voice recognition experiment, again showing increased parietal area positivity for the more effortful task. An increase in the positivity of this component among the older group may therefore be indicative of an increase in the effort used by the old participants to recollect an item they see as familiar. More generally, Moscovitch and Winokur (1995) argue that frontal area deficits are strongly linked to episodic memory problems in older adults. Duncan and Owen (2000) go so far as to conclude that the frontal lobe is a necessary part of most forms of cognition, including both working and episodic memory. Therefore, any lowering of frontal area activity during a task would be seen as an indicator of decreased accuracy at the task. Duncan and Owen point to a network of areas within the PFC, dorsolateral, ventrolateral and anterior cingulate cortex as central to these processes, 3 of which showed dipole activity during correctly recalled stimuli. They concluded that Much of the remainder of frontal cortex, including most of the medial and orbital surfaces, did not show these changes in activation. While the results of the current work seem to give strength to Duncan and Owen's (2000) *Frontal Specificity* theory, the broad nature of their conclusions, which includes linking perception, response selection, executive control, working memory, episodic memory and problem solving to the frontal lobes, is too wide a research base to draw specific conclusions from.

It has been found that the prefrontal cortex participates in the process of inhibiting irrelevant and interfering information (Lepage, Ghaffar, Nyberg & Tulving, 2000), and that patients with traumatic brain injuries (TBI) to the prefrontal lobe are more prone to interference by irrelevant information, and the creation of false memories (Dockree, O'Keeffe, Moloney, Bishara, Carton, Jacoby & Robertson, 2006). Dockree et al. (2006) proposed that these patients are "captured" by highly accessible responses which leave them unable to engage in proper recollection of information. This model fits the current data, where a lack of activity on the scalp above, or dipole sources in, the prefrontal cortex correlates with fewer correct responses and to an inability to discriminate between target/relevant words, and distractor/irrelevant words in the older group.

Dipole modelling, while not a metabolism-based method of mapping the neural correlates of cognition or behaviours, allows researchers to attempt to bridge the gap between EEG data and neuroimaging techniques such as fMRI. The data found in the two ERP chapters in this thesis reflect this, showing a number of similarities with established results on the brain areas related to memory functions found by those functional techniques. The prevalence of frontal and parietal dipoles across the conditions and the increase in frontal dipoles among young adults at early stages and parietal dipoles among the older participants at later stages is not at odds with the findings of more general memory studies. The addition of parahippocampal area dipoles for lagged stimuli over unlagged stimuli is also not surprising, given the central role given to the MTL by major memory theories such as the Classical Consolidation Theory (Squire & Alvarez, 1995) and the Multiple Trace Theory (Nadel & Moscovitch, 1997, 2002). Given the specific nature of the memory being studied and the recording method used in the current work, it is difficult to conclude whether the MTL is active only during difficult source memory tasks or for all conditions to a greater or lesser extent. The increase in MTL activity for the longer lagged stimuli points to an important role for the structure in the accurate processing of source memory, but does not negate the basis of either of these major theories of memory creation and retrieval.

The increase in dipoles in these three areas for lagged stimuli points to the recruiting of the main areas involved with memory processing in general, but the data reported here suggest that young adults use frontal areas and MTL structures to better recall the source of a memory. For older adults, the lack of frontal dipoles seems to be linked to the deficit in their performance, but the increase in later temporal and parietal dipoles seems to show a possible migration of function, as adults score above chance for the lagged words. Swick et al. (2006) theorised that an alternate system may be used by older adults to recall source, and this LPC and associated dipoles may be such a system. Without this increase in the LPC, and the apparently associated recruitment of parietal and temporal areas not used by the young group, it is possible that the interference effect discussed by LePage et al. (2000) and examined by Dockree et al. (2006) in TBI patients could further reduce the accuracy of their responses. The use of these systems, which occurs later than the frontal activity in the young group, seems to be sub-optimal, as results remain lower than the young group, and this might also be linked to the general increase in reaction times found among the older adults across the studies carried out in the thesis. While the MTL and PFC are most commonly implicated in source memory processing, the parietal area has been found to have a role by Ragland et al. (2006) using an fMRI source memory task. Uncapher, Otten and Rugg (2006) used colour and location recall, finding that the parietal area, particularly the intra-parietal sulcus (IPS), was the only area to show activity for responses which were correct for all details. Lundstrom et al. (2005) also found strong activations in the posterior precuneus of the parietal lobe during a source memory task of word recall. These results point to a central role in the process of recalling source memory accurately for the parietal area. As such, if the ageing process interferes with frontal lobe functioning, increases in activity in these areas already linked to source recall could be seen as the most likely indicator of a migration of function.

The final experiment examined if a simple change in instruction could lessen the effect of lag or age on the results of the Opposition Task, using Craik's (1972, 1995,

2002) levels-of-processing framework. The results show that increased processing during encoding leads to increased accuracy in recall during the test phase. The younger deep-encoding adults showed an increase in accuracy for lagged stimuli, regardless of length of lag, to levels comparable to unlagged stimuli, as did older adults asked to process the study list more thoroughly. While it did not completely remove the effect of ageing on source recall, it showed an ameliorating effect on all lagged stimuli. Jacoby et al. (2005) found similar results using an unlagged source recall study, but the effect on lags has not been examined. The results clearly show an increase in accuracy, and the lack of the associated decrease in RT could be attributed to the higher-level processing necessary for recall of a sentence over a word, and not due to a speed-accuracy trade-off.

8.3 Implications of findings

8.3.1 Source Monitoring Framework

The source monitoring framework (SMF; Johnson, 1988; Johnson, Hashtroudi & Lindsay, 1993; Mitchell & Johnson, 2000) attributes thoughts and emotions experienced as memories to sources of past experiences. Memories are not explicitly recalled as from a certain source; rather the many aspects of the memory's context recall its source implicitly. This allows for the conclusion that the more cues you are given about the original memory, the more accurately you will recall it. Lindsay and Johnson (2001) give the example of a friend calling on the telephone. They might be recognized immediately if their greeting evokes a recall of events in which the speaker made similar utterances, but a failure in this implicit source recall might lead to recognition taking a longer time. However, likelihood of accurately recalling the caller increases as they provide more information. A false memory occurs if these thoughts, feelings, emotions etc. from a source are erroneously attributed to another source. This theory has a basis in the phenomenon of false memories in children for traumatic events (e.g. Loftus, 1993; Lynn & McConkey, 1998) and in problems with eye-witness testimony (e.g. Gudjonsson, 1992; Wells, 1993). At a basic behavioural level, the findings of the thesis are in line with this framework, with the prevalence of false alarms and increase in difficulty of source recall with the introduction of lags. It perhaps suggests that these lags are the interfering information that the SMF would see as causing an erroneous attribution of source.

This finding may be obvious; however, other aspects of the framework are that concentration and feature processing at encoding are important for recalling attributes of source. Since the source is a mixture of contextual information and cues, a greater degree of attention and a higher level of processing at encoding should result in greater accuracy in the recall of the source of a memory, especially when rehearsed (e.g. Johnson, Raye, Mitchell, Greene, Cunningham & Sanislow, 2005; see Mammarella & Fairfield, 2008 for a review). Johnson et al. (2005) found that if words were refreshed or repeated in a study list, accurate recall increased in the testing phase, with a linked increase in PFC activations using fMRI. Mammarella and Fairfield (2008) theorise that the working memory (WM) system is involved with this feature binding. The findings in Chapter 7 of this thesis can be seen to add a degree of strength to the hypothesis put forward, in that those participants asked to pay more attention to the study list and to more fully engage with the stimuli during the encoding phase, whether through the introduction of more semantic information or through the creation of an increased level of attention through repetition, showed a significant lessening in errors of source attribution, regardless of lag length or age, over those who were asked merely to read the list aloud. The SMF can therefore be seen as a useful method of examining not only the difference between imagined and real events, but can be expanded to include temporal sources as used in the Opposition Task.

8.3.2 Source Memory Processes

Glisky and Kong (2008) review a number of electrophysiological, imaging and patient studies in the area of source recall and differentiated source memory from episodic memory, pointing to the frontal lobe and prefrontal areas as to having the central role in source recall. Their review links Brodmann's Areas (BA) 10, 44, 45 and 47 to source memory over other types of memory, all of which are in frontal and prefrontal areas. While they mention that some studies (e.g. Gold et al., 2006; Schwerdt & Dopkins, 2001; Thaiss & Petrides, 2003) also implicate the MTL in source memory, it is believed that these areas are active due to the general memory processes involved, rather than the explicitly source memory processes. The dipoles found in the electrophysiological chapters lend a certain amount of evidence to this viewpoint. Young adults were found to have two frontal dipoles at lag 16 in BA 10 and 8, both frontal areas at longer lags, compared to one frontal dipole, at BA 10, for the unlagged information. Glisky et al. (2001) found that even a difficult item memory task did not show the same level of frontal activity as source tasks.

The introduction of MTL structures, though largely ignored by Glisky and Kong (2008), has been found in a number of studies, including those mentioned previously as well as in working memory tasks that include source, such as the work of Mitchell, Johnson, Raye, Mather, and D'Esposito (2000b), who implicated the right frontal lobe and left hippocampal formation (HF) in binding source to an event, which they suggested might be an absent or deficient process in older adults. The current study certainly shows findings that agree with that, with the young participants' lagged trials showing both frontal and parahippocampal activity absent in those of the older participants. It seems that it is this lack of ability to bind an item to its source through the use of the HF and PFC that impairs the source recall of older adults. As put forward by Swick et al. (2006), they seem to use a compensatory process based around parietal and temporal areas, which are not engaged to the same extent by the young group as the source recall has been successfully completed using optimal areas. The results suggest that these compensatory mechanisms, while sub-optimal, go some way to alleviating the problems older adults have with their ability to bind a specific memory to a specific context, or source.

8.3.3 Alzheimer's Disease

Alzheimer's disease (AD) is characterized by a profound deficit in episodic memory, but patients with AD have also been repeatedly found to suffer from source memory problems to a greater extent than healthy older adults (e.g. Mitchell, Sullivan, Schacter & Budson, 2006). Patients with the disease exhibit significant atrophy of important neocortical regions such as the temporal lobes and to a lesser extent, the frontal lobes (e.g. Juottonen, Laakso & Insausti et al. 1998; Fox, Warrington, Freeborough et al., 1996). These findings lend strength to the hypothesis put forward by Johnson et al. (2000b), that both the MTL and frontal lobe are necessary for correct attribution of source on a stimulus. Interestingly, Pierce, Waring, Schacter and Budson (2008) examined source recall in young, old and AD patients using a simple depth-of-encoding procedure, though not through the use of lags. Instead they asked patients to study either words (for the shallow group) or words with a matching picture (for the deep group). They found that while deeper encoding aided source recall in young and old adults, as found by the current work, those patients with AD did not show an improvement in source recall with deeper encoding. This implies that further connections exist than merely between the HF and PFC or a compensatory mechanism in the parietal and temporal areas, as MTL atrophy is a common part of AD (Juottonen et al., 1998).

8.4 Future Directions

The Opposition Task as laid out in the current thesis has been found to be a robust and reliable index of simple source recall, with behavioural, electrophysiological and dipole model findings showing a high level of similarity between Chapters 4-7. As such, the task could be used as the basis of further investigation in the area, in terms of both normal and abnormal ageing. The effect found in Chapter 5, with middle aged participants scoring comparably to young adults and the steep drop-off in performance found in the older group warrants further investigation, perhaps with the addition of a further intermediate group aged 50-60. The results found for these “Old Middle-Aged” adults would be extremely useful in examining whether source memory problems occur during a more specific time period or if a gradual decrease is observable between the previous middle-aged and old groups through this new group. An electrophysiological examination of these groups may also prove beneficial, to examine whether middle-aged participants are engaging frontal and MTL areas for source recall, or if there is evidence of a migration of function to more parietal areas such as the precuneus.

However, Vandenbroucke, Goekoop, Duschek, Netelenbos, Kuijer, Barkhof, Scheltens &, Rombouts (2004) bring up the problem of inter-individual differences in studies of ageing, examining fMRI data on an individual and group basis in older participants during an episodic memory task for face recall. They found that, while individually, correctly encoded words showed changes in MTL structure in the majority of participants, the high variability in both volume and area of activation within the structure meant that these findings were not produced when the group was analysed as a whole using a standard brain atlas.

The findings of Chapter 6 give a good deal of insight into the differences between source memory recall in young and old adults, with the electrophysiological and neural correlates of the task lending strength to established results and adding to them. However, the use of dipole modeling is not as powerful a tool as that of functional imaging, and an fMRI study using the same task on a young and old group could certainly give further useful information on the possible existence of compensatory mechanisms in older adults for source recall. This research direction also comes with a caveat due to recent findings on the use of methods such as fMRI with older populations. Studies have found that age-related problems with memory may be due in part to distraction from impaired inhibition of task-irrelevant input during encoding and retrieval (Dockree et al., 2006). Stevens, Hasher, Chiu and Grady (2008) suggest that the auditory input of methods such as fMRI cause create an artificial rise in this distraction, due to the unfamiliarity and loudness of the situation, in older participants, thereby possibly skewing the results of old groups towards lower scores, regardless of the actual recall ability of participants. Older adults showed increased activity in areas such as the auditory cortex and left PFC, as well as parietal areas, that were not linked to task-specific input, and instead to environmental monitoring. Therefore, while the information gleaned from the use of such tools would undoubtedly be useful in examining the posited underlying mechaniss for source recall examined herein, this finding means that fMRI results from older adults, especially those unused to such environs, should not be accepted as the only method of examining the neural correlates of behaviour and cognition in an aged population. Groups that exhibit episodic-type memory problems such as those suffering from subjective memory complaints (SMC) or mild cognitive impairments (MCI) could also be examined to discover if source memory deficits are greater than those found in a healthy group of older adults, and if so, which areas of the cortex are not being used by these groups.

The finding of the final experimental chapter (Chapter 7) gives a large scope for further research. Firstly, an EEG study based on the results would be advantageous, examining the neural underpinnings of the use of both source and deep-encoding recall. Nessler, Johnson, Bersick and Friedman (2006, 2008) completed simple depth-of-encoding studies for source with ERPs and found that the deep-encoding old group mirrored the ERP data of the shallow-encoding old group at encoding. An ERP-based examination of deep and shallow encoding of the Opposition Task would add the examination of ERPs at recall and over differing lags, in order to find if the use of deep encoding allowed older adults to engage brain areas not used during their source recall for shallow encoding, and to map any improved memory performance onto neural correlates.

Based on the findings of Pierce et al. (2008), the addition of a group of AD patients to such a study would add another level of interest. Since that study found no increase in accuracy for AD patients despite deeper processing at encoding, an examination of the ERP and dipole data for such a group would give an invaluable insight into whether the damage caused by the disease has cause irreperable problems in source memory recall. If the AD patients fail to engage either the HF-PFC areas accessed by younger participants or the tempero-parietal areas seemingly used instead by healthy old participants, this may give a possible reason for the deficits found in patients with AD. Again, the use of fMRI may shed further light on results found, but the same caveats apply to patients with AD as to a normal old-aged group with regards to that mode of analysis.

While the results found in the current work point to a good reason for continuing in the use of source memory studies and opposition-type designs in examining age-related changes in memory, the high level of variability reported in brain-imaging studies of the elderly (e.g. Vandenbroucke et al., 2004) and in AD patients (e.g. Small, Perera, De La Paz, Mayeux & Stern, 1999), as well as the questions asked about whether a fixed brain atlas is a useful tool in indexing the activations of variable populations (Toga & Thompson, 2001), mean that fMRI results must be examined thoroughly in order to ensure that results reported are due to actual changes in pertinent brain areas among participants, rather than a misrepresentative amalgamation based on imperfect indexing or a high distractibility level.

8.5 Concluding Remarks

This discussion has overviewed the findings of the thesis and laid them in their context in the literature to date, showing that the results reported herein give new information and add further detail to that reported previously on the source monitoring framework and on age-related difficulties with source memory. The findings of the behavioural chapters suggest that a lag-based source memory task is a useful method of examining age-related source memory problems, and point to the possibility that it is a late-life problem, with an onset after the age of 50. The results of Chapter 7 support the theories underpinning the source monitoring framework; that interference leads to source misattribution and that a greater level of concentration at encoding leads to a better binding of the source to the memory, leading to higher recall accuracy. The electrophysiological chapters show that the PFC is central to source recall, and also that the input of MTL areas has been understated in previous research. Chapter 6 highlighted the use of a possible compenatory parieto-temporal system in older adults to make up for a lack of frontal activity, expanding on the thoughts of Swick et al. (2006) in the area. The findings of this thesis represent a valuable addition to the field of source memory, in that they shed new light into the effect of lagged interference on recall for temporal sources even in young adults, as well as finding that the problems associated with older participants in the area may be ameliorated by a specific neural pathway, not used by younger adults, based in the tempero-parietal regions. Finally, that deeper encoding leads to the lessening of both the lag and age effects on source recall is an area that can be further studied in both normal and abnormal ageing. This thesis creates a possible neural model for source recall in young and old adults based on behavioural and electrophysiological data, with young adults seemingly reliant on MTL-PFC interaction to correctly recall the source of information, while oder adults show less activations in these areas and more reliance on later activations of the temporal-parietal regions based in the cortex around the precuneus.

References

Acosta, V.W. & Nasman, V.T. (1992). Effects of task decision on P300. *International Journal of Psychophysiology*. 13, 37–44.

Anderer, P., Klosch, G., Gruber, G., Trenker, E., Pascual-Marqui, R.D., Zeitlhofer, J., Barbanoj, M.J., Rappelsberger, P. & Saletu, B. (2001). Low-resolution brain electromagnetic tomography revealed simultaneously active frontal and parietal sleep spindle sources in the human cortex. *Neuroscience.* 103: 581-592.

Atkinson, R.C. & Shiffrin, R.M. (1968). Human memory: A proposed system and its control processes. In Spence, K.W. & Spence, J.T. (Eds). *The psychology of learning and motivation (Volume 2)*. New York: Academic Press. pp. 89–195.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature reviews: Neuroscience,* 4:10, 829-39.

Bartlett, J.C., Strater, L. & Fulton, A. (1991). False Recency and False Fame of Faces in Young Adulthood and Old Age. *Memory and Cognition*, 19:2, 177-188.

Bayen, U.J. & Murnane, K. (1996). Aging and the use of perceptual and temporal information in source memory tasks. *Psychology and Aging, 11,* 293-303

Beck, A. (1890). Localising brain and spinal cord function by electrical findings. *Zentralblatt fur Physiologie*. 4, 437-476.

Bennington, J.Y. & Polich, J. (1999) Comparison of P300 from passive and active tasks for auditory and visual stimuli. *International Journal of Psychophysiology*. 34:2, 171-177.

Berg, P. & Scherg, M. (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalography and Clinical Neurophysiology*. 90, 229-241.

Berger, H. (1929). Hans Berger on the electroencephalogram of man; the fourteen original reports on the human electroencephalogram. Translated from the original German and edited by Gloor, P. (1969) Amsterdam, Elsevier.

Bowles, R.P. & Salthouse, T.A. (2008).Vocabulary test format and differential relations to age. *Psychology of Aging*, 23:2, 366-76.

Bridson, N.C., Fraser, C.S., Herron, J.E. & Wilding, E.L. (2006). Electrophysiological correlates of familiarity in recognition memory and exclusion tasks. *Brain Research,* 1114; 149-160.

Broadbent, D.E., Cooper, P.F., FitzGerald, P. & Parkes, K.R. (1982). The Cognitive Failures Questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology,* 21, 1-16.

Burke, D., MacKay, D. G., Worthley, J. & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults? *Journal of Memory and Language*, 30, 542-579.

Cabeza, R., Grady, C.L., Nyberg, L., McIntosh, A.R., Tulving, E., Kapur, S., Jennings, J.M., Houle, S. & Craik, F.I. (1997). Age-related differences in neural activity during memory encoding and retrieval: a positron emission tomography study. *Journal of Neuroscience,* 17, 391–400

Caton, R. (1875). The electric currents of the brain. *British Medical Journal*. 2, 278.

Cermak, L.S. (1972). *Human Memory; Research and Theory,* New York, Ronald Press.

Chalfonte, B.L. & Johnson, M.K. (1996). Feature memory and binding in young and older adults. *Memory and Cognition,* 24, 403–416.

Chao, L., Nielsen-Bohlman, L. & Knight, R. T. (1995). Auditory event-related potentials dissociate early and late memory processes. *Electroencephalography and Clinical Neurophysiology*, 96, 157-168,

Coenen, A.M.L. (1995). Neuronal activities underlying the electroencephalogram and evoked potentials of sleeping and waking: Implications for information processing, *Neuroscience & Biobehavioral Reviews*. 19, 447–463

Cohen, D. (1972). Magnetoencephalography: detection of the brain's electrical activity with a superconducting magnetometer. *Science*. 175,664-66

Corkin, S. (1984). Lasting consequences of bilateral medial temporal lobectomy: Clinical course and experimental findings in H.M. *Seminars in Neurology*, 4:4, 249–259.

Coull JT (1998). Neural correlates of attention and arousal: insights from electrophysiology, functional neuroimaging and psychopharmacology. *Progress in Neurobiology*. 55, 343-361.

Craik, F. I. (1977). Age differences in human memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging*. Oxford University Press, Oxford.

Craik, F.I. (2002). Levels of processing: past, present. and future? *Memory*. 10:6-6, 305-318.

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

Craik, F.I., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, 104, 268-294.

Craik, F.I., Morris, L.W., Morris, R.G. & Loewen, E.R. (1990). Relations between Source Amnesia and Frontal Lobe Functioning in Older Adults. *Psychology and Ageing*, 5:1, 148-151.

Czernochowski, D., Fabiani, M. & Friedman, D. (2008). Use it or lose it? SES mitigates age-related decline in a recency/recognition task. *Neurobiology of Aging*. 29:6, 945-58.

Daselaar, S.M., Fleck, M.S., Dobbins, I.G., Madden, D.J. & Cabeza, R. (2006). Effects of healthy aging on hippocampal and rhinal memory functions: an event-related fMRI study. *Cerebral Cortex*, 6:12, 1771-82.

Dawson, G.D. (1954). A summation technique for the detection of small evoked potentials: EEG. *Clinical Neurophysiology*. 6, 65-84

Démonet, J.F., Thierry, G. & Cardebat, D. (2005). Renewal of the neurophysiology of language: functional neuroimaging. *Physiological reviews*. 85:1, 49-95.

Dennis, N.A., Hayes, S.M., Prince, S.E., Madden, D.J., Huettel, S.A. & Cabeza, R. (2008). Effects of aging on the neural correlates of successful item and source memory encoding. *Journal of experimental psychology. Learning, memory, and cognition*. 34:4, 791-808.

Dien, J. (1998). Issues in the application of the average reference: review, critiques, and recommendations. *Behavioural Research: Methods Instruments and Computation*. 30, 34–43.

Dockree, P.M., Kelly, S.P., Robertson, I.H., Reilly, R.B. & Foxe, J.J. (2005). Neurophysiological Markers of Alert Responding During Goal-Directed Behaviour: A High Density Electrical Mapping Study. *NeuroImage*. 27:3. 587-601.

Dockree P.M., O'Keeffe, F.M., Moloney, P., Bishara, A.J., Carton, S., Jacoby L.L. & Robertson, I.H. (2006). Capture by misleading information and its false acceptance in patients with traumatic brain injury. *Brain: a journal of neurology*. 129:1, 128-40.

Duarte, A., Henson, R. & Graham, K. (2008). The effects of aging on the neural correlates of subjective and objective recollection. *Cerebral Cortex*, 18:9, 2169-2180.

Duncan J, Owen AM (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends in Neuroscience*. 23:10, 475-83

Duncan-Johnson, C.C. & Donchin, E., (1982). The P300 component of the event-related brain potential as an index of information processing. *Biological Psychology*. 14, 1–52.

Dywan, J. & Jacoby, L.L. (1990). Effects of Ageing on Source Monitoring: Differences in Susceptibility to False Fame. *Psychology and Ageing*, 5:3, 379-387.

Dywan, J., Segalowitz, S.J. & Arsenault, A. (2002). Electrophysiological Response during Source Memory Decisions in Older and Younger Adults. *Brain and Cognition,* 49; 322-340.

Dywan, J., Segalowitz, S.J. & Webster, L. (1998). Source Monitoring: ERP Evidence for Greater Reactivity to non-target information in Older Adults. *Brain and Cognition*, 36*;* 390-430.

Dywan, J., Segalowitz, S. J., Webster, L., Hendry, K. & Harding, J. (2001). Event-related potential evidence for age-related differences in attentional allocation during a source-monitoring task. *Developmental Neuropsychology*, 19; 99–120.

Dywan, J., Segalowitz, S.J. & Williamson, L. (1994). Source Monitoring during Name Recognition in Older Adults: Psychometric and Electrophysiological Correlates. *Psychology and Ageing,* 9:4, 568-577.

Eichenbaum, H. & Cohen, N.J. (2001). *From conditioning to conscious recollection: Memory systems of the brain*. Oxford University Press; Oxford: 2001.

Ellenbogen, J.M., Hulbert, J.C., Stickgold, R., Dinges, D.F., Stickgold, R. & Thompson-Schill, S.L. (2006). Interfering with theories of sleep and memory: Sleep, declarative memory and associative interference. *Current Biology*.16, 1290-4.

Eysenck, M.W. (1974). Age differences in incidental learning. *Developmental Psychology*. 10, 936-941.

Fabiani, M. & Friedman, D. (1995). Changes in brain activity patterns in aging: The novelty oddball. *Psychophysiology*, 32, 579-594.

Falkenstein, M., Hoorman, J. &. Hohnbein, J. (2001). Changes in error-related ERPs with age, *Experimental Brain Research*. 138, 258–262.

Fletcher, P.C., Frith, C.D. & Rugg, M.D. (1997). The Functional Neuroanatomy of Episodic Memory. *Trends in Neuroscience,* 20:12. 557-558.

Ficca, G., Lombardo, P., Rossi, L. & Salzarulo, P. (2000). Morning recall of verbal material depends on prior sleep organization. *Behavioural brain research.* 112:1-2 159-63.

Fischler, I. & Juola, J.F. (1971). Effects of Repeated Tests on Recognition Time for Information in Long-Term Memory. *Journal of Experimental Psychology,* 91, 54-58.

Fox, N.C., Warrington, E.K., Freeborough, P.A., Hartikainen, P., Kennedy, A.M., Stevens, J.M. & Rossor, M.N. (1996). Presymptomatic hippocampal atrophy in Alzheimer's disease. A longitudinal MRI study. *Brain*. 119:6, 2001-7.

Friendly, M., Franklin, P.E., Hoffmann, D. & Rubin, D.C. (1982). The Toronto Word Pool: Norms for Imagery, Concreteness, Orthographic Variables and Grammatical Usage for 1080 Words. *Behavioural Research Methods and Instrumentation,* 14:4; 375-399.

Gevins, A.S., Bressler, S.N., Morgan, N.H., Cutillo, B.A., White, R.M., Greer, D.S. & Illes, J. (1989) Event related covariances during a bimanual visuomotor task. Part I.

Methods and analysis of stimulus- and response-locked data. *Electroencephalography and clinical Neurophysiology*. 74

Glisky, E.L. & Kong, L.L. (2008). Do young and older adults rely on different processes in source memory tasks? A neuropsychological study. *Journal of Experimental Psychology: Learning, Memory and Cognition*. 34:4, 809-22.

Glisky, E.L., Rubin, S.R. & Davidson, P.S.R. (2001). Source Memory in Older Adults: An Encoding or Retrieval Problem? *Journal of Experimental Psychology,* 27, 1131-1146.

Gold, J.J., Smith, C.N., Bayley, P.J., Shrager, Y., Brewer, J.B., Stark, C.E.L., Hopkins, R.O. & Squire, L.R. (2006). Item memory, source memory, and the medial temporal lobe: Concordant findings from fMRI and memory-impaired patients. *Proc Natl Acad Sci U S A,* 103:12, 9351-56.

Grady, C.L., McIntosh, A.R., Horwitz, B., Maisog, J.M., Ungerleider, L.G., Mentis, M.J., Pietrini, P., Schapiro, M.B. & Haxby, J.V. (1995). Age-related reductions in human recognition memory due to impaired encoding. *Science,* 269, 218–221.

Gudjonsson, G.H. (1992). *The psychology of interrogations, confessions and testimony*. Wiley, Chichester, England.

Guo, C., Duan, L., Li, W., & Paller, K.A. (2006). Distinguishing source memory and item memory: Brain potentials at encoding and retrieval. *Brain Research*. 1118, 142-154.

Gutchess, A.H., Ieuji, Y. & Federmeier, K.D. (2007). Event-related Potentials Reveal Age Differences in the Encoding and Recognition of Scenes. *Journal of Cognitive Neuroscience*. 19:7, 1089-1103.

Handy, T. (Ed.). (2005). *Event-related potentials: A methods handbook*. Cambridge, Massachusetts: MIT Press.

Hayama, H.R., Johnson, J.D. & Rugg, M.D. (2008). The relationship between the right frontal old/new ERP effect and post-retrieval monitoring: Specific or non-specific? *Neuropsychologia*. 46:5, 1211-23.

Henkel, L.A., Johnson, M.K. & De Leonardis, D.M. (1998). Aging and source monitoring: Cognitive processes and neuropsychological correlates. *Journal of Experimental Psychology: General*, 127, 251–268.

Hillyard, S.A. (1985). Electrophysiology of Human Selective Attention. *Trends in Neuroscience*, 8, 400-405.

Hillyard, S.A., Teder-Sälejärvi, W.A. & Münte, T. (1998). Temporal dynamics of early perceptual processing. *Current Opinion in Neurobiology*, 8:2, 202-210.

Hjorth, B. (1975). An on-line transformation of EEG scalp potentials into orthogonal source derivations, *Electroencephalography and Clinical Neurophysiology*. 39.

Hoechstetter, K., Bornfleth, H., Weckesser, D., Ille, N., Berg, P. & Scherg M. (2004). BESA source coherence: A new method to study cortical oscillatory coupling. *Brain Topography,* 16, 233-238.

Howard, M.W., Bessette-Symons, B., Zhang. Y. & Hoyer, W.J. (2006). Aging selectively impairs recollection in recognition memory for pictures: evidence from modeling and receiver operating characteristic curves. *Psychology of Aging*, 21:1, 93–106.

Hyde, T.S. & Jenkins, J.J. (1973). Differential effects of incidental tasks on the organization of recall of a list of highly associated words. *Journal of Experimental Psychology*. 82, 472-481.

Ille, N., Berg, P & Scherg, M. (2002). Artifact correction of the ongoing EEG using spatial filters based on artefact and brain signal topographies. *Journal of Clinical Neurophysiology*. 19, 113-124.

Israel, J.B., Chesney, G.L., Wickens C.D. & Donchin, E. (1980b). The event-related brain potential as an index of display-monitoring workload. *Human Factors*. 2, 211-224.

Izquierdo, I. (1987). The effect of exposure to novel and non-novel videotaped material on retrieval in two memory tests. *Neuropsychologia* 25, 995–998.

Izquierdo, A., Barros, D.M., Medina J.H. & Izquierdo, I. (2002). Stress hormones enhance retrieval of inhibitory avoidance learned 1 day or many months before in rats. *Behavioral Pharmacology*. 13, 203–213

Jacoby, L.L. (1999). Deceiving the Elderly: Effects of Accessibility Bias in Cued-Recall Performance. *Cognitive Neuropsychology*, 16, 417-436.

Jacoby, L.L., Shimizu, Y., Velanova, K. & Rhodes, M.G. (2005). Age differences in depth of retrieval: Memory for foils. *Journal of Memory and Language*. 52, 493–504.

Jasper, H.A. (1958). The ten–twenty system of the International Federation. *Electroencephelography and Clinical Neurophysiology* 10, 371–375.

James, L.E. & Burke, D.M. (2000) Phonological priming effects on word retrieval and tip-of-the-tongue experiences in young and older adults, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26, 1378–1391.

Jennings, J.M. & Jacoby, L.L. (1997). An Opposition Procedure for Detecting Age-Related Deficits in Recollection: Telling Effects of Repetition. *Psychology and Ageing*, 12:2, 352-361.

Johnson, M.K. (1988). Discriminating the origin of information. In: Oltmanns, T.F. & Maher, B.A. (Eds) (1988). *Delusional beliefs*. Wiley, New York, pp. 34–65.

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

Johnson, M.K., Raye, C.L., Mitchell, K.J., Greene, E.J., Cunningham, W.A. & Sanislow, C.A. (2005). Using fMRI to investigate a component process of reflection: prefrontal correlates of refreshing a just activated representation. *Cognitive, Affective, and Behavioral Neuroscience*. 5, 339-361.

Juottonen, K., Laakso, M.P., Insausti, R., Lehtovirta, M., Pitkänen, A., Partanen, K. & Soininen, H. (1998). Volumes of the entorhinal and perirhinal cortices in Alzheimer's disease. *Neurobiology of Aging*. 19:1, 15-22.

Kausler, D.H. & Wiley, J.G. (1990). Temporal memory and content memory for actions, Adult age differences in acquisition and retention. *Experimental Aging Research,* 16, 147–150.

Kertesz, A. (1994) Neuropsychological evaluation of language. *Journal of Clinical Neurophysiology*.11:2, 205-15.

Kim, Y.Y, Roh, A.Y., Yoo, S.Y., Kang, D & Kwon, J.S. (2009). Impairment of source memory in patients with obsessive–compulsive disorder: Equivalent current dipole analysis. *Psychiatry Research*. 165, 47–59.

Kolb & Whishaw (2003). *Fundamentals of Human Neuropsychology*. USA, Freeman.

Kramer M.A. & Szeri, A.J. (2004). Quantitative approximation of the cortical surface potential from EEG measurements. *IEEE Transactions on Biomedical Engineering*. 51, 1358-1365.

Lancaster, J.L., Summerlin, J.L., Rainey, L., Freitas, C.S. & Fox, P.T. (1997). The Talairach Daemon, a database server for Talairach Atlas Labels. *Neuroimage*. 5:4, 633.

Lang, P.J., Bradley, M.M., Fitzsimmons, J.R., Cuthbert, B.N., Scott, J.D., Moulder, B. & Nangia, V. (1998). Emotional arousal and activation of the visual cortex: An fMRI analysis. *Psychophysiology*. 35:2, 198-210.

Laver, G.D. & Burke, D.M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology of Aging*. 8:1, 34–43.

Lawson, A.L., Guo, C., & Jiang, Y. (2007). Age effects on brain activity during repetition priming of targets and distracters. *Neuropsychologia*. 45, 1223-1231.

Lehman, E.B. & Mellinger, J.C. (1984). Effects of ageing on memory for presentation modality. *Developmental Psychology*. 20, 1210-1217.

Lepage, M., Ghaffar, O., Nyberg, L. & Tulving, E. (2000). Prefrontal cortex and episodic memory retrieval mode. *Proceedings of the National Academy of Science U S A.* 97:1, 506-11.

Lindsay, D.S. & Johnson, M.K. (1997). False memories and the source monitoring framework: Reply to Reyna and Lloyd. *Learning and Individual Differences*. 12:2, 145-161

Light, L.L., LaVoie, D., Valencia-Laver, D., Albertson-Owens, S.A., & Mead, G. (1992). Direct and indirect measures of memory for modality in young and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 1284-1297.

Loftus, E.F., Miller, D.G. & Burns, A.J. (1978). Semantic integration of verbal information into a visual memory. *Journal of Experimental Psychology: Human Learning and Memory*. 4, 19–31.

Luck, S.J. (2005) *An Introduction to the event-related potential technique*. The MIT Press.

Luck, S.J., Fan, S., & Hillyard, S.A. (1993). Attention-related modulation of sensory-evoked brain activity in a visual search task. *Journal of Cognitive Neuroscience*. 5, 188-195.

Lundstrom, B.N., Ingvara, M. & Petersson K.M. (2005). The role of precuneus and left inferior frontal cortex during source memory episodic retrieval. Neuroimage, 27:4, 824-34.

Lye, T.C., Piguet, O., Grayson, D.A., Creasey, H., Ridley, L.J., Bennett, H.P. & Broe, G.A. (2004). Hippocampal size and memory function in the ninth and tenth decades of life: the Sydney Older Persons Study. *Journal of neurology, neurosurgery, and psychiatry,* 75:4, 548-54.

Lynn, S.J. and McConkey, K.M. (1998). *Truth in memory*, Guilford Press, New York, NY.

Machulda, M., Ward, H., Borowski, B., Gunter, J., Cha, R., O'Brien, P., Petersen, R., Boeve, B., Knopman, D., Tang-Wai, D., Ivnik, R., Smith, G., Tangalos, E. & Jack, C. (2003). Comparison of memory fMRI response among normal, MCI, and Alzheimer patients. *Neurology*, 61, 500 – 506.

Maddock, R.J., Garrett, A.S. & Buonocore, M.H. (2001). Remembering familiar people: the posterior cingulate cortex and autobiographical memory retrieval. *Neuroscience,* 104(3):667–676

Maguire, E.A, Burgess, N., Donnett, J.G., Frackowiak, R.S.J., Frith, C.D. & O'Keefe, J. (1998). Knowing Where and Getting There: A Human Navigation Network. *Science*, 280; 921-924.

Mammarella, N. & Fairfield, B. (2008). Source monitoring: the importance of feature binding at encoding. *European Journal of Cognitive Psychology*. 20, 91-122.

Marklund, P., Fransson, P., Cabeza, R., Petersson, K.M.,Ingvar, M. & Nyberg, L. (2007). Sustained and transient prefrontal brain activity related to working memory, long-term memory and attention. *Cortex,* 43: 22-37.

Mathewson, K.J., Dywan, J. & Segalowitz, S.J. (2005). Brain bases of error-related ERPs as influenced by age and task. *Biological Psychology, 70*, 88-104.

Maylor, E.A. (1990. Recognizing and naming faces: aging, memory retrieval, and the tip of the tongue state. *Journals of Gerontology,* 45.

Miller, G.A. (1956), The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information. *Psychological Review*, 63, 81-97.

Mitchell, K.J. & Johnson, M.K. (2000). Source monitoring: attributing mental experiences. In: Tulving, E. and Craik, F.I. (Eds) (2000). *Oxford handbook of memory,* Oxford Univ. Press, New York, pp. 179–195.

Mitchell, K.J., Johnson, M.K., Raye, C.L. & D'Esposito, M. (2000) FMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Cognitive Brain Research*. 10, 197–206.

Mitchell, J.P., Sullivan, A.L., Schacter, D.L & Budson, A.E. (2006). Misattribution Errors in Alzheimer's Disease: The Illusory Truth Effect. *Neuropsychology*. 20:5, 185-192.

Mori, E., Yoneda, Y., Yamashita, H., Hirono, N., Ikeda, M. &Yamadori, A. (1997). Medial temporal structures relate to memory impairment in Alzheimer's disease: an MRI volumetric study. *Journal of Neurology, Neurosurgery and Psychiatry,* 63:2, 214–221.

Moscovitch, M. (1994). Models of Consciousness and Memory. In *The Cognitive Neurosciences*, ed. M.S. Gazzaniga, MIT Press, Cambridge, MA, 1341-1356.

Moscovitch, M., Rosenbaum, R.S., Gilboa, A., Addis, D.R., Westmacott, R., Grady, C., McAndrews, M.P., Levine, B., Black, S.E., Winocur, G. & Nadel, L. (2005). Functional neuroanatomy of remote episodic, semantic and spatial memory: A unified account based on multiple trace theory. *Journal of Anatomy*. 207, 35-66.

Mosher J.C., Lewis P.S. & Leahy R.M. (1992). Multiple dipole modeling and localization from spatio-temporal MEG data. *Brain Pharmacology*. 39, 541-557.

Nadel, L. (1992) Multiple Memory Systems: What and Why. *Journal of Cognitive Neuroscience,* 4: 179-188.

Nadel, L. & Moscovitch, M. (1997). Memory consolidation, retrograde amnesia and the hippocampal complex, *Current Opinions in Neurobiology*, 7(2):217-27.

Nadel, L., Ryan, L., Hayes, S., Gilboa, A., & Moscovitch, M. (2003) The role of the hippocampal complex in episodic long-term memory. In T. Ono, G. Matsumoto, R.R. Lllinas, A. Berthoz, R. Norgren, H. Nishijo & R., Tamura (Eds),) *Cognition and Emotion in the Brain: Selected Topics of the International Symposium on Limbic and Association*

Cortical Systems, Toyama, Japan. (*Excerpta Medica International Congress Series*, 1250, pp. 215-235).

Nessler, D., Johnson, R., Jr., Bersick, M. & Friedman, D. (2006) On why the elderly have normal semantic retrieval but deficient episodic encoding: An ERP study of left inferior frontal ERP activity. *NeuroImage*. 30, 299-312,

Nessler, D., Johnson, R., Jr., Bersick, M. & Friedman, D. (2008). Age-related ERP differences at retrieval persist despite age-invariant performance and left-frontal negativity during encoding. *Neuroscience Letters*. 432, 151–156.

Nunez, P. (1989)Estimation of large scale neocortical source activity with EEG surface Laplacians. *Brain Topography*. 2, 141–154.

Nunez, P.L. & Srinivasan, R. (2006) *Electric Fields of the Brain: The Neurophysics of EEG.* New York: Oxford University Press.

Osorio, A., Ballesteros, S., Fay, S. & Pouthas, V.(2009). The effect of age on word-stem cued recall: a behavioral and electrophysiological study. *Brain research*. 1289, 56-68.

Otten L.J. & Rugg M.D. (2001). Task-dependency of the neural correlates of episodic encoding as measured by fMRI. *Cerebral Cortex*. 11, 1150–1160.

Park, D. C. & Schwarz, N. (2000). *Cognitive aging: A primer*. Philadelphia, PA: Psychology Press.

Park, D.C., Smith A.D., Lautenschlager, G. Earles, J.L., Frieske, D., Zwahr, M. & Gaines, C.L. (1996). Mediators of long-term memory performance across the life span. *Psychology and aging*. 11:4, 621-37.

Paz-Caballero, M.D. and Garcia-Austt, E. (1992) ERP components re- lated to stimulus selection processes. *Electroencephalography in clinical Neurophysiology*. 82: 369-376.

Perrin, F., Bertrand, O. & Pernier, J. (1987). Scalp current density mapping: value and estimation from potential data. *IEEE Trans. Biomedical Engineering*. 34, 283–287.

Peters, J. & Daum, I. (2009). Frontal but not parietal positivity during source recollection is sensitive to episodic content. *Neuroscience Letters*, 454(3):182-6.

Pierce, B.H., Waring, J.D., Schacter, D.L. & Budson, A.E. (2008) Effects of distinctive encoding on source-based false recognition: further examination of recall-to-reject processes in aging and Alzheimer disease. *Cognitive Behavioural Neuroscience*. 21:3, 179-86.

Postma, A. (1999). The influence of decision criteria upon remembering and knowing in recognition memory. *Acta Psychologica*, 103:1, 65-76.

Puglisi, J.T, Park, D.C., Smith, A.D. & Hill, G.W. (1985). Memory for two types of spatial location: Effects of instruction, age and format. *American Journal of Psychology, 98*: 101-118.

Ragland, J.D., Valdez, J.N., Loughead, J., Gur, R.C. & Gur, R.E. (2006).Functional magnetic resonance imaging of internal source monitoring in schizophrenia: recognition with and without recollection. *Schizophrenia Research*. 87:1-3, 160-71.

Rakitin B.C., Stern Y. & Malapani, C. (2005). The effects of aging on time reproduction in delayed free-recall. *Brain & Cognition,* 58:1, 17–34.

Raz, N., Rodrigue, K.M., Head, D., Kennedy, K.M. & Acker J.D. (2004). Differential aging of the medial temporal lobe: a study of a five-year change. *Neurology,* 10, 433–438.

Roche, R.A.P. & O'Mara, S.M. (2003). Behavioural and electrophysiological correlates of visuomotor learning in a visual search task. *Cognitive Brain Research*, 15, 127-136.

Rolls, E.T. & Treves, A. (1998). *Neural Networks and Brain Function*. Oxford: Oxford.

Rosenbaum, R.S., McKinnon, M.C., Levine, B. & Moscovitch, M. (2004). Visual imagery deficits, impaired strategic retrieval, or memory loss: disentangling the nature of an amnesic person's autobiographical memory deficit. *Neuropsychologia,* 42, 1619–1635.

Saykin, A.J., Janssen, R.S., Sprehn, G.C., Kaplan, J.E., Spira, T.J. & O'Connor, B. (1991). Longitudinal evaluation of neuropsychological function in homosexual men with HIV infection: 18-month follow-up. *Journal of Neuropsychiatry Clinical Neuroscience.* 3, 286–98.

Schacter, D. L. & Tulving, E. (1994). What are the memory systems of 1994? In: Schacter, D. L. & Tulving, E. (Eds). *Memory systems 1994*, MIT Press, Cambridge, pp. 1–38.

Scherg, M., Vajsar, J.& Picton, T.W. (1989)A source analysis of the late human auditory evoked potentials. *Journal of Cognitive Neuroscience*. 1, 336–355.

Schmolck, H., Kensinger, E.A., Corkin, S. & Squire, L. (2002). Semantic knowledge in Patient H.M. and other patients with bilateral medial and lateral temporal lobe lesions. *Hippocampus*, 12, 520–533.

Schulman, A.I. (1971) Recognition memory for targets from a scanned word list. *British Journal of Psychology*. 62, 335-346.

Schulman, A.I. (1974) Memory for words recently classified. *Memory & Cognition*. 2, 47-52.

Schwerdt, P.R. & Dopkins, S. (2001). Memory for content and source in temporal lobe patients. *Neuropsychology*. 15:1, 48-57.

Scoville, W.B. & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurological and Neurosurgical Psychiatry*, 20:11-21

Selfridge, O.G. & Neisser, U. (1960). Pattern recognition by machine. *Scientific American*, 203, 60-68.

Shimamura, A.P., Janowsky, J.S. & Squire, L.R. (1990).Memory for the temporal order of events in patients with frontal lobe lesions and amnesic patients. *Neuropsychologia*, 28, 803-813.

Siedlecki, K.L., Salthouse, T.A., Berish, D.E. (2005). Is there anything special about the aging of source memory? *Psychology of Aging*, 20:1,19-32.

Slotnick, S.D., Moo, L.R., Segal, J.B. & Hart J.Jr. (2003). Distinct prefrontal cortex activity associated with item memory and source memory for visual shapes. *Cognitive Brain Research*. 17, 75–82.

Small, S.A. Perera, G.M., De LA Paz, R., Mayeux, R. & Stern, Y. (1999). Differential regional dysfunction of the hippocampal formation among elderly with memory decline and Alzheimer’s Disease. *Annals of Neuroscience*. 45, 466-472.

Somberg, B.L. & Salthouse, T.A. (1982). Divided attention abilities in young and old adults. *Journal of Experimental Psychology of Human Perceptual Performance,* 651–663

Squire, L.R. (1989). On the Course of Forgetting in Very Long Term Memory. *Journal of Experimental Psychology of Learning, Memory and Cognition*, 15(2):241-5.

Squire, L.R. & Alvarez, P. (1995). Retrograde amnesia and memory consolidation: a neurobiological perspective. *Current Opinions in Neurobiology,* 5(2):169-77.

Squire, L.R., Knowlton, B. & Musen, G (1993). The Structure and Organisation of Memory. *Annual Review of Psychology*, 44, 453-495.

Stevens, W.D., Hasher, L., Chiew, K.S. & Grady, C.L. (2008). A neural mechanism underlying memory failure in older adults.*The Journal of neuroscience: the official journal of the Society for Neuroscience*. 28:48, 12820-4.

Stratta, P., Daneluzzo, E., Rinaldi, O., Gianfelice, D. & Rossi, A. (2003).Subjective cognitive evaluation in a university student population by cognitive failure questionnaire (CFQ). *Schizophrenia Research*. 60:1, 159-159

Stuart-Hamilton, I. (2006). *The Psychology of Ageing: An Introduction*, London.

Stuss, D.T., Eskes, G.A. & Foster, J.K. (1994). *Handbook of Neuropsychology*. Elsevier, Amsterdam, NL.

Swick, D., Senkfor, A.J. & Van Petten, C. (2006). Source Memory Retrieval is Affected by Ageing and Prefrontal Lesions: Behavioural and ERP Evidence. *Brain Research*, 1107, 161-176.

Taconnat, L., Clarys, D., Vanneste, S., Bouazzaoui, B. & Isingrini, M. (2007). Aging and strategic retrieval in a cued-recall test: the role of executive functions and fluid intelligence. *Brain and cognition*, 64:1, 1-6.

Talairach, J. & Tournoux, P. (1988). *Stereotaxic Atlas of the Human Brain*. Thieme, Stuttgart.

Thaiss, L. & Petrides, M. (2003). Source versus content memory in patients with a unilateral frontal cortex or a temporal lobe excision. *Brain: A Journal of Neurology*.126:5, 1112–1126.

Till, R.E. & Jenkins, J.J. (1973). The effects of cued orienting tasks on the free recall of words. *Journal of Verbal Learning and Verbal Behavior*. 12, 489-498.

Toga, A.W. & Thompson, P.M. (2001). The role of image registration in brain mapping. *Image and vision computing*. 19, 3–24.

Treisman, A. (1964). Selective attention in man. *British Medical Bulletin*. 20, 12-16.

Tulving, E., Kapur, S., Craik, F.I., Moscovitch, M. & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: positron emission tomography findings. *Proceedings of the National Academy of Science, U S A*, 91:6, 2016–2020.

Uncapher, M.R., Otten, L.J. &Rugg, M.D. (2006). Episodic encoding is more than the sum of its parts: an fMRI investigation of multifeatural encoding. *Neuron*. 52:3, 547-556.

Underwood, B.J. & Freund, J.S. (1970). Word Frequency and Short-Term Recognition Memory. *The American Journal of Psychology*, 83:3, 343-351.

Valenstein, E., Bowers, D., Verfaellie, M., Heilman, K.M.. Day, A. & Watson, R.T. (1987). Retrosplenial Amnesia. *Brain*, 110:6, 1631-1646.

Vandenbroucke, M.W.G., Goekoop, R., Duschek, E.J., Netelenbos, J.C., Kuijer, J.P., Barkhof, F., Scheltens, P. &, Rombouts, S.A. (2004). Interindividual differences of medial temporal lobe activation during encoding in an elderly population studied by fMRI. *Neuroimage*, 21:1, 173-180

Wallace, J.C., Kass, S.J., & Stanny, C. (2001). Predicting performance in ‘Go’ Situations: A new use for the Cognitive Failures Questionnaire? *North American Journal of Psychology*. 3, 481–490.

Walsh, V. & Pascual-Leone, A. (2003). *Transcranial Magnetic Stimulation: A Neurochronometrics of Mind (1st ed.)*. Boston, MA: MIT Press.

Wegesin D J; Jacobs D M; Zubin N R; Ventura P R; Stern Y, (2000). Source memory and encoding strategy in normal aging. *Journal of clinical and experimental Neuropsychology*. 22:4, 455-64.

Wells, G.L. (1993). What do we know about eyewitness identification? *American Psychologist*. 48, 553–571.

Wiese, H. & Daum, I. (2006). Frontal Positivity Discriminates True form False Recognition. *Brain Research,* 1075, 183-192.

Wilding, E.L. (2000). In what way does the parietal ERP old/new effect index recollection? *International Journal of Psychophysiology*. 35:1, 81-87.

Wilding, E.L., Doyle, M.C. & Rugg, M.D. (1995). Recognition Memory with and without Retrieval of Context: An Event-Related Potential Study. *Neuropsychologia,* 33:6, 743-767.

Wilding, E.L. & Rugg, M.D. (1996). An Event-Related Potential Study of Recognition Memory with and without Retrieval of Source. *Brain,* 119:3, 889-905.

Wilding, E.L. & Rugg, M.D. (1997). An Event-Related Potential Study of Memory for Words Spoken Aloud or Heard. *Neuropsychologia,* 35:9, 1185-1195.

Wilding, E.L. & Rugg, M.D. (1998). Electrophysiological evidence for dissociable processes contributing to recollection. *Acta Psychologica*, 98, 231-252.

Wolk, D.A., Sen, N.M., Chong, H., Riis, J.L., McGinnis, S.M., Holcomb, P.J., Daffner, K.R. (2008). ERP correlates of item recognition memory: effects of age and performance. *Brain Res*. 23;1250, 218-31.

Wolk, D.A., Schacter, D.L., Lygizos, M., Sen, N.M., Holcomb, P.J., Daffner, K.R., & Budson, A.E. (2006). ERP correlates of recognition memory: effects of retention interval and false alarms. *Brain Research*. 1096, 148-62.

Zanto, T., Toy, B. Gazzaley, A. (2009). Delays in neural processing during working memory encoding in normal aging. *Neuropsychologia,* In Press.

Zelinski, E. M. & Light, L. L. (1988). Context effects in spatial memory of young and older adults. *Psychology and Aging*, 3, 99-101

Appendices

Appendix I: Word lists use chosen from the Toronto Noun Pool

Appendix II: Informed Consent Form

Appendix III: The Cognitive Failures Questionnaire

Appendix 1: Word lists use chosen from the Toronto Noun Pool

Primacy and Recency Buffers

angle
baton
hornet
nursery
runner
buggy
maiden
oboe
thimble
whiskey

Study and Test Words

adult
advantage
album
baseball
boxer
chance
corpse
creek
decline
dogma
edition
fetish
figure
gate
hint
idiom
illusion
journey
mineral
mosaic
ocean
octopus
pickle
referee
seat
skirt
spice
statue
ticket
wrinkle
apron
audit
bar
buddy
butterfly
center
cloak
custard
deity
delight
envelope
fallacy
game
hedge
institute
irony
knife
medicine
mildew
opinion
optimist
pastry
rescuer
savage
shame
shyness
star
stress
traveler
windmill

Appendix 2: Informed Consent Form

Consent Form

In agreeing to participate in this research I understand the following:

This research is being conducted by Páraic Scanlon at the Department of Psychology, National University of Ireland Maynooth. It is the responsibility of Mr. Scanlon to adhere to ethical guidelines in his dealings with participants and the collection and handling of data. If I have any concerns about participation I understand that I may refuse to participate or withdraw at any stage. I have been informed as to the general nature of the study.

All data from the study will be treated confidentially. The data will be compiled, analysed and submitted in a report to the Department of Psychology, NUI Maynooth. My data will not be identified by name at any stage of analysis or in the final report. At the conclusion of my participation, any questions or concerns I have will be fully addressed. I may withdraw from this study at any time and may withdraw my data at the conclusion of my participation if I still have concerns.

If during your participation in this study you feel that the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the National University of Ireland Maynooth Ethics Committee at pgdean@nuim.ie or 01 7086018. Please be assured that your concerns will be dealt with in a sensitive manner.

Signed:

___________________________ Participant

___________________________ Researcher

___________________________ Date

Appendix III: Cognitive Failures Questionnaire

The Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald & Parkes, 1982)
The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to your in the past 6 months. Please circle the appropriate number.

		Very Often	Quite Often	Occasion-ally	Very Rarely	Never
1.	Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
2.	Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3.	Do you fail to notice signposts on the road?	4	3	2	1	0
4.	Do you find you confuse right and left when giving directions?	4	3	2	1	0
5.	Do you bump into people?	4	3	2	1	0
6.	Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7.	Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0
8.	Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9.	Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10.	Do you lose your temper and regret it?	4	3	2	1	0
11.	Do you leave important letters unanswered for days?	4	3	2	1	0
12.	Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
13.	Do you fail to see what you want in a supermarket (although it's there)?	4	3	2	1	0
14.	Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0

		Very Often	Quite Often	Occasion-ally	Very Rarely	Never
15.	Do you have trouble making up your mind?	4	3	2	1	0
16.	Do you find you forget appointments?	4	3	2	1	0
17.	Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18.	Do you find you accidentally throw away the thing you want and keep what you meant to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19.	Do you daydream when you ought to be listening to something?	4	3	2	1	0
20.	Do you find you forget people’s names?	4	3	2	1	0
21.	Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22.	Do you find you can’t quite remember something although it’s “on the tip of your tongue”?	4	3	2	1	0
23.	Do you find you forget what you came to the shops to buy?	4	3	2	1	0
24.	Do you drop things?	4	3	2	1	0
25.	Do you find you can’t think of anything to say?	4	3	2	1	0

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