THE ROLE OF WORKING MEMORY IN THE INHIBITION OF UNWANTED MEMORIES: AN ELECTROPHYSIOLOGICAL & BEHAVIOURAL EXPLORATION

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ABSTRACT

The experiments in this thesis were designed to contribute to an understanding of the links between working memory capacity (WMC) and cognitive control over retrieval from long-term memory. The specific focus was on control over recollection, as measured by event-related potentials (ERPs), and how this was moderated by individual differences in WMC. Two broad assumptions underlying the investigations were that: (i) cognitive control over recollection can be exerted only when there are sufficient cognitive resources to do so, and (ii) WMC indexes resource availability.

Evidence that could be interpreted in line with this account was accrued over the course of three experiments. Two consistent findings emerged. First, that there was no relationship between how well people completed the tasks and the extent to which control over recollection was exerted. Second, that there was a consistent positive correspondence between resource availability (as measured by WMC) and ERP evidence for the degree to which control over recollection occurred. This correspondence took two forms. First, a correlation between WMC and ERP evidence for the degree of control over recollection (Experiment 2). Second, the absence of evidence for control over recollection when WMC was temporarily reduced via the requirement to complete a demanding cognitive task prior to the memory retrieval task (Experiment 3).

In addition to these findings, the third experiment in this thesis permitted a direct investigation of whether control over recollection was accomplished via inhibition of task-irrelevant memory contents. The people for whom there was evidence of a high degree of control over what was recollected showed poorer memory subsequently for the memory contents that were subjected to control than did people who exerted less control. This finding is consistent with the view that cognitive control was exerted by inhibiting certain memory contents, thereby making them less accessible at a later point in time. Taken together, these data strongly suggest that inhibition of unwanted information occurs during memory retrieval when participants have the working memory resources available to support active inhibition processes.

DECLARATION

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

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Statement 1

This thesis is being submitted in partial fulfilment of the requirements for the degree of PhD

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This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references.

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CHAPTER 1: COGNITIVE CONTROL IN MEMORY RETRIEVAL

When bemoaning his lost love Rosaline, Romeo exclaimed "oh teach me how I should forget to think". Similarly, in the movie Eternal Sunshine of the Spotless Mind, the separated lovers seek a medical procedure to extinguish all memories of their time together. In life, it might sometimes be preferable to forget certain aspects of our earlier experiences and we may actively engage in processes to inhibit such experiences. That is, we may exert cognitive control over our memories. The question of how cognitive control operates during memory retrieval is central to the work in this thesis, with a key idea being that cognitive control strategies are not only employed when we are trying to suppress a painful memory, but also that control is used during everyday memory searches. For example, when presented with a retrieval cue, such as the word "school", any number of associated memories might be brought to mind. In order to search through memory effectively and select amongst competing representations, cognitive control operations may come into play to minimise the processing of inappropriate representations and/or direct resources towards the appropriate ones.

There is good evidence that participants can choose to actively suppress the recollection of items in long-term memory when they are explicitly instructed to do so (Anderson & Green, 2001; Anderson et al. 2004; Bergström, Velmans, de Fockert, &

Richardson-Klavehn, 2007; Bjork, LaBerge, & Legrand, 1968; Golding & MacLeod, 1998). Less is known, however, about the use of control when there is no conscious intent (or at least no explicit task requirement) to suppress or inhibit some memory contents. One reason for this is that it is difficult to demonstrate the control of memory in the absence of any explicit instruction to do so. Current neuroimaging techniques are useful in this regard, because they can provide indices of successful memory retrieval that are sufficiently sensitive to be used as tools to make inferences about whether or not retrieval has occurred, even in the absence of accompanying behavioural evidence. The experiments in this thesis utilise these neural correlates to infer the conditions under which one kind of memory retrieval - recollection - is subject to cognitive control operations.

1.1. The Constructive Nature of Recollection

The idea that memory is reconstructive is almost as old as the study of memory itself. The earliest memory scientists demonstrated that autobiographical memories are seldom verbatim replications of prior experience; they often contain inaccuracies and they tend to be inaccurate in predictable ways. In his 1932 book, Bartlett suggested that information is organised in memory into structures known as schema (Bartlett, 1932). These schema are derived from our daily interactions with the world and enable a wealth of information to be understood and stored efficiently. The trade-off of this efficiency, however, is that the subsequent recall of schematically organised information is biased in ways that match these schema. For example, Bartlett reports an experiment where participants were told a story from an unusual cultural context, a Native American folk story called The War of the Ghosts. Participants were subsequently asked to retell the story several times and Bartlett observed that participants tended to retell that story in a culturally familiar way. The retelling made more sense to the participant but was heavily distorted with respect to the original story. In this way Bartlett demonstrated that memory is not reproductive, but reconstructive. He wrote that *"Remembering is not a completely independent function, entirely distinct from perceiving, imagining, or even from constructive thinking, but it has intimate relations with them all" pp13.*

Although there have been no successful replications of Bartlett's repeated production experiment (and in fact the opposite pattern of data has been found, see Wheeler & Roediger, 1992), subsequent work has developed the idea that memory is constructive. Loftus and colleagues have demonstrated that eye-witness testimonies can be heavily distorted at the time of recall by leading questions (Loftus, 1975); for reviews see (Loftus, 1996, 2003). Other theorists consider that only part of a prior experience is ever remembered and a process of pattern completion and problem solving is necessary to generate a broadly accurate holistic representation of a prior experience. Failures in this pattern completion process are considered to lead to predictable memory errors (Burgess & Shallice, 1996; Schacter, Norman, & Koutstaal, 1998). The emphasis on problem solving in this framework reflects a general emphasis on cognitive control processes as an important part of memory reconstruction, and this problem-solving emphasis is also seen in accounts of confabulation.

1.1.1. Confabulation

Patients suffering with Korsakoff's amnesia, and on occasions those with lesions to the frontal lobes, can display confabulation (Berlyne, 1972; Burgess & Shallice, 1996). The term "confabulation" refers to a verbal statement of fabricated, distorted or misinterpreted memories about oneself or the world, without the conscious intention to deceive. Confabulation is thought to be caused by a frontal lobe dysfunction or a dysexecutive syndrome coupled with a memory deficit. Confabulators have been shown to perform poorly on some executive function tests (Burgess & Shallice, 1996).

To explain confabulation, Moscovitch (1989) distinguishes between two components of retrieval, the strategic/organisational component and the associative component. According to this account, in the process of retrieval, an individual must consider what information they need to recover in the context of the current demands and direct recovery of the appropriate associative information in a goal-orientated (strategic) way. In Moscovitch's account, it is the strategic component of retrieval that is disordered in confabulators. Search is not suitably targeted towards the relevant memory and inappropriate information is recovered. This information is then recombined in a disorganised fashion, and furthermore the patient accepts such recovered information as being veridical.

Burgess & Shallice (1996) reasoned that it is executive functions rather than long-term memory processes that are disordered in confabulators because confabulators often give similarly inappropriate responses on semantic problem solving tasks, such as the Cognitive Estimates Test (Shallice & Evans, 1978). In this task, participants are asked to estimate answers to questions, such as the average length of a man's spine, it is unlikely that participants would have the semantic knowledge to make all of these estimates precisely and that some problem solving may help them to deduce an appropriate response. One such confabulator reported that the average length of a man's spine was 5 feet 5 inches. This response could not logically be considered appropriate in the absence of any memory component, causing the authors to conclude that reasoning abilities are impaired. Importantly, the types of errors made by confabulators were also present, to a lesser degree, in non-confabulating controls, demonstrating that the same executive processes are present during normative memory retrieval. The account of confabulation provided by Burgess and Shallice incorporates the view that executive processes are necessary for successful recollection, in addition to the assumption that executive processes are required for the selection between, and the organisation of, competing representations in long-term memory.

1.2. Source Memory Deficits in Frontal Lobe Patients

Executive processes such as those described above are assumed to be supported by the prefrontal cortex and a number of studies have found that frontal lobe damage (caused by lesions or as part of normal aging) can affect the recollection process (Fletcher & Henson, 2001; Rugg, Fletcher, Chua, & Dolan, 1999; Spencer & Raz, 1994).

Although many memory processes have been shown to decline with advanced age, source memory (memory for the contextual details of an event) is disproportionately impaired. Spencer & Raz (1994) compared memory performance across three different estimate answers to questions, such as the average length of a man's spine, it is unlikely that participants would have the semantic knowledge to make all of these estimates precisely and that some problem solving may help them to deduce an appropriate response. One such confabulator reported that the average length of a man's spine was 5 feet 5 inches. This response could not logically be considered appropriate in the absence of any memory component, causing the authors to conclude that reasoning abilities are impaired. Importantly, the types of errors made by confabulators were also present, to a lesser degree, in non-confabulating controls, demonstrating that the same executive processes are present during normative memory retrieval. The account of confabulation provided by Burgess and Shallice incorporates the view that executive processes are necessary for successful recollection, in addition to the assumption that executive processes are required for the selection between, and the organisation of, competing representations in long-term memory.

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Although many memory processes have been shown to decline with advanced age, source memory (memory for the contextual details of an event) is disproportionately impaired. Spencer & Raz (1994) compared memory performance across three different types of memory test; facts, source and context in healthy young adults (ages 18-35) and older adults (65-80 years) using information about 110 famous personalities providing facts about these personalities (some of the 'famous' people were fictional and some of the facts were erroneous). Source memory was measured in a subsequent test phase by asking participants where they had originally acquired the information about each of the fictional personalities, and when participants responded that the information was acquired at the previous experimental session they were asked to indicate which of the two experimental testing labs was used for that training session and also whether the information was presented on pink or blue card. All participants were tested over a 2-min, 3-week and an 8-week delay. All memory processes declined with age to some extent, but this decline was more pronounced for source and context memory. Young adults retained source accuracy at ceiling over the 8 week period (0.98), whereas older adults' memory for source dropped to 0.7. Young adults' memory for context dropped to 0.55 whereas older adults dropped to 0.35. Performance on several prefrontal cortical function tests were also measured (the Wisconsin Card Sorting test, a Stroop Task, and an Activity Recognition Questionnaire) and although there was no clear relationship between these measures and memory decline the authors concluded that the neuropsychological assessments they used may not be optimal for assessment of healthy adults and concluded that prefrontal cortical atrophy is the factor most likely to have negatively influenced the memory performance of older adults.

Janowsky, Shimamura, & Squire (1986) investigated memory for facts and memory for when and where those facts were learned in patients with focal lesions to prefrontal cortex, age-matched elderly controls and young adults. All participants were taught general knowledge facts that they did not know before testing, and the learning phase continued until participants could correctly recall all 20 facts. After a 6-8 day retention period, participants were asked these general knowledge questions again along with 20 other questions that they had not been asked before. When a participant answered correctly they were asked where they had most recently heard that information. When participants incorrectly reported that they had heard the taught facts before the first testing session, this was considered a source error. Patients with frontal lobe lesions recalled as many facts as their age-matched controls but were more likely to misattribute these facts to incorrect sources and both of these groups were more likely to make source errors than younger adults. This implies that damage to the frontal lobes is sufficient to cause source memory deficits, however, patients had not 'forgotten' any more facts than controls, but misattributed these facts to incorrect episodes. This is consistent with the notion that the prefrontal cortex is necessary for selecting between competing representations in memory.

1.3. The Voluntary Suppression of Recollection

The literature described above concerns failures of memory and memory deficits that occur following brain damage or during ageing. The literature also, however, provides important clues about the executive processes that may assist successful retrieval in healthy participants. There are two principal ways that cognitive control operations may be recruited to help to select between competing representations and facilitate long-term memory retrieval. It is possible that cognitive resources may be efficiently targeted towards a certain class of items, making these items more readily accessible than unwanted alternatives. Alternatively, cognitive control operations may be recruited to suppress or inhibit unwanted items. The research literature has largely focussed on the latter possibility (Anderson & Green, 2001; Anderson et al. 2004; Bjork & Bjork, 2003; Bjork et al. 1968; Golding & MacLeod, 1998). Cognitive inhibition is analogous to the voluntary suppression of unpleasant memories proposed by Freud (Anderson et al. 2004; Freud, 1940/2005) and as a result the terms suppression and inhibition are used interchangeably here.

According to this framework, competing memory traces may be more strongly associated with a retrieval cue than the appropriate trace and response override operations come into play to select the appropriate one (see Figure 1). If overriding these pre-potent potential memory responses engages inhibition, then inhibition may also be used to prevent unwanted memories being reactivated, in a way analogous to the way in which inhibition is assumed to operate in other domains, including attention and studies of motor control (Aron, 2007; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Inhibitory processing of this kind may be involved in the completion of tasks where participants are asked to intentionally forget or refrain from remembering items (Anderson, 1983; Anderson, Bjork, & Bjork, 2000; Anderson, Bjork, & Bjork, 1994; Anderson & Green, 2001; Anderson et al. 2004; Anderson & Spellman, 1995; Bergström, de Fockert, & Richardson-Klavehn, 2009; Bergström et al. 2007; Bjork & Bjork, 2003; Bjork, 1972; Bjork et al. 1968). The directed forgetting paradigm and the Think/No-Think paradigm are two examples of this type, and key findings using these tasks are described below.

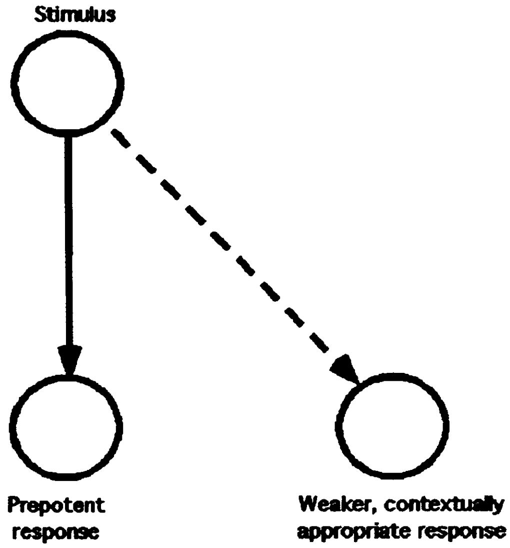


Figure 1: Schematic of a response override situation taken from Levy & Anderson (2002).

When presented with a retrieval cue many associated memories may be brought to mind and in some cases the contextually appropriate response is not the pre-potent one. In such circumstances inhibition mechanisms may be utilised to inhibit the pre-potent response and permit access to the weaker but appropriate memory.

1.3.1. The Directed Forgetting Paradigm

The directed forgetting paradigm was developed to investigate the avoidance of inappropriate or out of date memories in a laboratory setting (Brown, 1954; Golding & MacLeod, 1998; Johnson, 1994). Brown (1945) demonstrated that it was possible to direct participants to forget about one class of items over the short term. Participants were presented with four rapidly presented arrow-number pairs on each trial. Immediately before or immediately after the stimuli were presented, an instruction was displayed that prompted participants to recall the arrows only, the numbers only or both stimuli. Accuracy for the arrows was not affected by this manipulation; however, Brown observed that the instruction to recall only the numbers markedly improved recall for these items.

Brown reasoned that this may be due to selective rehearsal of the numbers but, given the rapid presentation, this account seemed unlikely. He called this manipulation directed forgetting.

Bjork and colleagues reasoned that for any memory system to be effective, it must be possible to overwrite memories that are out-of-date and require replacing with new information. For example, someone who has spent ten years at a particular office building would be very used to travelling to this location each day (Bjork et al. 1968). If his job was relocated to another building he would need to update this well-established information with the currently relevant details. Travelling to the old office building might be considered as the pre-potent response (it has been practiced and rehearsed many times), and in order to travel to the new work destination a process may be initiated that inhibits the retrieval of old information to reduce the likelihood of making an erroneous journey.

The typical directed forgetting paradigm is a variant of Brown's task, and involves presenting participants with some items that they must forget (to-be-forgotten (TBF) items), and some they must remember (to-be-remembered (TBR) items). On a subsequent recall test, participants are asked to recall both and people typically show poorer retention of the TBF than the TBR items (Bjork et al. 1968; Brown, 1954; Golding & MacLeod, 1998).

This outcome is consistent with the view that control can be exerted over what can be forgotten relative to what is remembered, but a fundamental interpretive problem concerns whether differences in rehearsal of TBF and TBR items are responsible for some or all of the subsequent accuracy differences (Bjork, 1972; Golding & MacLeod, 1998; Johnson, 1994; Rakover, 1976). Bjork (1972) and Johnson (1994) have argued that TBF words are simply more poorly encoded as a result of the TBF condition. MacLeod (1999) suggests that in the item method of the directed forgetting paradigm, where items are cued TBR or TBF on a trial by trial basis, online processing (such as elaborative rehearsal) is suspended until the TBR cue is presented, and if a TBF cue is presented then voluntary online processing is abandoned. The elaborative encoding account is less likely to be an issue in the list based method of the directed forgetting task, where a series of words are presented before the TBR/TBF cue because much online processing has already occurred. In this case, retrieval inhibition is a better account of the directed forgetting effect.

Geiselman, Bjork, & Fishman (1983) presented participants with an intentional learning task and an incidental learning task alternately. Some words were cued as to be learned (e.g. "learn hand") and others were to be judged ("e.g. judge boat"). For the later category of items participants made a judgement of how pleasant the item was on a 7 point scale. Participants were explicitly informed that the judged items were not to be learned. Half way through the study list, one group of participants were informed that what they had done thus far had been practice; therefore, they should forget the to-be-learned material. The second group of participants were simply presented with a message instructing them to continue trying to remember the to-be-learned words. After the study phase, participants were asked to recall or to recognise the to-be-learned words from a sheet of paper that contained all the items they had been presented with at study. The mid-list instruction to forget the items reduced later recall and recognition of items that were learned incidentally (the to-be-judged words) and intentionally (the to-be-learned words). This has two important implications for the directed forgetting paradigm. First, that selective rehearsal cannot offer a complete account for the effects of directed forgetting as the incidentally learned words should not have undergone elaborative encoding in either case. Second, these data call into question the voluntary nature of the suppression effect observed in the directed forgetting paradigm, given that participants were not voluntarily learning the to-be-judged items in the first place. This finding has been replicated several times (Bjork, 1972; Golding & MacLeod, 1998; however, see also Bjork & Bjork, 2003; and Paller, 1990).

There is also some concern about demand characteristics in a test where participants are explicitly instructed to forget a class of items (Orne, 1962). Macleod (1999) points out that participants may not be motivated to try as hard, or search as long to recover TBF words as they do TBR words. Additionally, they may recover F words, but not report having done so. To address this issue, Macleod (1999) presented participants with a typical directed forgetting paradigm and after the initial recall test participants were offered 50 cents for every additional TBF word they could recover. This was intended to increase motivation to recover TBF words and also encourage participants to report any recovered items that were being withheld. There was very little additional recall of TBF words with the added incentive of 50 cents, thereby providing no evidence for the operation of demand characteristics of this kind.

1.3.2. The Think/No Think Paradigm

Anderson & Green (2001) developed the Think/No Think (TNT) paradigm as a laboratory analogue of suppression that might overcome some of the problems of interpretation associated with the directed forgetting paradigm. The paradigm is based on the Go/No-Go paradigm for measuring response inhibition (Anderson & Green, 2001). The authors reasoned that just as response override mechanisms are brought into play to inhibit behavioural urges, perhaps the same processes are invoked to avoid thinking about difficult or painful episodic memories (see Figure 2). Participants are required to learn a series of unrelated word pairs. The first word in the pair is referred to as the "hint" and the second word is referred to as the "response". The learning procedure is repeated until at least 50% of the pairs are learned. In this way, all of the items should be learned equivalently. In a second phase of the experiment participants are re-presented with a proportion of the hint words and are cued to either 'THINK' of the response word or to not think of it with a 'NO THINK' cue; these are referred to as respond and suppress trials respectively, each suppress and respond trial is commonly repeated several times. The remaining hint words that are not represented at this time are baseline items. Finally, there are two types of post-test. On the same-probe test all of the original hint words are represented and participants are asked to respond with the appropriately paired respond word, regardless of whether it was previously encountered in a suppress or a respond trial in the previous phase. On the independent-probe test different cues are used to prompt recovery of the respond words.

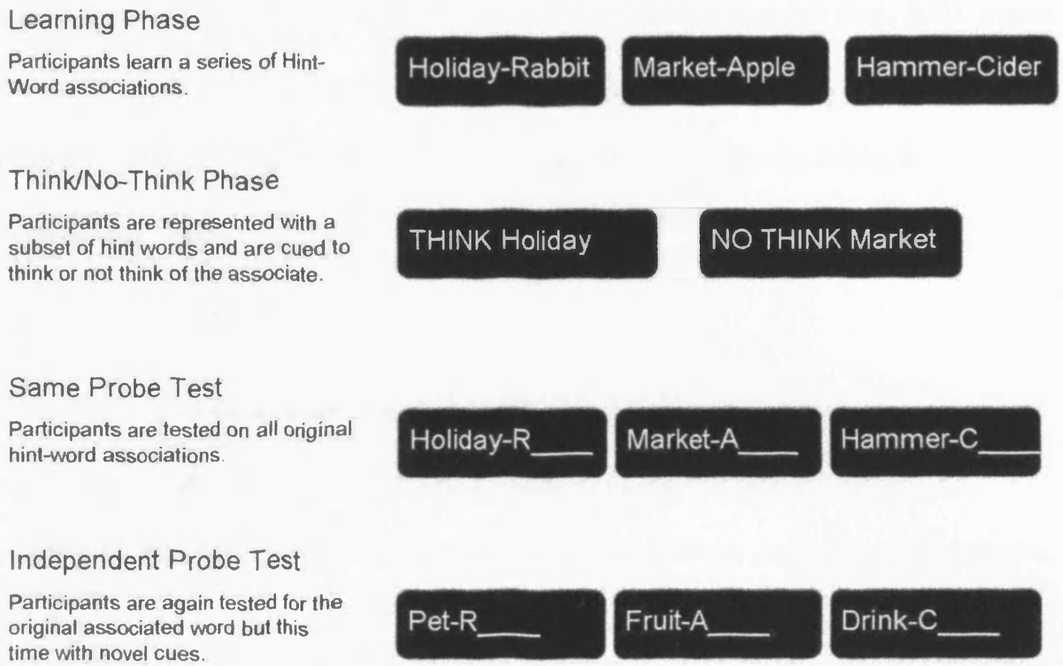


Figure 2: Schematic of the Think/No Think Paradigm

This is divided into three phases, an initial learning phase, the Think/No-Think phase and the test phase. Items that are not represented in the Think/No-Think phase of the experiment are considered to be baseline items. In the subsequent post-tests, suppression is inferred when the recovery of the baseline items is greater than those in the No Think condition, particularly in the independent-probe test.

There is typically superior response recall on final test performance for items in the THINK (respond) than in the NO-THINK (suppress) condition but this could occur for two reasons. The extended practice rehearsal for the THINK trials is likely to facilitate subsequent recovery of these items, and in addition, the active suppression thought to be initiated by the NO THINK cue may have degenerated the memory trace of the NO THINK items. This is why the baseline items are important. Where post-test recovery of the response items (Holiday-R____) is markedly larger than for the baseline items (Hammer-C_____), this is evidence of facilitation of these items, but more importantly, when recovery of the suppress items (Market-A____) is significantly lower than for the baseline items this is evidence of inhibition of the memory trace. This effect has been replicated several times (Anderson et al. 2004; Bergström et al. 2009; Bergström et al. 2007; Depue, Banich, & Curran, 2006; Depue, Curran, & Banich, 2007; Hertel & Calcaterra, 2005; Hertel & Gerstle, 2003; Joormann, Hertel, & Gotlib, 2005; Wessel, Wetzels, Jelicic, & Merckelbach, 2005).

When participants are presented with a No-Think cue, however, we do not have access to what strategy they use to avoid thoughts of the relevant associate. One possibility is that they directly inhibit the representation of the associate, but another is that they simply divert their thoughts to think about something else in response to the particular associate. For example, when presented with the stimulus "NO THINK- Market" participants may avoid thinking of the associate by intentionally conjuring alternative distracting thoughts, perhaps about when they went to a market, and come to associate this memory with the cue instead of the associate that they learned originally. If this latter explanation is true, then at the time of the post-test when the participant is presented with the cue "Market" on the post-test and asked to respond with the relevant associate, there are two competing representations that may be brought to mind; the one they acquired in the experiment ("Apple"), and their internally generated distracting thoughts. This would generate retrieval competition for the relevant associate in the post-test and may lower the accessibility of the associated relevant memory. There is evidence that such substitution strategies influence post-test responding in the Think/No-Think Paradigm (Bergström et al. 2009; Hertel & Calcaterra, 2005).

It is for this reason that the independent-probe test was introduced; if the memory of the learned associate is inhibited relative to baseline then this should be true even if that trace is accessed by alternative routes. The independent-probe method has a novel cue which is not associated with any words in the experiment, so there should be little or no retrieval competition for items associated with this cue. If suppressed items are less readily recovered than baseline items in the independent post-test this is taken as convincing evidence that the voluntary inhibition of the suppressed items has occurred. Anderson and Green (2001) found that recall for suppress items in the independent-probe test was significantly lower than recall of baseline items (81% vs. 88%) and concluded that the act of suppression had rendered the relevant associate relatively inaccessible for subsequent recall.

Evidence of inhibition on the independent-probe test has been demonstrated on some occasions (Anderson & Green, 2001; Anderson et al. 2004) but has been relatively difficult to obtain (Bulevich, Roediger, Balota, & Butler, 2006). Bulevich et al. (2006) set out to replicate Anderson and Green's (2001) finding that suppress items are less available for recall on subsequent independent-probe post-test but over three experiments were unable to do so. As a result of personal communication with Anderson (2010), the procedure was adjusted slightly to increase the likelihood of obtaining the post-suppression effect but using this method (Experiments 1 & 2) or using the original method (Experiment 3), Bulevich and colleagues failed to replicate the inhibition effect in the independent-probe test. Even when the data was collapsed across all three experiments there was no trend towards a suppression effect ($t(95) = 0.79$). Bulevich et al. concluded that this effect is not a robust experimental phenomenon in the Think/No Think paradigm. This paradigm is popularly used to investigate inhibition in long-term memory (Anderson et al. 2004; Bergström et al. 2009; Bergström et al. 2007; Depue et al. 2006; Depue et al. 2007; Hertel & Calcaterra, 2005; Hertel & Gerstle, 2003; Joormann et al. 2005; Wessel et al. 2005), but Bulevich et al. have suggested that the paradigms that have been developed so far to investigate suppression in long-term memory do not provide conclusive reliable behavioural evidence that inhibition has occurred.

1.4. Automatic Suppression of Memories

In the paradigms described above, forgetting was assumed to occur as a result of explicit instructions to forget or avoid thinking about target items. As part of our daily lives, however, we are not given *instructions* to forget and do not often consciously attempt to inhibit or suppress old information. Instead, it may be the case that inhibition occurs to overcome pre-potent memories quite spontaneously and indeed there is evidence that such suppression occurs automatically during the course of retrieval (Anderson et al. 2000; Anderson et al. 1994; Anderson & Spellman, 1995; Roediger, 1974).

1.4.1. Retrieval Induced Forgetting

Evidence from the Retrieval Practice Paradigm suggests that when presented with a retrieval cue there may be several competing representations that compete for access to conscious awareness and suppression is naturally used to reduce the competition of the unwanted items, facilitating recovery of the appropriate memory. This suppression effect is known as retrieval-induced forgetting (Anderson et al. 2000; Anderson et al. 1994; Roediger, 1974).

Anderson et al. (1994) set out to investigate whether, after a retrieval event, retrieval-induced suppression effects are responsible for the subsequent forgetting of content related to what was in fact retrieved. The paradigm they used comprised three phases. In the study phase, participants learned a series of category exemplar associations such as "Pet-Dog" (see Figure 3). There were eight different categories, each containing six exemplars. In the second learning phase, participants practiced retrieval of a subset of these items from only some categories. The practice stage involved presenting participants with the category cue and the word stem of a specific exemplar (such as "Pet-D__"). The purpose of the practice phase was to investigate whether retrieval practice of some exemplars would strengthen the association of those exemplar items to the category cue and whether this would also facilitate forgetting of unpractised exemplars from the same category. After a retention interval, there was a surprise category-cued recall test, in which participants were supplied with each category name and asked to recall any associated exemplars. The likelihood of recovery of unpractised exemplars from practised categories was substantially lower than that for exemplars from non-practiced categories and well as of practiced exemplars from practiced categories.

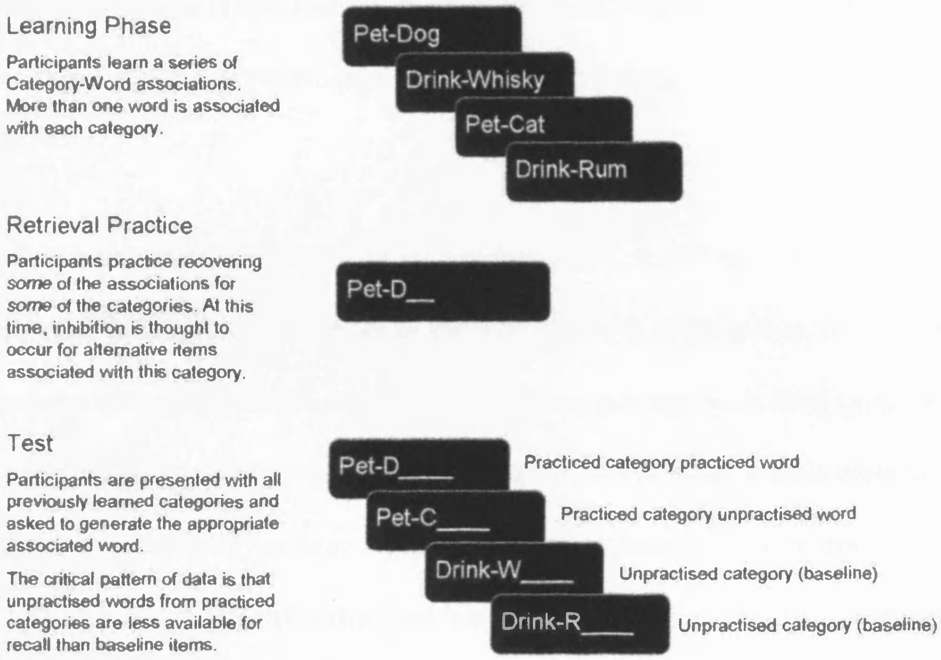


Figure 3: Schematic of the standard retrieval induced forgetting paradigm.

Items from two categories have been learned. After the initial learning, association "Pet-Dog" is practiced; the other items have not been practiced. In a subsequent recall test, practice is shown to facilitate recall of the practiced item at the expense of recall of the unpractised item in that category (Pet-Cat). The latter is also less available for recall than unpractised items from categories where no associations were practised.

These findings have been interpreted as providing strong evidence for the role of inhibition during typical memory retrieval, the argument being that the subsequent recall deficit for unpractised exemplars from practiced lists is a consequence of inhibition that operates at the time of the retrieval practice session, thereby making competing but unwanted completions during the practice session less accessible when recall is required at a later time point. This account rests on three assumptions (Anderson et al. 1994): First, memories that are associated with a cue compete for access to conscious recollection when the cue is presented; Second, that when the associative strength between one such memory and the retrieval cue is increased, the associative strength of competing memories is decreased proportionally; Third, that the act of cue based retrieval increases the associative strength of that memory and the associated cue.

One explanation for these findings which does not appeal to inhibition, however, is that the recall deficit is a consequence of the strengthening of the category-exemplar pairings for practiced exemplars, thereby making these pairings more likely to come to mind at the time of recall than unpractised exemplars. An attempt to adjudicate between these competing accounts has been made using a manipulation similar to the independent-probe condition for the think/no-think paradigm. Anderson & Spellman (1995) argued that if retrieval practice suppresses competing representations then those suppressed items should be less available for recall from *any* retrieval cue in a subsequent post-test. They presented participants with an adapted version of the retrieval practice paradigm where participants are required to learn categories such as "Red-Blood", "Red-Tomato" and "Food-Strawberry", "Food-Crackers". In the second phase, retrieval of some of these items is practiced, strengthening the association between these items (Red-Blood) and making subsequent recall of alternatives less likely (Red-Tomato). The principal difference between this experiment and the retrieval practice paradigm described earlier is that exemplars paired with one category could just as easily apply to another category (e.g. Strawberry is both Red and a Food) and as such, practice of the pair Red-Blood should also suppress recovery of the association Red-Strawberry, even though this is not learned during the experiment. Furthermore, if the memory of the item Strawberry itself has become compromised by the practice of the association Red-Tomato then the association Food-Strawberry should also be less available for recall, even though the food category was not practiced. The crucial comparison in this experiment is between the post-test recovery of unpractised items from unpractised categories that are similar to practiced categories (e.g. Food-Strawberry) and the post-test recovery of unpracticed items from unpractised categories that are unrelated to a practiced category (e.g. Tool-Drill, see Figure 4). In accordance with an inhibition account of the retrieval induced forgetting phenomenon, Anderson & Spellman (1995) showed that the recovery of similar unpracticed items was lower than that for dissimilar unpracticed items. This was taken as evidence that the increased strength of a competing association cannot fully account for the data in the retrieval practice paradigm, and that inhibition of competing representations has taken place, making such competing items less available for subsequent recall.

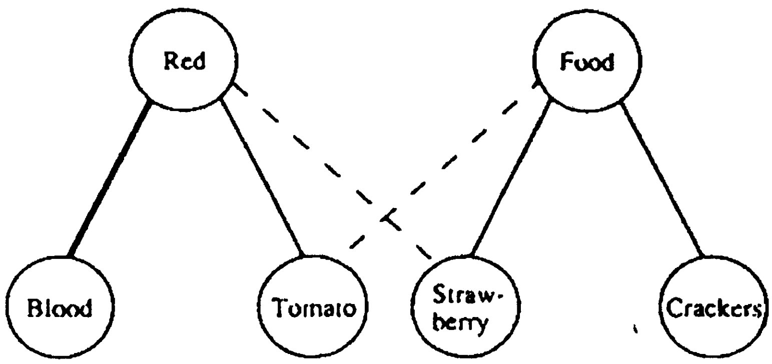


Figure 4: Predictions of the RIF paradigm taken from Anderson & Spellman (1995).

Practice of the category-exemplar pair Red-Blood should make recall of the word Tomato to the cue “Red-T___” less likely. However, this may be due to the strengthening of the association Red-Blood blocking the association of the category Red with competing exemplars. In this example, the dashed lines indicate associations that were not learned in the experiment.

1.5. Inferring the Suppression of Recovered Information from Event-Related Potentials (ERPS)

Researchers using the paradigms described above have primarily relied on post-test performance to make inferences about the occurrence of retrieval control processes that occurred at earlier stages in the experiments. In some cases however, it is also possible to measure neural correlates of recollection to make inferences about the inhibition. If recollection is indeed being controlled this should be revealed by changes in the magnitudes of neural indices of recollection.

This approach has been adopted in the Think/No-Think paradigm, using the relative magnitude of the left-parietal ERP old/new effect as an index of the extent to which recollection has occurred across respond and suppress trials (Bergström et al. 2009; Bergström et al. 2007; Mecklinger, Parra, & Waldhauser, 2009) The detailed evidence supporting the link between this effect and recollection is reviewed later (see pages 65-68). Briefly, across a number of paradigms (including source memory, the remember/know paradigm, false memory tasks, tasks requiring context judgements and tasks requiring memory confidence judgments), it has been consistently demonstrated that this effect correlates with the process of recollection (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Rugg, Schloerscheidt, & Mark, 1998; Senkfor & Van Pettern, 1998; Vilberg, Moosavi, & Rugg, 2006; Vilberg & Rugg, 2009a, 2009b; Wilding, 1999, 2000; Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996, 1997). Furthermore, the magnitude of the left-parietal old/new effect is greater when more contextual information is recollected, which is consistent with the notion that the effect indexes the quantity of information that is recovered (Vilberg et al. 2006; Vilberg & Rugg, 2009a, 2009b; Wilding, 2000; Wilding et al. 1995). Because of these characteristics, it is possible to use changes in the magnitude of this effect to infer the extent of recollection associated with test stimuli. Hence, when previously presented information is associated with a robust left-parietal effect in some circumstances, but not in other circumstances, it may be possible to infer that recollection has been strategically avoided in the latter case.

Bergstrom and colleagues used the Think/No-Think paradigm and acquired ERPs during the Think/No-Think phase (Bergström et al. 2009; Bergström et al. 2007). Bergstom et al. (2007) demonstrated that learned words that were subsequently paired with a THINK cue in the Think/No-Think phase, elicited a larger left-parietal old/new effect than learned items subsequently paired with the NO THINK cue. Furthermore, the left-parietal old/new effect for the NO THINK items was not greater than for items that were not learned. In combination, these findings imply that recollection was successfully avoided for these items. Bergstrom et al. (2007) did not, however, find any evidence for inhibition of items that were previously presented in the NO THINK phase behaviourally in the same-probe or independent-probe post-test.

In a subsequent study, Bergstom, de Fockert, Richardson-Klavehn (2009) also compared two strategies for completion of the Think/No-Think paradigm. During NO THINK trials participants were instructed to either suppress the memory actively or to distract themselves by thinking of something else. These were referred to as the 'active suppression' and 'thought distraction' conditions, respectively. Only the active suppression strategy was associated with attenuation of the left-parietal old/new effect across conditions as described above. Evidence for suppression of items associated with the NO THINK cue in a subsequent independent-probe test, however, was found only for the thought substitution condition. In summary, the use of ERPs in Think/No-Think tasks has provided evidence that people are able to suppress recollection at the time of the THINK and NO THINK instructions, and the findings of Bergstrom et al. (2009) suggest that successful suppression of recollection, at least when not accompanied by thought substitution, is not sufficient to lead to subsequent memory costs.

One additional potential use of the ERPs in a way similar to that employed by Bergstrom and colleagues is where changes in the size of the left-parietal old/new effect are used to investigate when recollection is controlled as a part of normative memory search. That is, when participants have not been explicitly instructed to avoid recollection, but control over recollection may nonetheless be exerted. Evidence that this kind of control is exerted has been inferred from findings in studies where people have completed exclusion tasks and while ERPs have been acquired.

1.5.1. Strategic Recollection in the Exclusion Task

Exclusion tasks were first introduced as part of the process dissociation procedure which was developed to provide estimates of the contributions of recollection and familiarity to recognition memory (see Dual Process Models of Memory in Chapter 2; and also Curran & Hintzman, 1995, 1997; Jacoby, 1991, 1998; Jacoby, Begg, & Toth, 1999; Jacoby & Shrout, 1997; Jacoby, Yonelinas, & Jennings, 1997; Yonelinas & Levy, 2002). Participants are presented with a series of to-be remembered items in two study contexts (such as words presented in 2 different font colours or 2 different encoding tasks). At test, items from one study context are designated "targets" and participants are asked to respond on one key to items that were previously presented in this context. Items from the other study context are designated "non-targets" and these are to be rejected on the same key as new items (see Figure 5).

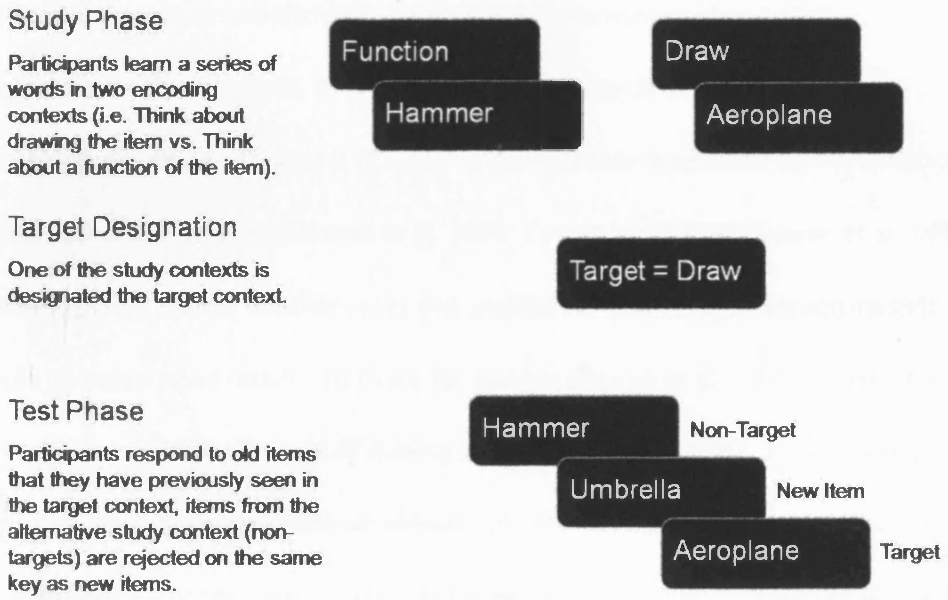


Figure 5: Schematic of the exclusion task (Context design)

In order to respond accurately in the exclusion task, it is not sufficient to simply identify that an item has been presented previously; participants also need to recover the associated context under which an item was initially presented and this discrimination necessitates the process of recollection. In line with this assumption, a consistent robust left-parietal old/new effect is commonly associated with the successful identification of targets (Bridson, Fraser, Herron, & Wilding, 2006; Dywan, Segalowitz, & Arsenault, 2002; Dywan, Segalowitz, & Webster, 1998; Dzulkifli, Herron, & Wilding, 2006; Fraser, Bridson, & Wilding, 2007; Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding, Fraser, & Herron, 2005).

The presence of reliable left-parietal old/new effects for non-targets, however, is mixed, which might be regarded as surprising if it is assumed that target/non-target discrimination is accomplished by recollecting information about non-targets as well as information about targets. In some cases the amplitude of the left-parietal old/new effect associated with non-targets is of equal or comparable magnitude to the amplitude associated with targets (Bridson et al. 2006; Dywan et al. 2002; Dywan et al. 1998; Herron & Rugg, 2003), while in other cases the amplitudes associated with non-targets are reliably attenuated relative to those for targets (Dywan et al. 2002; Dywan et al. 1998; Dzulkifli et al. 2006; Dzulkifli & Wilding, 2005; Fraser et al. 2007; Herron & Rugg, 2003). Moreover, in some cases the amplitudes to non-targets are statistically indistinguishable from those associated with correct judgements to new items (Dywan et al. 2002; Dywan et al. 1998; Dzulkifli et al. 2006; Dzulkifli & Wilding, 2005; Fraser et al. 2007; Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding et al. 2005). As the magnitude of the left-parietal old/new effect is considered to reflect recollection in a graded fashion, in circumstances where the left-parietal old/new effect is reliably smaller for non-targets than for targets it is possible that the recollection of non-targets has been controlled strategically (See Table 1).

Herron & Rugg (2003) were the first to comment on the marked differences between the amplitudes of left-parietal old/new effects for targets and non-targets that they observed across two experiments and were the first to propose that differences between the magnitudes of the left-parietal effects for targets and for non-targets may be used to make inferences about strategic recollection. Herron & Rugg presented data from two experiments in which the encoding task for the non-targets was identical but the encoding task for targets was different across the experiments. As a result, target accuracy differed significantly across the experiments. The encoding task for non-targets in both experiments was to incorporate the study word into a sentence and say that sentence aloud. In Experiment 1, the encoding task for targets was to verbally rate the study item on a five-point pleasantness scale. In Experiment 2 the task was to read each study word aloud. Response accuracy for targets was superior in Experiment 1 than Experiment 2 while accuracy for non-targets was equivalent in the two experiments.

The ERP old/new effects associated with non-targets were, however, no equivalent across the experiments. In Experiment 1 there were robust left-parietal effects for targets only, the amplitudes associated with non-targets were not reliably greater than those associated with new items. In Experiment 2, there were reliable old/new effects for targets and non-targets, and the non-target old/new effect was equivalent to that for targets. These data imply that the recollection of the non-target information occurred in these (more difficult) circumstances suggesting that such information was also *available* for recollection in Experiment 1, although it did not occur. Herron and Rugg (2003) concluded that under some circumstances (when target information is readily available for recollection) participants can neglect the recollection of non-targets and complete the task successfully by using the presence or absence of recollection of the appropriate target context to make the binary test judgement. When the task demands are higher (that is, when target information is not so readily available), they proposed that the recollection of non-targets is attempted to increase the probability of accurate responding.

The same pattern of data has been demonstrated when the encoding task for both targets and non-targets was held constant across experiments and accuracy was manipulated by adjusting the length of the study lists. Wilding, Fraser & Herron (2005) presented one group with long word lists (6 x 20 study words) and the other group with short word lists (12 x 10 study words). Half of the study words in each block were presented in red and the other half were presented in green. After each study phase, participants were informed of the target colour and asked to respond on one key to items that had previously been presented in that colour, and on a second key to items that were shown in the non-target colour, as well as to new items. Target accuracy was reduced and reaction times were increased when word lists were longer. There was marked attenuation of the left-parietal old/new effect elicited by non-target items relative to targets in the short list condition, and when the task was more difficult (longer lists), there were no reliable old/new effects associated with non-targets, implying that, when recollection of the target items was likely, participants prioritised the recollection of target information over non-target information, but when recollection of target information was less likely, participants attempted recall of information about both targets and non-targets. The data are consistent with Herron & Rugg's (2003) original conclusion that the relationship between task difficulty and non-target attenuation is crucial, and participants only exert control over recollection of non-targets when the likelihood of successfully recovering the appropriate information is high (for other finding consistent with this conclusion see Dzulkifli et al. 2006; Dzulkifli & Wilding, 2005; Evans, Wilding, Hibbs, & Herron, 2010).

The pattern of data described above has also been reported, for the most part, when a modified version of the exclusion task was used (Jacoby & Jennings, 1997, see Figure 6). In this modified exclusion task there is only one class of items at study. At test, a proportion of the new items are repeated, and participants are instructed to reject repeated test items on the same key as new items and only respond positively to items that were encountered in the study phase: studied words are targets, repeated test words are non-targets. This task was developed for use with populations who may find the instructions in the standard exclusion task complicated (Jennings & Jacoby, 1994). It has been argued that this paradigm is useful because the design is such that it can include a check on whether participants are adhering to the task instructions, something which is important when comparing performance across groups, particularly if there is a concern that one group is less likely to understand or adhere to the task instructions than the other. This can be achieved in the modified exclusion task by repeating some test items with few or no intervening items. If people respond correctly to the immediate repeats (on the same key as new items) then it can be assumed they can follow these task demands.

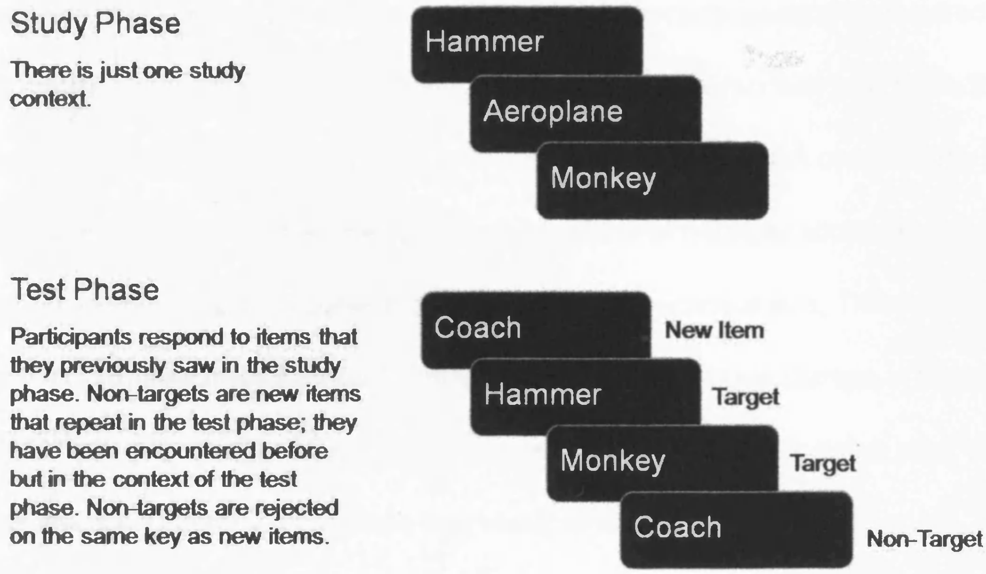


Figure 6: Schematic of an alternative exclusion paradigm referred to in this thesis as the 'lag' design.

In this case, all target items are presented in a single study phase. At test new items repeat, on the second presentation the repeated items are considered non-targets and have to be rejected on the same key as new items.

Dywan et al. (2002; Dywan et al. 1998) acquired ERPs during a modified exclusion task from young and older adults. At left-parietal scalp sites, older adults showed a greater relative positivity for repeated test items than for study words or new test items, while younger adults produced the greatest positivity to study words relative to repeated test words. These data imply that older adults are less likely to engage in a selective retrieval strategy than young adults. Importantly, however, there were behavioural differences between the young and older groups which challenge this interpretation. Older adults had poorer target/non-target discrimination, so the lack of evidence for controlled recollection might in fact reflect the fact that to prioritise recollection of target content was not an effective strategy for the older adults. In an additional condition, Dywan et al. attempted to lower the behavioural performance of young adults with the addition of a dual-task condition. In this group, younger participants were required to complete a concurrent auditory attention task alongside the retrieval task. While the behavioural advantage for younger adults persisted, in the dual task condition the ERP effects for young adults became more similar to those of the older adults: the sizes of the target and non-target left-parietal old/new effects were comparable. There are problems with interpreting these data confidently, because of the fact that changes in the pattern of ERP effects accompanied changes in accuracy, but one possibility is that older adults are less able to control recollection than young adults.

Bridson et al. (2006) and Fraser et al. (2007) both report data from experiments with a similar lag design to that employed by Dywan et al. (1998, 2002). All participants were young adults. Across two exclusion task experiments with slightly different encoding demands, Bridson et al. (2006) demonstrated that young adults showed no attenuation of the non-target ERP effect; the left-partial effect for targets was equal to non-targets in both experiments. This is somewhat at odds with the finding of Dywan et al. (1998, 2002) as target accuracy in both the Bridson et al. experiments was reasonably high (0.67 & 0.69) compared to the Dywan experiments with young adults (2002, Target accuracy = 0.60; 2005, Experiment 1: Target accuracy = 0.59; Experiment 2: Target accuracy = 0.56). This discrepancy across studies is inconsistent with the idea that when target accuracy is high, healthy young adults engage control processes that reduce the likelihood of non-target recollection. However, the methodological differences between the experiments make comparisons difficult (see Table 1 for a summary of exclusion task data across experiments).

Fraser, Bridson & Wilding (2007), however, compared data across two experiments from the same sample population using the same experimental design. In Experiment 1, participants responded on one key to targets and on a second to repeated test words and new items, consistent with the Dywan experiments and those of Bridson et al. (2006). Young adults showed robust left-parietal old/new effects for targets and showed reliable attenuation of the effect for non-targets. In Experiment 2, the experimental procedure was identical but task instructions were altered so that participants responded on one key to repeated test words and on a second key to new as well as studied words. In this case, repeated test items were now the targets and studied items were the non-targets. Target accuracy was higher in this experiment than in Experiment 1, and in accordance with the idea that target accuracy is the principal determinant of attenuation of the non-target effect, the amplitudes associated with non-targets were indistinguishable with those associated with new items. This finding is consistent with the proposal that when the target/non-target discrimination is relatively easy, participants are more likely to engage in selective recollection strategies.

In summary, the patterns of left-parietal old/new effects in two different kinds of exclusion tasks have been interpreted primarily as providing evidence for selective control over recollection according to the specific task demands. Throughout this literature, evidence of cognitive control of recollections is inferred when the left-parietal effects for targets are reliably larger than those associated with non-targets (see Table 1, T vs NT), or when the left-parietal effects associated with non-targets are indistinguishable from new items (NT vs N). The evidence described above suggests that cognitive control operations are at work in the exclusion task, despite the absence of specific cues instructing participants to engage in a control strategy. There is not, however, consistent data pointing to when or how this cognitive control is applied. One reason for the disparities in the published work may be the between-subjects designs of many of the key experiments. Typically, one group of participants is presented with a more difficult memory task than is another. As participants are randomly assigned to these conditions, individual differences within and across the sampled populations might explain some of the disparities across studies, if these individual differences are in fact determinants of when cognitive control is employed during task performance.

To address this possibility, in Experiment 1, a within-subjects difficulty manipulation was employed, by using two classes of non-targets, one of which is more memorable than the other. If the likelihood of remembering targets (target accuracy) determines when cognitive control will be exerted, then the ERP evidence for cognitive control will be evident for the more memorable class of non-targets. In addition, with the use of a relatively large sample size (n = 32) in Experiment 1 permits, for the first time, a different way of assessing the correspondence between target accuracy and ERP evidence for cognitive control over memory retrieval. If the target accuracy account is correct, then individual differences in target accuracy will predict the extent to which cognitive control occurs (as indexed by changes in the ERP index of recollection).

In accordance with the research literature summarised in Table 1, there are several ways that controlled recollection may be inferred from the electrophysiological data: when the old/new effects associated with targets are reliably larger than those for non-targets we may assume that the recovery target information was prioritised. Second, when there is a reliable old/new effect associated with targets but the amplitudes associated with non-targets is not reliably greater than new items, this can also be interpreted as evidence of cognitive control.

To anticipate the outcomes of Experiment 1, the data do not support the link between target accuracy and when cognitive control during the exclusion task will be exerted. This outcome motivates the subsequent experiments, where the emphasis is on the possibility that individual difference factors other than target accuracy explain when cognitive control will be exerted. In the second experiment, the focus of the investigation shifts to individual differences in working memory capacity (WMC), the rationale being that individual differences in the availability of working memory resources are linked to when and to what extent cognitive control processes are engaged. A detailed explanation of this issue is provided in the Introduction to Experiment 2, starting on page 72. For Experiment 2, the prediction is that participants with greater WMC are more likely to show evidence of cognitive control than are those with lower WMC. In the third experiment, the working memory resources available to participants are manipulated, by requiring some participants to complete a resource demanding task prior to the exclusion task. The detailed rationale for this approach is provided in the Introduction to

Experiment 3, starting on page 134. The prediction is that, when working memory resources are diminished, there will be less evidence of cognitive control.

The specifics of the experimental designs are described in Chapter 3, and they are preceded by a description of the ERP technique, and the ways in which ERPs are used to make inferences about cognitive processing operations in the remainder of this thesis.

Table 1: Summary of reported exclusion task data acquired in adult participants.

Herron & Rugg (2003) observed that when the probability of correctly identifying a target item (P(T hit)) was high, the magnitude of the old/new effects associated with targets were significantly larger than those associated with non/targets (T vs. NT). They suggested that this may be a marker of strategic recollection that occurs only when the recovery of target information is likely. The subsequent experiments summarised here are broadly consistent with the pattern of data described by Herron & Rugg but there is a growing body of incompatible results.
Behaviour: P(T hit) = The probability of correctly responding to a target item. P(NT fa) = the probability of incorrectly making a target response to a non-target item. **Electrophysiology:** T vs. NT = The probability that the target old/new effect is greater than the non-target old/new effect. NT vs. N = The probability that the amplitudes associated with non-targets are reliably greater than those associated with new items.

Author	**Year**	**Lag or Context**	**Groups/Conditions**	**Behaviour**		**Electrophysiology**		
				P(T hit)	P(NT fa)	Strategic Recollection	T vs. NT	NT vs. N
Herron & Rugg	2003	Context	Exp 1: Deep Encoding (Pleasantness)	0.76	0.17	yes	< 0.001	n.s.
			Exp 2: Shallow Encoding (Read Aloud)	0.63	0.26	no	n.s.	<0.001
Herron & Wilding	2005	Context	Exp 1: Immediate Test Phase	0.72	0.18	yes	< 0.05	n.s.
			Exp 2: 40Min Delay Before Test Phase	0.65	0.17	yes	< 0.05	n.s.
Wilding, Fraser & Herron	2005	Context	Exp 1: Long Lists	0.63	0.24	-	< 0.01	<0.01
			Exp 2: Short Lists	0.78	0.18	yes	< 0.001	n.s.
Dzukifli & Wilding,	2005	Context	Function/Draw	0.82	0.10	yes	<0.05	n.s.
Dzulkifli, Herron & Wilding	2006	Context	Function/Draw	0.69	0.18	yes	<0.05	<0.05
Evans, Wilding, Hibbs & Herron	2010	Context	Non-Target Similar To Target	0.65	0.14	yes	<0.05	<0.05
			Non-Target Dissimilar To Target		0.09		<0.05	<0.05
Dywan, Segalowitz & Arsenault	2002	Lag	Older Adults	0.57	0.38	no	n.s.	n.s.
			Young Adults	0.60	0.18	yes	< 0.05	< 0.05
Dywan, Segalowitz & Webster	2005	Lag	Exp 1: Older Adults	0.58	0.40	no	n.s.	n.s.
			Exp 1: Young Adults	0.59	0.18	yes	< 0.05	< 0.05
			Exp 2: Older Adults	0.46	0.11	no	n.s.	< 0.05
			Exp 2: Young Adults	0.56	0.08	yes	< 0.05	< 0.05
			Exp 2: Young Adults - Dual Task	0.51	0.17	no	n.s.	n.s.
Brisdon, Fraser, Herron & Wilding	2006	Lag	Exp 1: Read Aloud	0.69	0.17	no	n.s.	< 0.001
			Exp 2: Generate Rhyme	0.67	0.10	no	n.s.	< 0.001
Fraser, Bridson & Wilding	2007	Lag	Exp 1: Non-Targets Are Repeated Test Items	0.62	0.10	no	<0.001	n.s.
			Exp: 2 Targets Are Repeated Test Items	0.82	0.16	yes	<0.01	<0.01

CHAPTER 2: THE EVENT-RELATED POTENTIAL TECHNIQUE

2.1. The Electrogenesis of the Event-Related Potential

The electroencephalogram (EEG) is a record of the changes in voltage over time as a consequence of the combined electrical activity of large populations of neurons that is conducted through the brain, skull and scalp (Luck, 2005). When many experimental trials are averaged together time-locked to an event of interest the resulting deflections are referred to as Event-Related Potentials (ERPs). ERPs have a typical amplitude range of -100 to +100µv and have a frequency range extending from DC to 100Hz (Coles & Rugg, 1995). ERPs are a non-invasive way of investigating the distribution of neural activity preceding, during and after stimuli are presented and are useful in constraining and informing theories in cognitive psychology (Picton, Lins, & Sherg, 1995). In order for this research to be correctly interpreted, however, it is important to appreciate the electrical activity that gives rise to ERPs and key issues involved with their acquisition (Luck, 2005; Picton et al. 2000).

The ERPs recorded at the scalp reflect changes that occur in the membrane potentials of neurons as they become active. At rest, the inside of a neuron is negatively charged with respect to the outside. This is due to a difference in the concentration of positively charged and negatively charged ions located at either side of the membrane which is maintained by ion pumps. When the neuron becomes active there is a local reversal of the resting potential; ion channels in the membrane open, allowing the ions outside the cell to enter. As a result, the cell becomes depolarized and the interior of the cell becomes positively charged with respect to the exterior. This chemical change travels along the axon to a synapse. Communication between neurons occurs when neurotransmitter molecules are expelled from one cell into a synapse and, by diffusion, reach the next cell. These neurotransmitter molecules trigger an influx of positively charged ions in the post synaptic neuron, leading to a post synaptic potential. It is this chemical change that is documented in the electroencephalogram.

There are several conditions necessary for the electrical potential taking place at the neuron to be recorded at the scalp (Coles & Rugg, 1995). First, the voltage changes provided by one cell are small; a few microvolts in amplitude. Large populations of cells must be active synchronously in order for activity to be recorded at the scalp. Second, in order for the activity to propagate to the scalp, it is necessary that the cells are spatially aligned in such a way that a positive dipole of one cell does not cancel out a negative dipole of another. That is, only potentials produced by 'open field' configurations can be recorded at the scalp. An open field consists of neurons of the same orientation arranged in parallel. Closed fields consist of neurons of opposite orientation, or of neurons arranged radially that so that current can only flow inwards (Kutas & Dale, 1997). Purkinje cells in the cerebellar cortex are perfectly aligned but as the cortex is so highly folded the activity from these cells is inevitably cancelled out by nearby cells (Wood, 1987). The pyramidal cells in the neocortex, by contrast, satisfy the criteria for propagation to the scalp. Pyramidal cells constitute 70% of the neocortex and it is thought that these cells are the primary source of scalp recorded ERPs (Nunez, 1981).

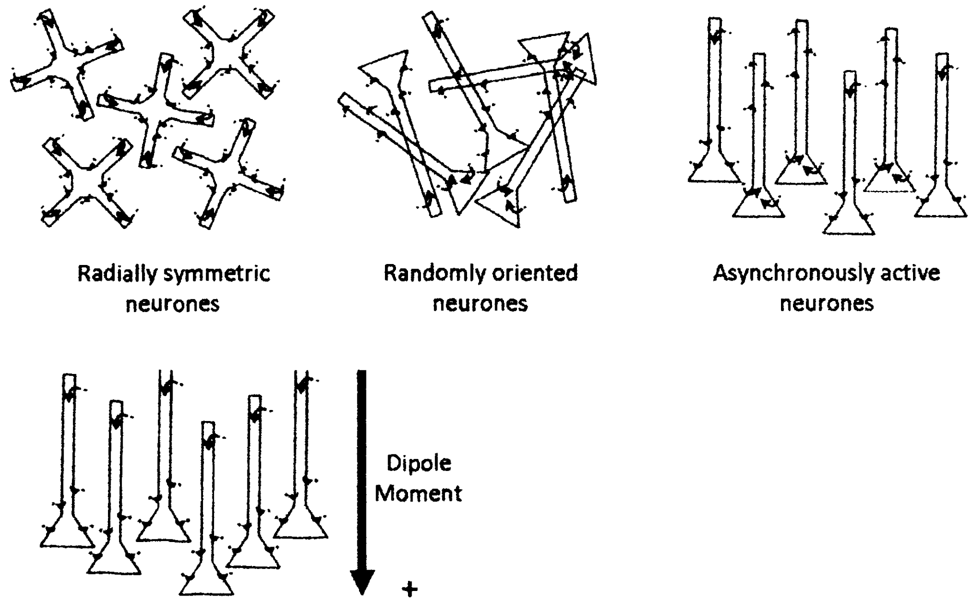


Figure 7: Examples of 'closed field' configurations of neurons (top) and 'open field' configuration (bottom). Adapted from Kutas and Dale (1997).

Only activity from neurons in an open field configuration summate and propagate so that they are recordable at the scalp.

What kinds of electrical activity generated intra-cranially are propagated to the scalp? The two principal candidates are action potentials and post-synaptic potentials. There are several reasons why post-synaptic potentials will be more readily detected at the scalp than action potentials. First, action potentials last for only a few milliseconds but post synaptic potentials last for tens or even hundreds of milliseconds (Luck, 2005). It is, therefore, more likely that several cells will be active synchronously and will summate to create voltage changes large enough to be recorded at the scalp. Second, action potentials travel along the axon. This means that summation can only occur with other cells that fire at precisely the same point as a very transient electrical potential. Post synaptic potentials, however, are largely confined to the dendrites and cell body, which makes it much more likely that other cells will fire synchronously.

A consequence of the foregoing description is that the EEG activity recorded at the scalp is an index of only a proportion of the total activity taking place within the brain at any given time, because activity taking place in closed fields or in cell populations that fire asynchronously cannot be recorded at the scalp. This has important implications for ERP data, as it is very difficult to interpret null effects in ERP research: there may be many brain areas that respond vigorously to stimuli but that activation is not recorded in EEG (examples include parts of the hippocampus, as well as the amygdala). Nevertheless, this does not of course diminish the value of positive effects in ERP research, as the electroencephalogram is a direct measure of cellular activity in an awake individual.

2.2. Acquisition

2.2.1. Recording

EEG is a record of the potential (voltage difference) between recording electrodes. Electrodes are commonly placed around the head in positions according to standardized systems. Perhaps the most common is the 'Ten-Twenty' system of electrode placement described by Jasper (1958). This method identifies the inion, nasion and pre-auricular points and locates electrodes on the basis of simple percentages of the lines linking those reference points in order to compensate for the varying size and shape of the human head (Figure 7). Each of the electrode sites has a standardized name (see Figure 8). It is also possible to place more electrodes in between those originally proposed by Jasper. With additional electrodes considerably more time is required to complete capping, and it is more likely that the electrolyte gel from one electrode will touch the gel from adjacent electrodes (bridging). If this occurs then nothing is gained from the separate electrode locations. Larger numbers of electrodes are, however, useful if ERPs are used in conjunction with fMRI with a view to localizing ERP sources (Luck, 2005).

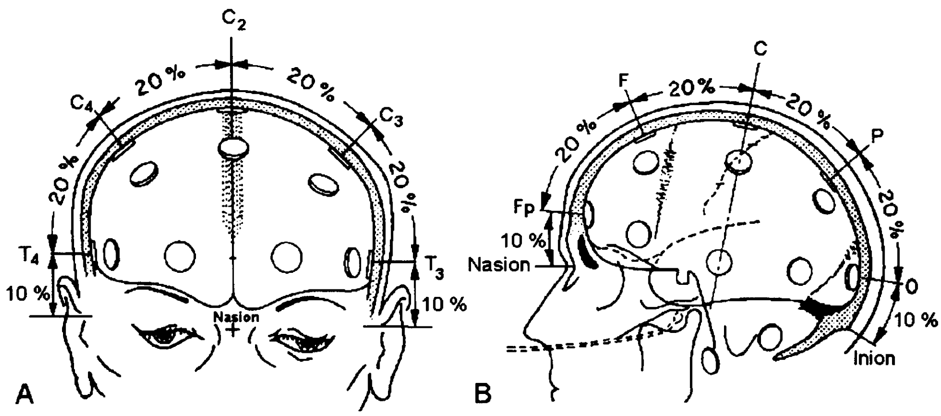


Figure 7: The 10/20 system of electrode placement (Jasper, 1958).

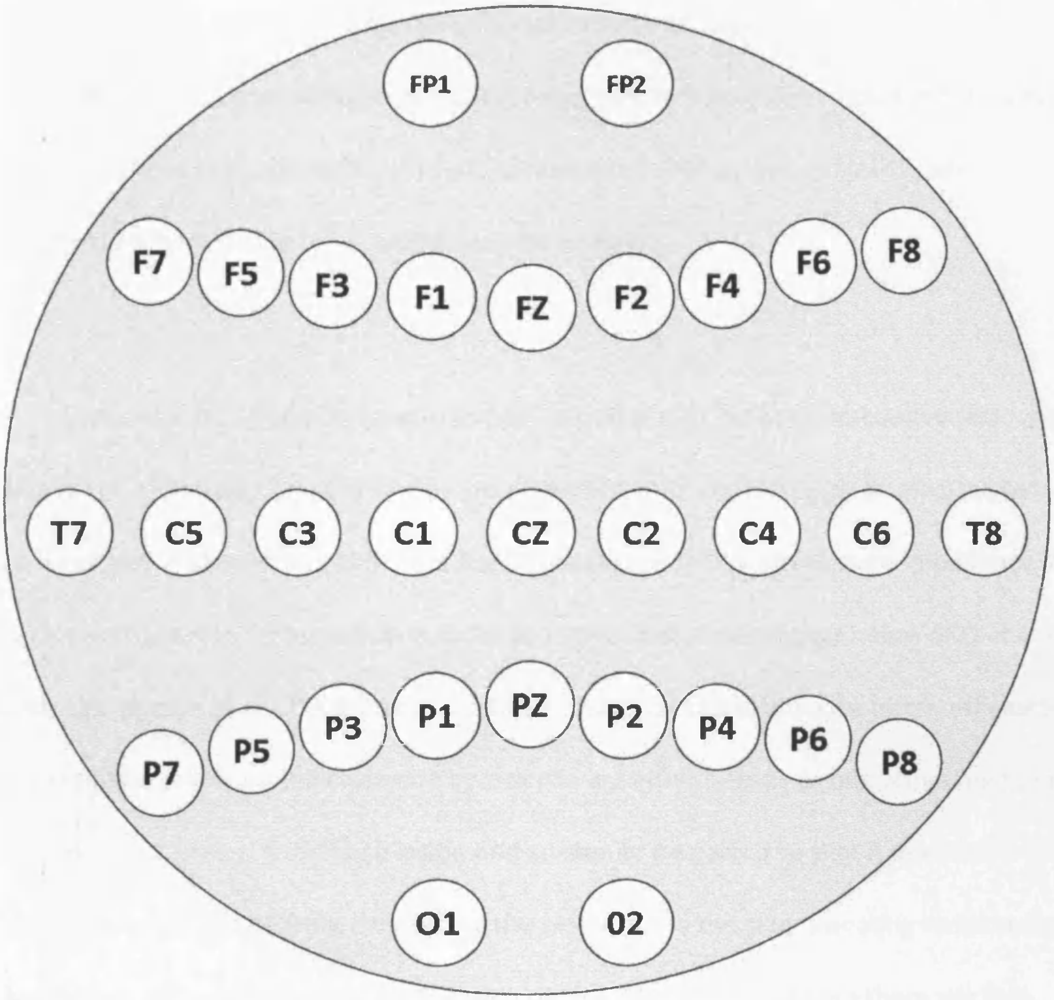


Figure 8: Schematic of the scalp locations from which electroencephalography is typically recorded and the naming convention associated with each scalp site.

The naming convention for each site describes the location as fronto-polar (FP), frontal (F), central (C), temporal (T), parietal (P) or occipital (O). Odd numbers are placed on the left hemisphere; even numbers are placed on the right hemisphere. Typically, lowest numbers are nearest the midline, and higher numbers are the most lateral.

Binnie, Dekker, Smit, & Van der Linden (1982) have criticised the ambiguity of the 10/20 system, noting that the system will only lead to the desired result (equivalent placement of electrode locations across individuals) if the head is symmetrical and the centre line is equidistant from the inion and the nasion. Binnie et al. (1982) conducted a review and concluded that most heads are not symmetrical and are plagiocephalic, meaning that, across individuals, the occipital and frontal regions are typically larger on one side than the other. Nevertheless, it is important to have standardized procedures used by various labs, and with sufficient sample sizes valid as well as statistically significant differences in brain activity can be revealed.

In order for the electrical current generated within the brain to conduct across the skin to the electrodes, the electrodes are separated from the skin with an electrolyte paste or jelly (Picton et al. 1995). It is standard practice in EEG to measure impedance at each electrode prior to recording in order to insure that impedance is below 5KΩ at each scalp site (Picton et al. 2000). To reduce the impedance, the electrolyte must sufficiently separate the skin from the electrode in order to act effectively as a conductive medium. Hair may also disrupt this transmission and so should be parted so that it does not prevent the electrolyte from connecting the electrode to the skin. Sweating reduces the impedance of the skin and can significantly distort ERPs in areas where there are high sweat gland concentrations. Dead skin cells on the skin also increase impedance and are typically removed with a cotton swab as the electrolyte paste is added. The skin is also typically cleaned with an alcohol wipe prior to testing, which will help to remove dead skin and sweat from the area. Moreover, even when the inter-electrode impedance is below 5KΩ before testing, small variations in the strength of the signal at each electrode are likely to persist, and the impedance is likely to increase during the course of an experiment. With the advent of high input impedance amplifiers, the requirements for low individual electrode impedance are ameliorated somewhat, although it still remains the case that low electrode impedance are beneficial for the quality of the data that are acquired.

The voltage at each electrode site is recorded relative to a reference electrode. Ideally the reference site would be neutral in that it would not receive any electrical activity from the brain at all but would be near enough to the head to receive similar levels of background electrical activity. Unfortunately, no site has these properties. Luck (2005) gives three guidelines for choosing an appropriate reference site. First, as there is no truly neutral reference site, it is sensible to use one that is convenient and comfortable. Second, it is important to choose a site that is not biased to either hemisphere, because if this is the case then activation from that hemisphere will be selectively attenuated. Third, as the reference site will impact on the overall morphology of the ERP waveform, it is important to use a consistent site over different experiments and with other research labs conducting related research. The most common reference site is the linked mastoid reference (Coles & Rugg, 1995). This is suitable because the mastoids are not greatly influenced by brain activity, are relatively comfortable for the participant, and as the two mastoids are linked together they are not biased to one hemisphere or the other (Nunez, 1981). Another popular method is to use the average of all electrode sites as a reference, under the assumption that background noise is evenly distributed about the head and the signal that remains is exclusive to particular electrodes but there are issues with this reference procedure also (see Desmedt, Chalkin, & Tomberg, 1990).

2.2.2. Amplification and Filtering

The voltage fluctuations of the scalp EEG are typically less than 1/100,000th of a Volt and must be amplified by a factor of 10,000-50,000 before they can be measured accurately (Luck, 2005). The electrodes are connected to an amplifier either directly, or through a capacitor, in order to magnify the voltage changes taking place. Direct coupled amplifiers usually amplify the fluctuations relative to the resting potential of each electrode, whereas capacitor coupled electrodes filter out any sustained potential difference between the recording electrodes (Picton et al. 2000). It is possible to amplify the signal at the electrode site, and this reduces the need for impedance testing as amplification can compensate for the weak signal. Where amplification occurs later, impedance checking is necessary, because the signal will be attenuated along the electrode wire connecting the electrode to the amplifier, and electrical 'noise' added along the length of the wire will be amplified along with the signal deriving from the brain. These observations emphasise that it is important in EEG to limit the electrical noise before amplification.

One way to exclude some electrical noise from the EEG is to attenuate frequency bands that are outside the range of those of interest to an ERP researcher. High-frequency activity, such as that produced by the muscles in the jaws, can be attenuated by applying a low pass filter. High pass filters are similarly used to remove frequencies below the range of interest. For both kinds of filter, it is important that they do not remove frequencies in which neural activity typically occurs.

2.2.3. A/D Conversion

It is necessary to convert the analogue EEG signal into digital format for data processing (Piction, Lins & Scherberg, 1995). The resulting waveform is a sequence of data points sampled at discrete intervals that demonstrate the potential between each electrode and the reference electrode to avoid aliasing, the sampling rate must be higher than half of the frequency of the highest frequency modulations in the digitised data.

2.2.4. Artifact Rejection and Correction

Artifacts from eye movement, blinks, muscle activity and skin potentials contaminate the EEG. The electrical potential produced by such artifacts is often greater than that produced by neural activity and greatly decreases the signal to noise ratio in a dataset. Furthermore, some of these artifacts may be more likely in some conditions than others, so averaging cannot remove them. It is very important to take as much care as possible to collect clean, artifact free data, but it is also possible to minimise the influence of these artifacts offline before data analysis begins.

In order to assess and/or index the influence of eye-movements, electrodes can be placed lateral to the eyes in order to detect horizontal eye movements (horizontal electrocculogram HEOG), and above and below each eye to detect vertical eye movements, such as those produced by blinks (vertical electrocculogram VEOG). Trials that are contaminated by a large amount of electrical activity that is a consequence of eye movements are identified and eliminated. One approach to this is to simply remove all trials in which these contaminants are present. In another approach, this information is used to estimate the impact of each blink on the electrodes, as the potentials associated with eye movement artifacts (in particular, eye blinks) propagate across the scalp. The signal can then be corrected at the other scalp sites in order to compensate for the activity link with eye movements (Luck, 2005). This method helps to prevent an excessive number of trials from being rejected, and one instantiation of this approach is used in the experiments described in this thesis.

2.2.5. Averaging

In the vast majority of ERP experiments, the ERP waveforms are isolated by signal averaging procedures (Luck, 2005). Averaging together the voltage changes associated with the same stimulus type helps to maximise the signal to noise ratio in the EEG. On any given trial, the neural activity evoked by a stimulus is small compared to the background neural activity that is also taking place and to the background level of electrical noise. This noise is, however, distributed randomly across the EEG. As such, averaging together many trials will attenuate the noise, while leaving the portion of the activity on each trial which is consistently related to that stimulus in a given epoch relatively unaffected.

The process of averaging can, however, lead to distortions in the waveform (Luck, 2005). The single trial waveforms may vary trial to trial, particularly when latencies of particular modulations vary. A consequence of this 'latency jitter' is that the average waveform will be of lower amplitude, and contain lower frequency elements, than the single trials that contribute to the average (see Spencer, Vila Abad, & Donchin, 2000). There are other averaging techniques that can be introduced to mitigate the reduction in amplitude caused by averaging latency variable trials. Response locked averages rather than stimulus locked averages may help to reduce the variability in latency for some modulations. The Woody filter technique estimates the latency of the modulation of interest on a trial by trial basis and uses this latency as the time locking point for averaging (Woody, 1967). Using this method, it is possible, however, that the modulation/deflection used in averaging may not actually be the modulation/deflection of interest. Time-locked spectral averaging is a means of extracting and averaging oscillatory responses that have random onset times (Pfurtscheller & Lopes da Silva, 1999). This method preserves oscillations with variable latencies but discards the temporal information in the EEG (Luck, 2005).

2.3. The Nomenclature of ERPs

ERP waveforms comprise a series of peaks and troughs, these are referred to as deflections and can index information processing that is correlated with a given task and stimulus type. These deflections are often named according to their polarity, latency and scalp distribution, but other researchers have expressed concern that such labels are ambiguous because any number of underlying computational processes could underlie any given component (Coles & Rugg, 1995).

In order to disambiguate these deflections, physiological researchers such as Näätänen & Picton (1987) have suggested that a defining feature of an 'ERP component' is its anatomical source within the brain. As such, the peaks and troughs in the waveform that are constant across trials should be referred to by the theoretically neutral term "deflection" and "components" should only be referred to when evidence of the physiological origins of the activity is available. This evidence might come from alternative neuroimaging methods, such as functional magnetic resonance imaging (fMRI), or through inference from statistical procedures enabling accurate source localisation (e.g. Scherg, 1990).

Cognitive psychologists, by contrast, are less concerned with the neural origins of ERP activity than with the principle that distinct brain activities underlie a given psychological process. The observation that ERPs differ across experimental manipulations is of fundamental importance to the research, often irrespective of the neural generators that give rise to those differences. The functional approach to component classification focuses on designing experimental paradigms that are tightly controlled to elucidate the cognitive process of interest. These can be plotted as difference waves that are thought to reflect the ERP signature of the particular cognitive construct. When over many experiments, the same cognitive computations are reliably associated with a specific signature in the encephalograph these can be considered functional ERP components (Luck, 2005). These components may extend over more than a single peak or trough in the electrical record.

Principal Components Analysis (PCA) and Independent Components Analysis (ICA) can also be used to isolate ERP deflections that may reflect underlying psychological components. This approach can avoid some of the problems with latency jitter (McCarthy & Wood, 1985). There are, however, further methodological issues that arise when employing a PCA and/or ICA to identify components. Wood and McCarthy (1984) found that PCA can sometimes misallocate variance. Currently, researchers in cognitive neuroscience tend to think of components as both a physiological and a functional phenomenon. Luck (2005) defines a component as "scalp-recorded neural activity that is generated in a given neuroanatomical module when a specific computational operation is performed".

2.4. Strengths and Limitations of the ERP Technique

There are several caveats necessary for the appropriate interpretation of ERP data. It is difficult to identify the brain regions responsible for generating a given pattern of electrical activity on the scalp. There are three major reasons why this is problematic with EEG data. First, the skull and scalp are electrically conductive materials, and the electrical fields that are recorded at any scalp location will also propagate across the head and be recorded at other scalp locations. This creates the confound of "component overlap" wherein observed waveforms may be generated from numerous regions. As a result, it is incorrect to assume that the electrical activity recorded at any site is likely to derive from the nearest brain regions. A related issue is that the skull will distort the electrical signal. Second, the topographies of brain structures within the scalp are heterogeneous and are not highly correlated with skull landmarks. In their review, Steinmetz, Furst and Meyer (1989) suggested that the inter-individual variation of craniocerebral topography is greater than that originally estimated by Jasper and colleagues in all brain areas and this problem is increased in areas remote from the relatively constant central and lateral sylvian structures. As a result, the scope of ERPs to provide information about the function of specific brain regions is extremely limited.

Third, and most critically, any volumetric localisation within the head has to be generated based on data collected at or just outside the scalp and this is a mathematically ill-posed problem (Kutas & Dale, 1997). Although there are several methods of modeling that can be used to generate source information from the EEG (for review see Grech et al. 2008), it is difficult to validate the accuracy of the results and there are inherent limitations in the localization of deep temporal structures. Miltner, Braun, Johnson, Simpson, & Ruchkin (1996), consistent with the views of many researchers (Luck, 2005), suggest that all interpretations based on such methods should be treated with considerable caution. Despite this limitation, it is still possible to make inferences about whether different brain regions are engaged, even if specific knowledge about the location of those regions is not available. This can be done by analysing differences between the topographies (or shapes) of patterns of neural activity across the head (McCarty & Wood, 1985). Reliable differences between topographies indicate qualitatively different engagement of neural activity, and provide a basis for arguing that, across the conditions being compared, not entirely the same cognitive processes were engaged to the same degree.

Alongside the caveats, it is also important to acknowledge that EEG has a number of advantages over haemodynamic imaging techniques such as Positron Emission topography (PET) and functional Magnetic Resonance Imaging (fMRI). First, EEG records the neural activity taking place, whereas haemodynamic imaging techniques rely on an indirect measure of brain response; the changes in venous oxygenation level that follow neural activity (Savoy, 2001). Because of this, haemodynamic techniques have poor temporal resolution, as the increase in blood flow begins in a variable time period after stimulation and peaks 5-7s after stimulation, although there may be observable changes in oxygen concentration a few 100ms after simulation (Rosen, Buckner, & Dale, 1998; Burock, Buckner, Woldorff, Rosen, & Dale, 1998).

2.4.1. Conclusions

The cognitive approach to deploying ERPs, as described above, is the one employed in this thesis. Experiments are designed to isolate specific kinds of processes, and the ERP correlates of these processes – identified by differences between electrical activity across conditions - are used to make inferences about when, as well as to what extent, particular processes are engaged. The focus is on ERP correlates of processes that support long-term memory judgments, and the review below incorporates descriptions of indices of specific memory processes that can be observed using ERPs. These descriptions are provided in the context of relevant theoretical models of the processes that support judgments of prior occurrence (recognition memory judgments), as well as judgments about contextual details associated with prior events (context or source memory judgments).

2.5. ERPs in Recognition Memory

There is a substantial and converging body of evidence that two dissociable processes support recognition memory judgements. These are commonly labelled recollection and familiarity (Atkinson & Juola, 1974; Gardiner, 1988; Hintzman & Curran, 1994; Jacoby, 1991; Mandler, 1980; Yonelinas, 2002; Yonelinas & Jacoby, 1994, 1995; Yonelinas & Levy, 2002). Although there are a number of dual-process models in which definitions vary slightly, there is a general consensus that recollection reflects the controlled retrieval of qualitative or associative information about a prior event, while familiarity is an automatic process that gives rise to a feeling of 'oldness' and comprises a graded memory strength signal. The findings from various manipulations and paradigms suggest that these two processes are independent (Jacoby, 1991; Yonelinas & Jacoby, 1995).

The focus in this thesis is on questions about the control of recollection, and, as already emphasised in the previous chapter, some of these questions are addressed by analysing changes in an ERP correlate of recollection – the left-parietal ERP old/new effect. The data supporting the link between this effect and recollection are described in detail below. Also described are two other ERP old/new effects. The mid-frontal ERP old/new effect has been identified as a correlate of familiarity, while the right-frontal old/new effect has been identified as a correlate of processes that operate on the products of retrieval in service of task goals. While these latter effects are not the principal focus for this thesis, in each results section the effects of critical manipulations on these ERP modulations are described, and for that reason the effects are detailed briefly. All three of these old/new effects are revealed in contrasts between ERPs elicited by old and new test items that attract correct test judgments. The effects all comprise a greater relative positivity for old items, but they differ in their time courses, their scalp distributions and their sensitivities to specific experiment manipulations.

There are other ERP effects that are evident in retrieval tasks, including those associated with preparing to retrieve information from memory, those indexing memory search operations, and those indexing processes that act on the products of retrieval in service of task demands. These will not be discussed in detail here because the two processes of greatest relevance to the work in this thesis are recollection and (to a lesser extent) familiarity.

The mid-frontal old/new effect is largest at fronto-central electrode locations between 300 and 500ms post-stimulus. The effect predicts the accuracy of memory judgments in recognition memory tasks, as it has been shown that ERPs elicited by incorrect 'new' responses to items that were previously presented in an encoding task (misses) are more similar to correctly rejected new items than they are to hits at mid-frontal sites in the 300-500ms time window. The link between this effect and familiarity has been made because of the insensitivity of this effect to manipulations thought to influence recollection (Curran & Cleary, 2003; Curran & Hancock, 2007; Rugg & Curran, 2007; Speer & Curran, 2007). More critically, the effect has been shown to vary in magnitude according to manipulations that influence familiarity (Azaimian-Faridani & Wilding, 2006; Woodruff, Hayama, & Rugg, 2006). While there remains some debate over whether this effect indexes conceptual priming rather than familiarity (Paller, Voss, & Boehm, 2007) the current consensus is that the former account is more likely (for a recent discussion, see Lucas, Voss & Paller, 2009, 2010; Sternberg, Hellman, Johansson & Rosen, 2009).

The right-frontal old/new effect is largest at right-frontal scalp sites, onsets around 500ms post-stimulus and can be maintained for up to 1500ms. The effect is larger in tasks that require source memory judgments than those that only require old/new judgments. This finding, in combination with the frontal distribution and time course of this effect, has prompted the view that it indexes processes that are engaged after retrieval has occurred. The precise nature of these processes, however, and their specificity to episodic memory, remain matters of debate.

2.5.1. Recollection and the Left-Parietal Old/New Effect

The left-parietal old/new effect onsets approximately 500ms post stimulus, lasts between 200 and 800ms and as the name suggests, it is largest at left-parietal scalp sites (Donaldson & Rugg, 1998, 1999a, 1999b; Wilding et al. 1995; Wilding & Rugg, 1996, 1997; Wilding & Sharpe, 2003). The effect comprises a greater positivity for previously presented items than new items, however, unlike the mid-frontal effect, the left-parietal effect is larger when item memory is accompanied by accurate memory for source relative to when there is item memory but no source memory (Wilding & Rugg, 1994, 1995). Furthermore, the magnitude of the left-parietal old/new effect increases when more source information is recovered which provides substantial evidence for the notion that the left-parietal effect is sensitive to the amount or quality of information that is retrieved from episodic memory in a graded fashion (Rugg et al. 1998; Vilberg et al. 2006; Wilding & Rugg, 1996). Key data points substantiating these claims are described below.

Wilding & Rugg (1996) presented participants with words auditorily in either a male or female voice. In the test phase, participants were asked to indicate if the word had been presented before and if so, in which voice. Correct 'old' judgments that were accompanied by correct source judgments reflect recollection, whereas correct old judgments in the absence of source information may be based on familiarity. The results showed greater positivity at left-parietal scalp sites when there were correct source judgments than when there were incorrect source judgments or correct rejections. More recently, Wilding (2000) conducted a similar experiment but with two source judgments (male/female voice and two different encoding tasks) and found that the amplitude of the left-parietal old new effect was greater when there were two correct source judgments than one alone or none. The fact that the magnitude of the left-parietal old/new effect is greater when more source information is available which provides substantial evidence that the left-parietal effect is sensitive to the amount or quality of information that is retrieved from episodic memory.

The Remember/Know paradigm was introduced by Tulving (1985) to dissociate between episodic memory (memory for life events associated with a particular place and time) and semantic memory (memory for acquired information such as facts). In this design participants are presented with a list of to-be-remembered items and, in the memory test, are asked to make a three-way judgment as to whether they have no memory at all of the item (i.e. it is new), if they remember that they have seen the item before but cannot recall any representation of the item (i.e. it is familiar) or if they distinctly recall being exposed to that test item before (i.e. they recollect it). Vilberg et al. (2006) modified the remember/know paradigm to include two classes of remembered items, participants could select between, items that were 'new', items they 'know' they have seen before but cannot remember any contextual details, and whether they 'partially remember' or 'fully remember' the items. The left-parietal old/new effect was larger for the fully remembered items but the effects for fully and partially remembered items were topographically identical, implying that the same neural generators were employed. This provides further evidence that the left-parietal old/new effect indexes recollection in a graded fashion (Vilberg & Rugg, 2008, 2009a, 2009b).

Rugg et al. (1998) compared the scalp recorded ERPs across source memory tasks and the remember/know task and demonstrated that the left-parietal old/new effects were indistinguishable for "remember" responses and for correct source judgments. These data suggest that recollection defined operationally as the "subjective experience of remembering" and as "memory that is accompanied by accurate source information" is supported by the same underlying neural generators and that these are functionally equivalent. Despite the differences in the methodology associated with each of these paradigms, and that these tasks were both designed to tap the processes associated with recollection, this is good evidence that these tasks appear to consistently tap the same underlying neural populations and that these populations support the process of recollection.

The strengths of the links between the left-parietal ERP old/new effect and recollection are such that the effect has been used extensively to make inferences about the extent to which recollection has contributed in different task contexts. Paller & Kutas (1992) were the first to suggest that the effect might be used as an index of recollection even in the absence of accompanying direct behavioural evidence, and a comparable rationale underlies the use of the effect in the Think/No-Think paradigm described earlier. A related approach is employed here, where a task that is assumed to rely on recollection is employed, but at issue is how recollection is employed, and under what conditions. These questions are pursued in the experiments that are described starting in Chapter 4, following an outline of the General Methods that are employed in this thesis (Chapter 3).

CHAPTER 3: GENERAL METHODS

3.1. Introduction

This chapter outlines the recording and analysis strategy common to the experiments in this thesis. Approval for all experiments in this thesis was given by the Ethics Committee in the School of Psychology at Cardiff University.

3.1.1. Experimental Procedures

This section refers to the particulars of the experimental procedures employed throughout the thesis.

3.1.2. Participants

All were between 18 and 30 years of age, were right-handed, reported that they spoke English as their first language, had normal or corrected-to-normal vision, reported that they did not have a diagnosis of dyslexia and were not taking psychoactive medication at the time of testing. All participants were paid £10 per hour for their time or given course credit towards the undergraduate psychology Research Methods module. In Experiments 1 & 3 participants were recruited via Cardiff University School of Psychology Experiment Management system. Participants in Experiment 2 were recruited from the Undergraduate Psychology population directly; the recruitment method for this experiment is described in more detail in Experiment 2 (Chapter 6).

3.1.3. Materials

Words used in the exclusion task were selected from the MRC psycholinguistic database (www.psy.uwa.edu.au/MRCDatabase/uwa_mrc.htm). They had a frequency of 1-7/million, and ranged from 4-9 letters in length. They were presented in white on a black background on a computer monitor placed 1m from participants. The words subtended a maximum of 5° of visual angle horizontally and 0.6° vertically.

3.1.4. Design

All study and test phases were completed in the same testing chamber. All words were counterbalanced fully across participants so that they were each presented as a target/non-target and new item an equal number of times. The hand with which responses to each type of stimulus were required was counterbalanced across participants and lists. The task was divided into sections each containing one study list followed by one test list. There was a short (self-paced) break between each study-test cycle. Test timings were identical to those in the study phase in each experiment. Each trial started with a fixation asterisk (500 ms duration), which was removed from the screen 100ms prior to presentation of a study word (300ms duration). The next trial started 1000ms after the offset of the study word.

The ERP effects of interest are acquired during the test phase of the exclusion paradigm (see Introduction: Figures 5 & 6) concern those associated with correct responses to targets, non-targets and new items. The magnitude of the parietal old new effect for targets shall be compared to those for non-targets, where reliable differences between these two effects exist, this shall be interpreted as evidence of controlled recollection.

3.2. Electrophysiology

This section refers to the particulars of the EEG acquisition as well as the processing and subsequent analysis of the electrophysiological data.

3.2.1. EEG Acquisition

There were some differences in the recording parameters between Experiment 1 and Experiments 2 and 3 as the data was acquired in two different EEG laboratories in Cardiff University, School of Psychology. In all experiments, EEG was recorded from 25 silver/silver chloride electrodes at midline (Fz, Cz, Pz) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, T3/T4, C5/C6, C3/C4, T5/ T6, P5/P6, P3/P4, O1/O2) located according to the ten–twenty system (Jasper, 1958; see Figures 7 and 8 in Chapter 2). Additional electrodes were placed on the mastoid processes. EOG was recorded from above and below the left eye (VEOG) and from the outer canthi (HEOG). Data were re-referenced off-line to linked mastoids. Trials containing large electrooculogram (EOG) artefact were rejected, as were trials containing A/D saturation or baseline drift exceeding ±80 μV. These rejection criteria are in line with those typically employed in studies of memory retrieval, and it is notable that they are liberal in the sense that they are likely to retain some noise that is not directly related to the manipulation of interest, but by being liberal they reduce the likelihood that data that does reflect activity of interest will be discarded. Other EOG blink artefacts were corrected using a linear regression estimate (Semlitsch et al. 1986). A 7-point binomially weighted smoothing filter was applied prior to analysis (28.57Hz). In Experiment 1 EEG (range 0.03–40 Hz; sampling rate 200 Hz) was acquired referenced to Fz. The data from Fz were recovered. In Experiments 2 and 3 data were acquired from 7 locations in addition to those used in Experiment 1 (F1/F2, C1/C2, P1/P2, Oz). EEG (range 0–419 Hz; sampling rate 2048 Hz) was acquired referenced to linked electrodes located midway between POz and PO3/PO4, respectively. Data were high-pass filtered offline (0.03 Hz), low pass filtered (40Hz) and finally down-sampled to 200 Hz. Epoched data in each experiment comprised 200 points (1s epoch length, including a 100ms pre-stimulus baseline relative to which all mean amplitude values were calculated).

3.2.2. Focused analyses

The key element of the ERP data is the differences between target and non-target left-parietal ERP old/new effects, and in keeping with this, the first analyses of the ERP data were restricted to parietal electrodes in the 500-800ms epoch. These are the sites and the time period in which left-parietal ERP old/new effects are commonly observed and analysed (Allan & Rugg, 1997; Paller & Kutas, 1992; Vilberg et al. 2006; Wilding, 2000; Wilding et al. 1995; Wilding & Rugg, 1996, 1997; Wilding & Sharpe, 2003). Support for this analysis decision is also provided by the spherical spline interpolated potential maps which are presented in each experimental chapter and reveal robust left-parietal distributions of the target and non-target ERP old/new effects from 500-800ms post-stimulus.

In Experiments 1 & 2, once the left-parietal old/new effect had been revealed at the group level, subsequent regression analyses were conducted to identify variables that predict the magnitude of the effects and also the relative difference in the magnitude of the effect for target and non-targets. To increase the power of these investigations they were further restricted to the scalp site where the effect of interest was largest. This decision was made to include a greater range of values in the regression analyses, alternatively, if the analyses were conducted on the average values of more lateral scalp sites we may have diluted the effect of interest. This decision was made to provide as sensitive an index of the process of recollection as possible. Importantly, these decisions are taken on the basis of a strong literature linking the left-parietal old/new effect to recollection and also to increase the statistical power of out correlational analyses. Selecting scalp sites for these analyses does not increase the likelihood of a spurious correlation with any variable, but makes it more likely that genuine effects will be revealed.

The outcomes of subsidiary analyses are also reported for two other memory-related ERP effects. One of these is the mid frontal old/new effect, which is a putative index of the process of familiarity (see Chapter 2 and reviews by Curran & Hancock, 2007; Mecklinger, 2000; Wilding & Sharpe, 2003). Analyses of this effect are restricted to mid frontal scalp sites (F3 & F4) in the 300-500ms epoch as these are most commonly associated with the familiarity effect. The second effect is the late right-frontal old/new effect, which is associated with post-retrieval monitoring (see Introduction as well as reviews by Allan, Wilding, & Rugg, 1998; Donaldson, Allan, & Wilding, 2002). Analyses of this effect are restricted to right frontal scalp sites (F4, F6, & F8). The outcomes of these subsidiary analyses are not discussed until the General Discussion (Chapter 7).

CHAPTER 4: CONTROLLED RECOLLECTION & THE AVAILABILITY OF TARGET INFORMATION

4.1. Introduction

In order to understand the nature of controlled recollection in the exclusion task Experiment 1 was designed to investigate some of the boundary conditions that determine when healthy young adults engage in controlled retrieval processing. As described in detail in the introductory chapters, the left-parietal ERP old/new effect is a neural correlate of recollection (see Chapter 2, the left-parietal old/new effect) and has been used to make inferences about the extent to which recollection occurs in combination with, and sometimes independently of, converging behavioural data (e.g. Wilding, 2000; Wilding et al. 1995). When the size of the left-parietal old/new effect for one class of old items is reliably larger than the effect for a second class of items that were encountered under similar circumstances, but the recollection of which is not necessary for accurate task performance, this has been considered to be evidence of controlled recollection (Bridson et al. 2006; Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding et al. 2005).

The findings in several studies where the exclusion task has been employed (see Chapter 1) have been interpreted in this way (Bridson et al. 2006; Dywan et al. 2002;

Dywan et al. 1998; Dzulkifli et al. 2006; Dzulkifli & Wilding, 2005; Evans et al. 2010; Fraser et al. 2007; Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding et al. 2005; Wilding & Rugg, 1997). To recap, in this task participants are typically presented with items in two different encoding tasks. The test instructions are for participants to respond on one key to items encountered in one of the encoding tasks ("targets") while items from the alternative task ("non-targets") are rejected on the same key as new items. In order to respond correctly to target items participants must recognise that they have seen the items before and recover the appropriate contextual information necessary to establish that the item was presented in the target context. In accordance with this, robust left-parietal effects are consistently found for target items in the exclusion task.

Herron & Rugg (2003) were the first to note that recollection is not necessary for the accurate rejection of non-targets. They found that, at least under some circumstances, left-parietal old/new effects for non-targets are smaller than those for targets, they observed that a non-target item that is not remembered will be correctly rejected along with new items if the failure to recollect content related to targets is used as a basis for separating targets from non-targets as well as new test items. It may, therefore, be optimal to strategically direct recollection towards targets (and/or away from non-targets) in the exclusion paradigm under some circumstances. Given that the behavioural response to non-targets is identical whether contextual information associated with an item is recollected or not, it is not possible to ascertain from behavioural data alone which strategy was used (recollection of information about targets only, or recollection of content about non-targets as well as targets). As implied above, however, this can be inferred from analyses of how left-parietal old/new effects for targets and for non-targets differ.

In their original experiments, Herron & Rugg (2003) held the encoding task for non-targets constant across two experiments. In one experiment there was a relatively shallow encoding task for targets (read words aloud), while in the other the encoding task was somewhat deeper (sentence generation). With the deeper encoding task, target accuracy was higher. Herron & Rugg (2003) found evidence for controlled recollection for the deeper target encoding task only. Consistent with the interpretation given above, this comprised larger parietal old/new effects for targets than for non-targets only in the experiment where targets were subjected to the sentence generation manipulation.

Following up this work, Wilding et al. (2005) acquired ERPs in the test phases of two exclusion tasks, and in both the targets and non-targets were distinguished by the colour that they were presented in at study. In Experiment 1 there were 6 study test cycles containing 20 words each, while in Experiment 2 there were 12 study test cycles containing 10 study words. Due to the increased length of the study lists, target accuracy was lower in Experiment 1 (0.63) than Experiment 2 (0.78). In Experiment 2, the left-parietal old/new effect for non-targets was attenuated relative to the target effect for non-target recollection (hence controlled retrieval). This is again consistent with the notion that the availability of target information predicts the engagement of a controlled recollection strategy in the exclusion task.

While data consistent with this account have also been reported in other studies (Herron & Rugg, 2003; Bridson et al. 2006; Fraser et al. 2007; Wilding et al. 2005; Dzukifli & Wilding, 2005; Dzulkifli et al. 2006; Wilding & Rugg, 1997; Evans et al. 2010), in the only published attempt to demonstrate ERP evidence for the control of recollection in one condition but not in another in the same participants, converging data was not obtained. In the study reported by Herron & Wilding (2005), participants completed two study-test phases. The encoding tasks associated with targets and non-targets were identical in each phase, but target accuracy was reduced in the second phase by having a 40min delay between study and test. Although target accuracy was significantly reduced by the introduction of the delay (65% vs 72%), the extent to which non-target left-parietal old/new effects were attenuated relative to target effects was the same in the two experiments. Herron & Wilding (2005) suggested that target accuracy may not be sufficient to explain all of the boundary conditions for when strategic recollection occurs (for related discussion, see Evans et al. 2010).

In summary, although target accuracy predicts the use of a controlled recollection strategy across the majority of relevant published experiments, this pattern of data has not yet been demonstrated entirely consistently. The primary aim of the first experiment was to employ a task that would permit an assessment at the level of individual differences of the target accuracy account for when ERP evidence for controlled retrieval processing in exclusion tasks will be observed. This was implemented by assessing correlations between the ERP marker of control over recollection – the difference between the magnitude of target and non-target left-parietal ERP old/new effects – and levels of target accuracy. The currently dominant account of this ERP signature of controlled retrieval predicts that the degree of attenuation of the non-target effect relative to the target effect will increase as target accuracy increases.

In addition to this part of the experiment rationale, two classes of non-target were used in this study. The lag version of the exclusion task was employed (see Chapter 1) and an equal number of words were repeated at test (non-targets) at either a short or a long lag. This manipulation was introduced as a preliminary means of assessing performance in a task that might be used subsequently with other participant populations, and where the use of different lags might be employed as a means of equating performance (c.f. (Jennings & Jacoby, 1997).

4.2. Method

4.2.1 Participants

Twenty-six participants (5 male) were recruited through the Cardiff University Experiment Management System. Data sets from 2 participants were excluded due to excessive artefacts in the EEG data (for the rejection criteria, see page 74, General Methods).

4.2.2. Materials

300 words were selected from the MRC psycholinguistic database. See General Methods (Chapter 3) for parameters.

4.2.3. Design

The experiment was divided into four study test blocks, each containing 25 study words and 125 test words. At test all old words were presented interspersed with 50 new words. 25 of these new words repeated after a short lag (7-9 words later) and 25 after a long lag (15-17 words).

4.2.4. Procedure

The study phases in each experiment were preceded by a period of approximately 30 min during which participants were fitted with an electrode cap (see General Methods section, Chapter 3). EEG was recorded during the test phase only.

In each study phase participants were told that 25 words would be presented and were asked to read each word aloud. After the offset of the study words the screen was then blanked and the next trial started in 3000 ms. After each study block participants took a self paced rest. They were told to press any key when they were ready to begin the test phase. Participants made a binary response in the test phase, pressing one key for words they had spoken in the study phase and another key for words that they had not previously spoken. They were asked to keep their fingers over a button box during the test, and the hand with which participants responded to each type of stimulus was counterbalanced across participants. Participants were informed before testing that the new test words would repeat but to always press the same key for all words presented only at test.

4.3. Results

4.3.1. Behavioural Data

Behavioural data is shown in Table 2. Discrimination accuracies are calculated as the likelihood of making a target response to a target vs. (i) the likelihood of a target response to a non-target (separately for each lag), and (ii) the likelihood of a target response to a new item. These three discrimination measures are reliably above chance $t(23) > 13.0$, $p < 0.001$ in each case. A one-way ANOVA revealed a main effect of measure, and paired contrasts revealed that target/non-target discrimination is inferior to target/new discrimination at long as well as at short lags ($t(23) = 5.0$, $p < .001$). Target/non-target discrimination does not vary with lag ($t(23) < 1$).

RTs are analysed across the correct responses to all four stimulus categories via a within-participants ANOVA. There is a main effect of stimulus, $F(3, 36) = 12.3$, $p < 0.001$. Follow-up tests demonstrate that participants are slower to respond correctly to target items than to short lag non-targets, $t(23) = 5.0$, $p < 0.001$; long lag non-targets, $t(23) = 4.4$, $p < 0.001$; and new items $t(23) = 4.6$, $p < 0.001$. No other significant differences in the RT data are revealed in the remaining possible paired contrasts.

Table 2: Mean Proportions of Correct Responses to Targets, Non-targets and New words (N = 24)

Standard deviations in parenthesis, RT = Reaction time. Target = studied word, Short Lag = test word repeated after 7-9 intervening items, Long Lag = test word repeated after 15-17 intervening items, New = First presentation of a new test word.

	Word Status			
	Target	Short Lag Non-Target	Long Lag Non-Target	New
P(correct)	0.62	0.89	0.89	0.96
	(0.13)	(0.06)	(0.11)	(0.06)
RT (ms)	776	687	696	671
	(247)	(239)	(247)	(215)

4.3.2. Electrophysiological Data

Figure 9 shows ERPs for sample scalp sites for targets, non-targets and new words that attracted correct responses at test. The scalp distributions of the ERP old/new effects for the 300-500, 500-800 and 800-1100ms epochs are shown in Figure 10.

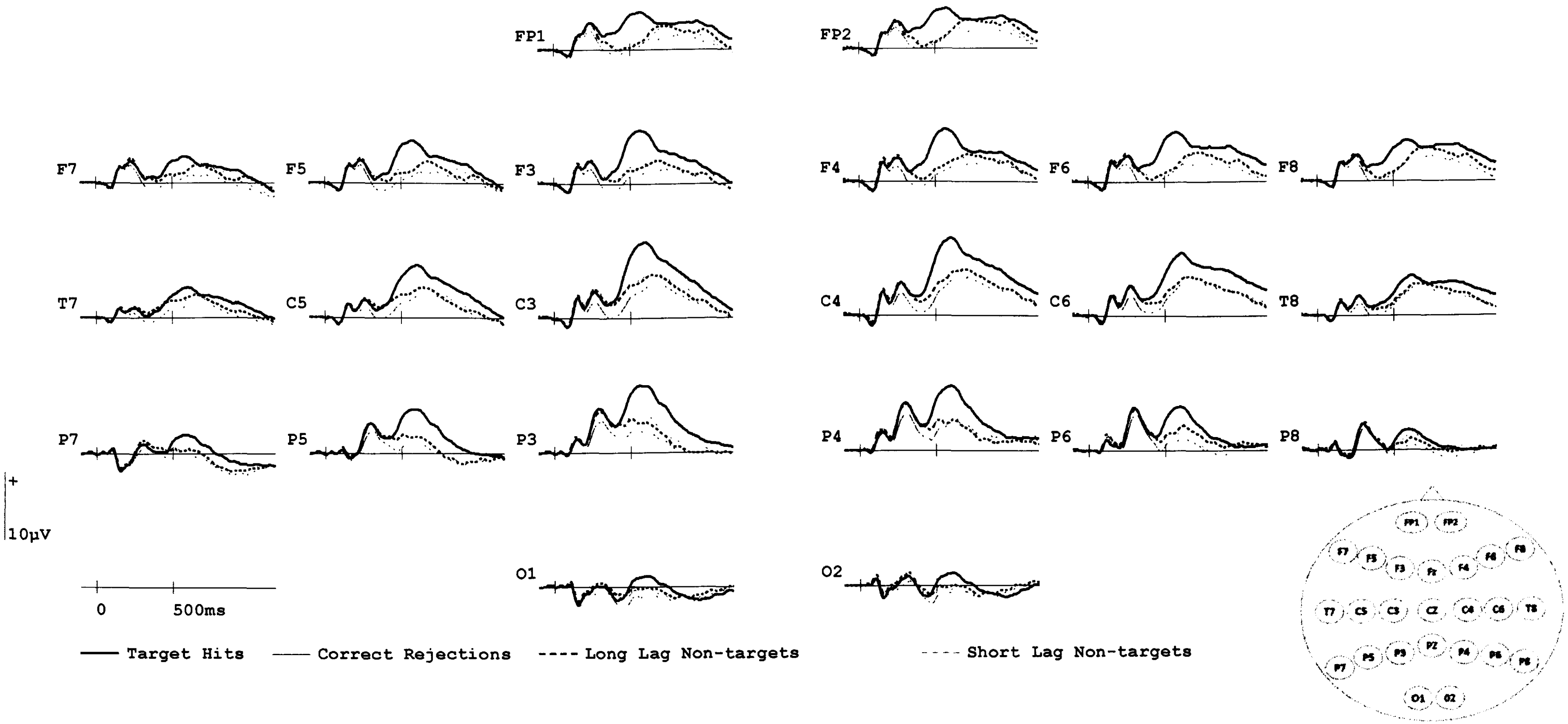


Figure 9: Grand average ERPs elicited by correct rejections and correct responses to targets (Target Hits) and non-targets (Non-Target Hits) that repeat after short and long lag. Data are shown for 22 sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, F4, F6, F8), central (C5, C3, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, P4, P6, P8), and occipital (O1, O2) scalp sites.

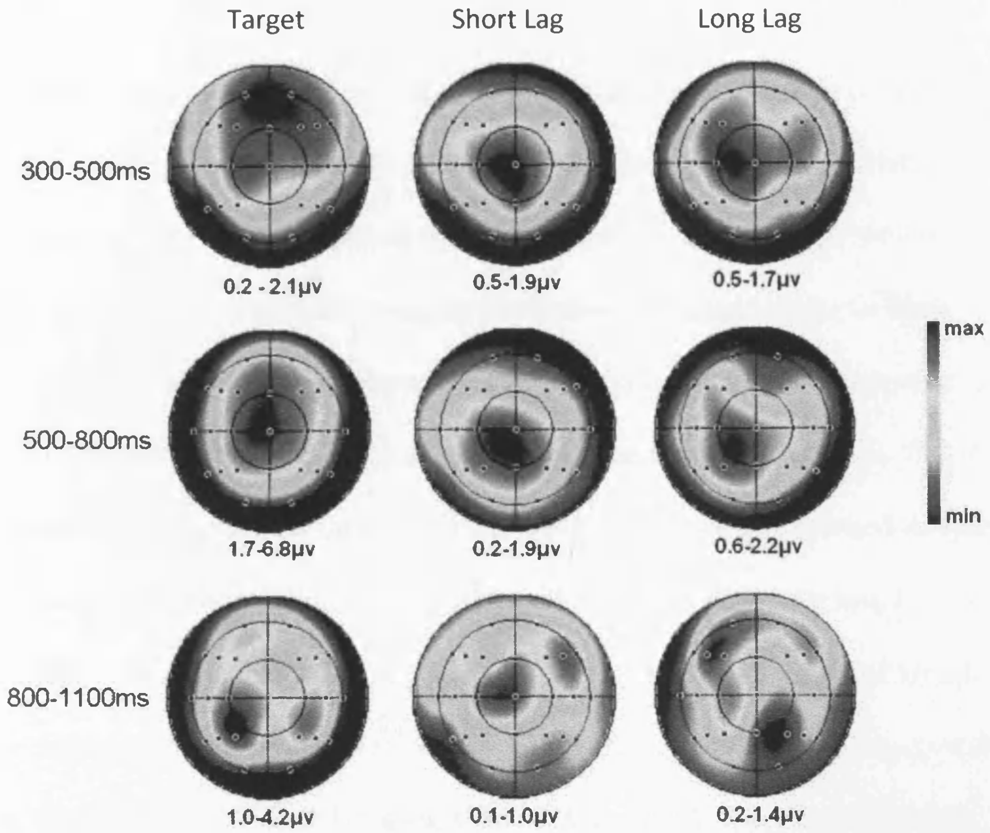


Figure 10: Topographic maps showing the scalp distributions of the old/new effects for each class of old item that attracted a correct judgment

Voltage maps are computed on the basis of difference scores obtained by subtracting mean amplitudes for the event-related potentials elicited by new words from each type of old word. Each map is proportionately scaled between the maxima (red) and minima (blue) of the depicted effect and the maximum and minimum values are shown below each map and can be interpreted relative to the colour bar on the right-hand side of the Figure.

4.3.3. The Left-Parietal Old/New Effect: ANOVA

Focused analyses are conducted at parietal scalp sites P5 and P6 (see Figure 11). These sites are selected as a result of the topographical distributions displayed in Figure 10 and fall within the group of sites that are typically employed to analyse sensitively changes in the left-parietal effect (see Introduction). A repeated-measures ANOVA is conducted on data for these electrode sites with factors of hemisphere (left: right) and response category (target: long: short: new). Only data associated with correct responses are used in the analyses. The ANOVA reveals a main effect of response category only, $F(3,69) = 18.1$, $p < 0.001$. Planned comparisons collapsed across hemisphere showed that old/new effects are significant for targets, $t(23) = 4.8$, $p < 0.001$, short lag non-targets, $t(23) = 3.7$, $p < 0.05$, and long lag non-targets, $t(23) = 2.0$, $p < 0.05$. The magnitude of these parietal effects were larger for targets than non-targets with a short lag, $t(23) = 4.0$, $p < 0.001$, and long lag, $t(23) = 4.5$, $p < 0.001$. There is no difference between the magnitude of the effect when compared across each class of non-targets, $t(23) = 1.29$.

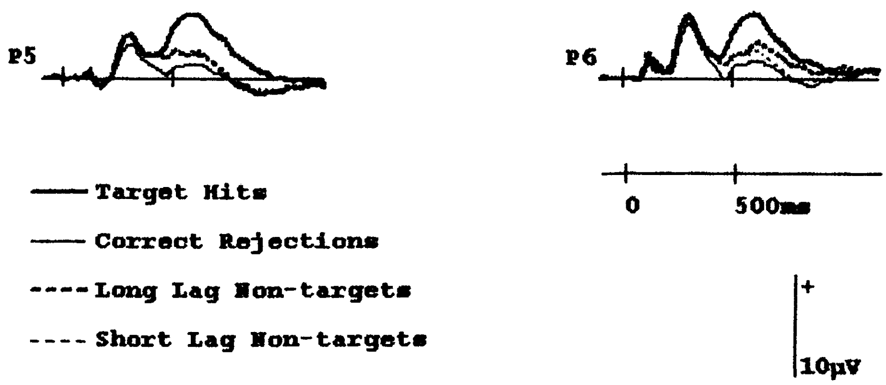


Figure 11: Grand average event-related potentials (ERPs) elicited by correct rejections and correct responses to each class of non-target item for scalp sites P5 (left-parietal) and P6 (right-parietal).

4.3.4. Left-Parietal Old/New Effect: Regression

In keeping with the rationale for completing this experiment, the target accuracy account for the circumstances under which ERP evidence for control over recollection is observed was assessed by inspecting changes in the amplitudes of critical old/new effects in relation to target accuracy at the level of individual participants. If the target accuracy account is correct, then the degree to which target effects exceed non-target effects should increase along with increases in target accuracy.

In order to investigate how changes in the amplitudes of old/new effects vary with the other variables of interest, separate regression analyses are conducted for the target old/new effects (mean amplitudes of correct rejections subtracted from those for targets) and the comparable non-target effects. In addition, a regression analysis using the difference between these two (which reduces to non-targets subtracted from targets because of the common correct rejection baseline) were also computed to investigate that there was in fact a reliable difference in the correspondences between these two effects and the other variables of interest.

Three separate analyses were conducted on the data from 500-800ms post stimulus. Two analyses were conducted to investigate the relationship between target accuracy and the size of the left-parietal effect for targets and non-targets. The third was conducted to investigate whether target accuracy predicts the difference between the size of target and non-target left-parietal ERP old/new effects. As there is no reliable difference between amplitudes to long lag and short lag non-targets these are averaged to create one class of non-targets for each participant. Similarly, as there is no reliable interaction between response category and hemisphere, both regressions are performed on data averaged over scalp sites P5 and P6 (See Figure 12).

Mean amplitudes to correct rejections were subtracted from those for targets and non-targets and entered as dependent variables in a regression analysis with target accuracy as the independent variable. This regression is not significant, $R^2 = 0.03$, $F(1, 22) < 1$. There is no reliable relationship between target accuracy and the amplitude of target hits $\beta = -0.2$, $t = 0.8$. The same procedure is adopted for the magnitude of the non-targets effects, and again, the regression is not significant: there is no evidence for a relationship between the left-parietal old/new effects associated with non-targets and target accuracy $R^2 = 0.01$, $F(1, 22) < 1$, $\beta = -0.02$, $t = 0.9$.

In the third regression analysis, target accuracy is again the independent variable and the dependent variable is a difference score computed by subtracting the amplitudes associated with the non-target parietal old/new effect from those associated with the target effect for each participant. The regression is non-significant; target accuracy does not explain variance in this difference measure, $R^2 = 0.4$, $F(1, 22) < 1$.

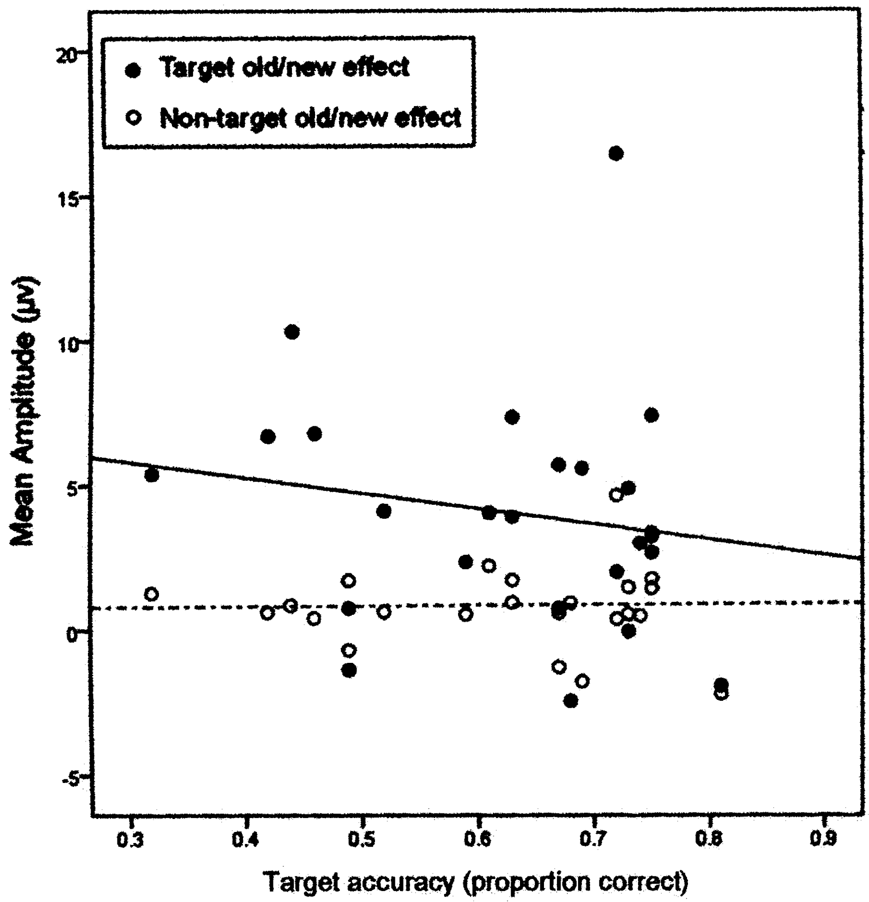


Figure 12: The relationship between target accuracy and the magnitude of the left-parietal old-new effect to targets (filled circles) and non-targets (unfilled circles)

4.3.5. Subsidiary ERP Analyses: Mid-Frontal Old/New Effect.

Data from two mid-frontal scalp sites (F3 & F4) were averaged and subject to a one-way ANOVA with a factor of stimulus (target: long lag: short lag: new). This reveals a main effect of stimulus type, $F(3, 69) = 20.5$, $p < 0.001$. Planned paired t-tests reveal a greater positivity for target hits than correct rejections, $t(23) = 5.6$, $p < 0.001$, and this is also the case for long lag hits $t(23) = 4.7$, $p < 0.001$, and short lag hits, $t(23) = 4.7$, $p < 0.001$. In addition, the mid-frontal old/new effect is larger for correct responses to target items than to each class of non-target items: long lag items, $t(23) = 3.6$, $p < 0.001$; short lag items, $t(23) = 4.3$, $p < 0.001$. There is no difference between the magnitude of the mid-frontal old/new effect for short lag non-targets and long lag non-targets, $t(23) = 0.9$. The old/new effects associated with targets were reliably larger than those associated with non-targets, $t(23) = 2.3$, $p < 0.05$.

A regression analysis is adopted to examine any relationship between target accuracy and the size of the mid-frontal ERP effects. Target accuracy is entered as the dependent variable and the amplitudes of the target old/new effect and non-target old/new effects are entered as independent variables collapsed across the two types of non-target. This regression is not significant, $R^2 = 0.3$, $F(3, 20) < 1$. There is no reliable relationship between target accuracy and the amplitudes to target hits $\beta = -.2$, $t = 0.1$ or target accuracy and amplitudes to non-target hits $\beta = -0.2$, $t = 0.8$.

4.3.6. Subsidiary ERP Analyses: Late Right-Frontal Effect

Data from right- and left-frontal scalp sites (F3, F5, F7, F4, F6 & F8) were targeted for the 800-1100ms time-window and subjected to an ANOVA with factors of hemisphere (left: right) and response category (target: long: short: new). As for the previous analyses, only ERP data associated with correct responses are used for the analyses. A reliable main effect of stimulus is revealled, $F(3, 23) = 6.2$, $p < 0.05$. Paired comparisons reveal reliable old/new effects for targets $t(23) = 2.9$ but no reliable old/new effects for either category of non-targets (largest $t = 1.0$).

A regression analysis is also conducted to investigate whether target accuracy predicts the size of the late right-frontal old/new effect. Target accuracy is entered as the dependent variable and the magnitude of the old/new effect associated with correct responses to targets is entered as a predictor. This regression is not significant, $R^2 = 0.01$, $F(1, 22) < 1$, $\beta = 0.11$, $t = 0.5$. Because there is no interaction with the size of the old/new effects and hemisphere, data are collapsed across hemisphere for this analysis.

4.4. Discussion

There are several notable findings in this experiment. At the group level, marked attenuation of the non-target left-parietal old/new effect relative to the target effect occurred despite target accuracy in this experiment being lower than in previous experiments with a similar design and where non-target left-parietal effect amplitudes were equivalent to those for targets (Bridson et al. 2006; Dywan et al. 2002; Dywan et al. 1998; Herron & Rugg, 2003). These observations are of course across experiments with different groups of participants, but these findings coincide with the fact that the individual differences analysis reported here implies that participants with low target accuracy are at least as likely to engage in a selective recollection strategy as those with higher target accuracy. These data are thus inconsistent in two ways with the view that marked non-target attenuation of old/new effects in the 500-800ms epoch occurs only when target information is readily recoverable (and this is reflected in the accuracy of target responses). Both elements of the data are discussed in turn below.

In this experiment, target accuracy is only 0.6 and marked non-target attenuation is evident at the group level. By contrast, Wilding et al. (2005) reported target accuracy of 0.63 in one condition where target amplitudes were equivalent to non-targets. Wilding et al. employed a colour manipulation (see Introduction for details), but it is notable that the lack of correspondence between these and previous findings remains when comparing the group level findings in this experiment with those that bear the most similarities to this. These are the experiments reported by Fraser et al. (2007) and by Bridson et al. (2006). In these experiments, the methodology is very similar to that applied here: the experiments in both papers comprised the lag version of the exclusion task where non-target items are new items that repeat after a lag of a certain number of items. Despite these similarities there is little or no evidence for attenuation of the non-target left-parietal ERP old/new effect relative to the effect for targets in these studies. The data reported here can, however, be interpreted as a replication of the Dywan et al. (1998) research with younger adults: they had a similar pattern of response accuracy as well as marked attenuation of the left-parietal effect for non-targets relative to targets.

One important difference between this experiment and those of Fraser et al. (2007) and Bridson et al. (2006) is the increased heterogeneity of the non-targets because only in this experiment were there were two lags. One possibility, therefore, is that a strategy of relying upon recollection of target information was adopted here because it was economical to do so rather than rely upon an assessment of target content as well as two different kinds of non-target content. This account moves away from the view that target accuracy is the key determinant of the conditions under which ERP evidence for selective retrieval will be observed, a position which is also broadly encouraged by the outcome of the regression analysis in which target accuracy is not related positively to the size of the difference between target and non-target left-parietal ERP old/new effect amplitudes. These kinds of analyses at the level of individual participants have not been reported before, thus this one outcome must be treated cautiously. Considerations about individual differences do give rise, however, to a second possibility for some of the apparently inconsistent findings in published studies and the present study. This second possibility is that individual differences in the resources necessary to exert cognitive control determine, at least in part, when ERP evidence for the exertion of cognitive control over retrieval will occur.

If this account is correct, then it will explain the reported relationship between target accuracy and ERP evidence for cognitive control via the argument that increases in target accuracy make tasks less demanding overall, so on average the degree to which resource availability is an issue for the exertion of control decreases as target accuracy increases. Apparent inconsistencies across otherwise similar studies in the ERP data alongside comparable behavioural data might then be explained by differences across groups in resource availability: if there is sufficient variability across individuals then selecting participants without reference to available cognitive resources might lead to inconsistent findings. These arguments, along with a more detailed consideration of the relationships between the processes responsible for retrieval control and measures of resource availability are described at the start of the next chapter, where the starting point is a consideration of working memory, and the relationship between measures of working memory and resource availability, as well as long-term memory.

CHAPTER 5: WORKING MEMORY & THE CONTROL OF RECOLLECTION

5.1. Introduction

The concept of working memory refers to a limited capacity system allowing the temporary storage and manipulation of information (Baddeley, 2000; Baddeley & Hitch, 1974; Gathercole, 2008). There are considerable individual differences in working memory capacity (WMC), and these have been linked to individual differences in a range of cognitive abilities such as reasoning and reading comprehension (Engle, Cantor, & Carullo, 1992; Kyllonen & Chrystal, 1990), childhood academic ability in reading and mathematics (Gathercole, Adams, & Hitch, 1994; Gathercole, Pickering, Knight, & Stegmann, 2003; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Hitch, Towse, & Hutton, 2001; Jarvis & Gathercole, 2003; Swanson, Ashbaker, & Lee, 1996; Swanson & Beebe-Frankenberger, 2004) and adult fluid intelligence as well as academic achievement (for reviews see, Daneman & Merikle, 1996; Engle, Tuholski, Laughlin, & Conway, 1999). For present purposes, one important link is that individuals with high working memory capacity (WMC) are more successful on tasks that are assumed to require inhibition (Brewin & Smart, 2005; Conway & Engle, 1994; Redick, Heitz, & Engle, 2007). According to the Resource Model of Inhibition (Conway & Engle, 1994), inhibition is an active and resource demanding process and as such, in situations where working memory resources are compromised (by virtue of task demands or individual differences), inhibition will not be employed to the same extent as when resources are not compromised.

Following from the observations that were made at the end of the preceding chapter, it is possible that individual differences in working memory capacity can reconcile some of the apparently inconsistent data points that have been obtained in ERP studies where people completed exclusion tasks. As previously discussed, evidence of controlled recollection in the exclusion task is more likely to be observed when the demands of the task are relatively low. That is, when the likelihood of recovering information about targets is relatively high. It is reasonable to assume that, in easier test situations, fewer demands are placed on cognitive resources and more resources are available that can support the exertion of cognitive control. The experiment described below is designed to investigate the links between individual WMC and strategic recollection in the exclusion task. This is preceded by a review of the literature linking working memory to long-term memory storage and retrieval.

5.1.1. The Role of Working Memory in Long-term Memory Storage and Retrieval

Since the first conceptualisation of working memory, it was considered to have an important role in long-term memory processing. Baddeley & Hitch (1974) suggested that information was temporarily maintained in an active state before being stored in long-term memory; they referred to this 'active state' as working memory. According to their initial multi-component model, working memory contained three components, an "articulatory loop" for holding information in a speech based form and a "visuo-spatial scratch pad" specialised for the on-line maintenance of visual information. These were both supervised by a "central executive"; a modality free attentional control system that directs resources towards these two sub-systems and away from irrelevant information. The model was later reformulated by Baddeley to include an additional component, the "episodic buffer", which is capable of storing information in multi-dimensional code and as such is specialised for the integration of information from the visuo-spatial scratch pad and the phonological loop into complex representations (Baddeley, 2000). The episodic buffer enables information about colour, location, movement, smell etc to be bound into coherent "episodes" for long-term memory storage and subsequent reinstatement. The buffer is said to be episodic in that it integrates information across space and time and is a crucial interface between memory and conscious awareness. The buffer, however, is distinct from Tulving's concept of episodic memory (Tulving, 1983, 1985) in that it is assumed to be a temporary store that is important for feeding information into, and retrieving information from, long-term memory.

Conway & Engle (1994) suggested that individual differences in WMC lead to differences in the ability to suppress the retrieval of irrelevant information from long-term memory. In their "Resource-Dependent Inhibition Model" they suggest that, when the recovery of information is automatic, working memory resources play an important role in preventing interference from inappropriately retrieved items. In accordance with Anderson's ACT (Adaptive Control of Thought) Model (Anderson, 1983), Conway & Engle presume that concepts or representations are linked such that a cue will activate several competing representations. A concept becomes accessible when the amount of associated activation reaches threshold. Hence, when presented with a retrieval cue, many associated items in memory may become active automatically. The model put forward by Conway & Engle suggests that, when WMC resources are available, inhibition mechanisms come into play to select between the competing representations. When WMC resources are not sufficient, these inhibition processes are compromised and accurate selection may fail (Unsworth & Engle, 2007a) described two other basic functions that WMC fulfils. They posited that WMC is necessary for the maintenance of new and novel information in a heightened state of activity, particularly in the presence of distraction, and secondly, that WMC is necessary to discriminate task-relevant information from irrelevant information in long-term memory.

5.1.2. Working Memory and Episodic Memory Deficits in Clinical Populations

Working memory is thought to explain some of the memory deficits associated with clinical populations. It is widely established that various clinical diagnoses, including depression, post-traumatic stress disorder, acute stress disorder, eating disorders and borderline personality disorder are associated with an inability to generate specific autobiographical memories (Williams & Broadbent, 1986; Williams, Chan, Crane, & Barnhofer, 2006; for review see Williams et al. 2007). In the Autobiographical Memory Test (AMT), participants are asked to generate a specific autobiographical memory in response to a series of cues (Williams & Broadbent, 1986). For example, the cue "holiday" might be used to generate a memory such as "I remember the day we went to Barry Island last year". Importantly, participants are instructed that a specific memory, defined as a memory for a particular event that occurred on a particular day, must be recovered. Williams and Broadbent (1986) discovered that participants with various clinical disorders are more likely to produce generalised memories such as "I always enjoyed going to Barry Island on holiday" and even when prompted to generate a more specific memory this generalisation often persists. The phenomenon can also be observed in those with sub-clinical depressed mood (Ramponi, Barnard, & Nimmo-Smith, 2004) and has been demonstrated in mood induction studies (Au Young, Dalgleish, Golden, & Schartau, 2006).

The currently leading explanation for this phenomenon is that clinical populations fail to inhibit categorical descriptors associated with retrieval cues. This failure of inhibition leads to the production of overly general responses. There is a range of evidence that depressed mood is associated with reduced working memory capacity (Ellis & Ashbrook, 1988; Gotlib & Joormann, 2010; Hartalage, Alloy, Vazquez, & Dykman, 1993) and this generates the possibility that executive capacity diminution is responsible for over-generality on the AMT. This account mirrors the description of the role of inhibition in retrieval tasks described earlier (Conway & Engle, 1994): when prompted to generate a memory associated with a cue word many representations are brought to mind (some general and some more specific), and WM resources are necessary to select between competing representations. Depressed mood is likely to compromise the executive processes necessary to select an appropriate representation, therefore, depressed participants are more likely to falsely accept a general memory response. In support of this theory, Dalgleish et al. (2007) demonstrated across a series of experiments that the number of over-general memories produced by dysphonic participants correlated highly with task errors on a range of executive paradigms and working memory span tests. Williams et al. (2006) required participants to retrieve autobiographical memories either in isolation or while also performing a random button pressing task. In this secondary task, participants were asked to press any of the number keys on the keyboard 0-9 but to make their responses appear as random as possible, i.e. to not respond with sequential numbers or use the same number too often. This task was selected as it places high demands on executive resources (see Experiment 1 of Williams et al. 2006). When the AMT was completed under these resource demanding circumstances, participants produced a greater number of over-general responses. This implies that working memory may have a causal role in supporting the active search for content during autobiographical memory retrieval.

Dalgleish et al. (2007) also presented participants with a revised version of the autobiographical memory test (AMT-R) in which participants were asked to only provide general memory responses and avoid specific ones. Depression severity was measured with the Beck Depression Inventory, and in addition, working memory was measured using the O-Span task, which is a measure of WMC (see section 5.2 later in this chapter for a detailed description). In this case, depression severity was associated with reduced WMC and with a greater number of inappropriate specific memories on the AMT-R. Importantly, WMC correlated with correct general responses even after controlling for scores on the Beck Depression Inventory. This further implies that the memory deficits on the AMT associated with clinical populations can be explained by a deficit in selecting between appropriate representations as a consequence of impaired WMC.

5.1.3. Deficits of Long-term Memory in Older Adults that are Related to WMC

Memory performance declines from late to early adulthood and age-related memory losses are far more pronounced on some tasks than others (Park et al. 1996; Salthouse & Babcock, 1991 see Figure 13). There is considerable evidence that older adults show deficits in long-term memory that are associated with inhibition impairments (Hasher, Quig, & May, 1997; Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Malmstrom & LaVoie, 2002; Schacter, Koutstaal, & Norman, 1997) and furthermore that working memory may be mediating this relationship (Hogge, Adam, & Collette, 2008; Park et al. 1996; Piolino et al. 2010b; Salthouse & Babcock, 1991, See Figure 13). Hasher & Zacks (1988) proposed that the age-related deficit in working memory is caused by impaired inhibitory mechanisms that fail to prevent irrelevant information from entering or being maintained in working memory, but it could equally be true that working memory resources are necessary for successful inhibition of unwanted items.

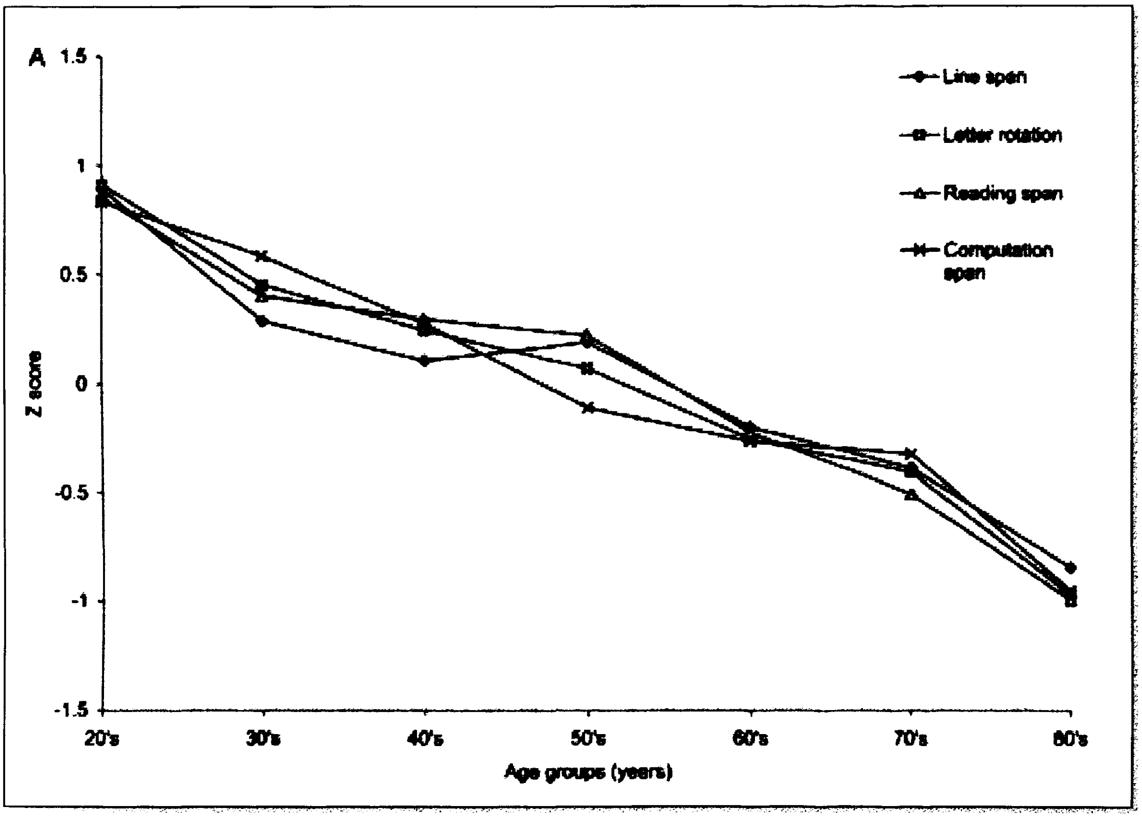


Figure 13: Working memory is documented to decline from young adulthood across the life-span (Park et al 1996).

Park et al (1996) demonstrated that older adults show a cognitive decline on working memory tasks, as well as cued and free recall tasks, but that performance was spared on picture recognition memory, prospective memory and implicit memory tasks. Park et al. set out to investigate if working memory might mediate these age-related changes in long-term memory performance by collecting data from 301 participants aged 20-90 years. Working memory was measured with three tasks: a backwards digit span test, a reading span test and a computation span test. Park et al. also collected several measures of inhibition from negative priming paradigms, a Stroop colour naming task and a reading distraction task in which words that are to be ignored are interspersed in italics within the target text. Participants were also given two free recall tests and two cued recall tests.

The principal finding was that working memory predicts age-related performance in memory function for more effortful types of memory (cued recall and free recall) independently of processing speed or general memory ability. The authors predicted that processing speed mediated this relationship between age and working memory. There was no statistical difference between the model they presented (see Figure 14) and a more complex model where age has a direct relationship with working memory. As predicted, performance on implicit memory (spatial recall) tasks was not adversely affected by advanced age. Unfortunately, the inhibition tasks were not successful, in that there were no significant effects of inhibition in the tasks used, and as a result this construct was not entered into the model.

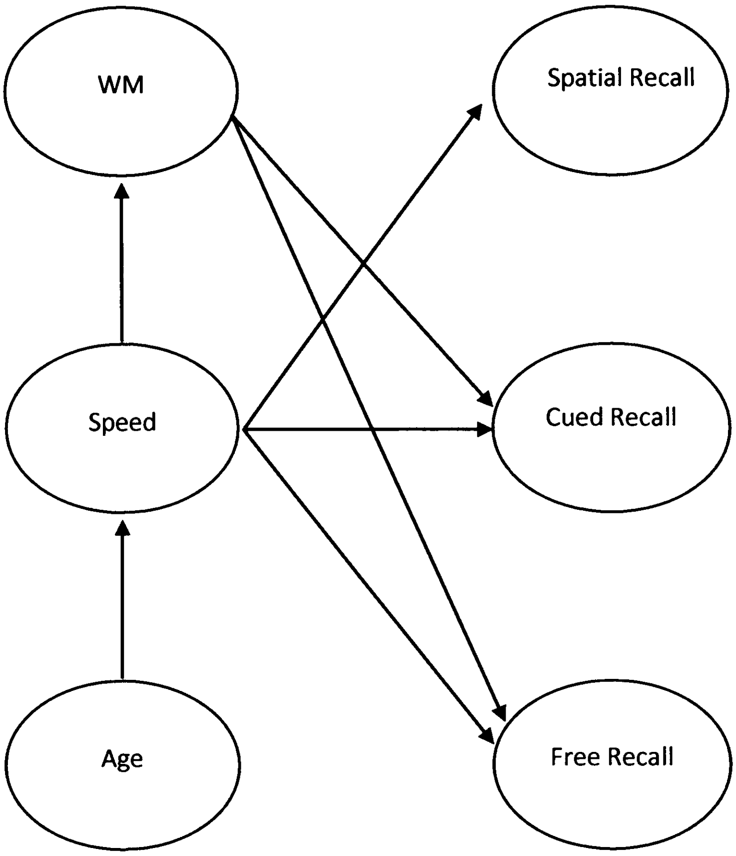


Figure 14: Results adapted from Park et al. (1996) indicating a link between WMC and recovery of mnemonic information in a cued and free recall task.

Given that older adults have reduced working memory capacity (Hasher & Zacks, 1988; Park et al. 1996; Salthouse & Babcock, 1991), it follows that they should also have difficulty selecting between competing representations in the autobiographical memory test. Piolino et al. (2010a) compared younger (N = 50, 20-33 years) and older adults (N = 50, 65-89 years) in a revised autobiographical test where participants were asked for increasingly specific information from events that lasted several years (e.g. time spent at university), events that lasted for a few days/weeks or repeated events (e.g. holidays in Wales), specific events (e.g. a particular day in Cardiff Bay) and sensory, affective, and cognitive details that lasted a few minutes/seconds (e.g. how I felt when I had my first beer after submitting my thesis). The authors also administered a range of executive function and neuropsychological tests. Older adults made more errors than young adults at all levels of specificity, which suggests that they consistently fail to select task-relevant memories. Furthermore, older adults showed poorer performance (relative to younger adults) with increasing levels of specificity. Older adults had lower scores on all executive function tests that were administered. In addition, various working memory measures (alpha verbal span, n-back test, awkward visuo-spatial span) predicted performance at various levels of specificity across younger and older participants. This demonstrates that some age-related memory defects may be explained by age-related declines in WMC, which may be acting by compromising the inhibition of competing representations in long-term memory.

There is some evidence from the directed forgetting paradigm that working memory mediates age-related changes in inhibition-related performance on this task (Andres, Van der Linden, & Parmentier, 2004; Zacks, Radvansky, & Hasher, 1996). As described previously (see Chapter 1 & Bjork, 1972), in the directed forgetting paradigm items are presented and subsequently cued "to be remembered" (TBR) or "to be forgotten" (TBF). In a later test, participants are asked to report TBF as well as TBR items recovery of TBF items is poorer than TBR items. The recovery of fewer of the TBF items in the test is assumed to be indicative (at least in part) of greater success of inhibition processes that occur post-encoding to make these items less available for recovery (Ullsperger, Mecklinger, & Muller, 2000). Zacks et al. (1996) demonstrated over a series of experiments that older adults have difficulty in inhibiting the TBF items in comparison to young adults, a finding which is in accordance with their inhibition deficit hypothesis of normal aging.

Andres et al. (2004) reported evidence that elderly people show a relatively reduced ability to inhibit no longer relevant information in a directed forgetting paradigm over short delays. They used three conditions and in all of them the test occurred immediately after the study phase. In the first condition, a single TBR trigram was presented. Elderly and young participants did not differ in their ability to remember a single trigram over short delays. In the second condition, two TBR trigrams were presented consecutively (this was referred to as the interference condition) and in this case performance fell for both young and older adults but this deficit was more pronounced in the older group. In the third condition, two trigrams were again presented. One was TBR and the other TBF, and performance in this condition was again lower than in the single item condition and older adults were again disproportionally affected. Andres et al. compared the errors made by younger and older adults and found that older adults were more likely to omit the TBR information and also make a higher proportion of TBF intrusions than the younger group. The data suggest that elderly people inhibit no-longer-relevant information less effectively than young adults in a working memory task.

5.1.4 Working Memory and Controlled Recollection in the Exclusion Task

Given the preceding arguments and observations, it seems reasonable to assume that the use of a controlled recollection strategy in the exclusion task (as indexed by the pattern of target and non-target ERP old/new effects described in Chapter 1) will depend on the cognitive resources available to support cognitive control. While this possibility has not been tested directly, there is some support for it. Dywan et al. (1998) compared older and young adults using behavioural and ERP measures in the exclusion task and found that older adults were just as successful as younger adults at correctly identifying targets but were less accurate at rejecting non-targets. This is consistent with Oberauer & Lange's (2009) observation that older adults have more difficulty rejecting intrusion probes. Dywan (1998) also assessed a second group of young adults who were given an additional task demand. Young adults in this group were asked to monitor a series of spoken numbers at the same time as completing the exclusion task, indicating via key press when specified sequences of numbers were heard. Young adults in this dual task group performed similarly to older adults in that they also made a greater number of intrusion errors. Again, this is consistent with Oberauer & Lange's (2009) account, but of course in both cases an alternative account is that older adults and young adults in the dual task condition simply showed a more liberal in response bias.

Although Dywan was not explicitly investigating controlled retrieval processing, the pattern of ERP data she reported is also consistent with a resource dependent controlled retrieval account. Parietal old/new effects associated with targets were reliably larger than those for non-targets for young adults in the single-task condition. There were no differences between the old/new effects for targets or non-targets for young adults in the dual task condition or for older adults. These findings for older and younger adults can be explained in the following way. Advanced age is associated with reduced WMC and so older adults did not have the resources necessary for the successful engagement of controlled retrieval processing. Young adults did have the resources necessary to inhibit non-targets in the exclusion task but when these resources were compromised by the introduction of a second, attentionally demanding task, inhibition processing failed.

The logic of this argument is that working memory capacity is compromised by increasing age as well as by the requirement to complete two tasks at the same time, and the consequence of this is an inability to adopt a controlled retrieval strategy in the exclusion task. Experiment 2 was designed to test this possibility directly, by measuring WMC (as a proxy for resource availability) and investigating how ERP evidence for controlled retrieval processing in the exclusion task changes according to variations in WMC. The WMC measure was the O-Span task, which is a complex span measure, in that it involves a simple letter span memory test in conjunction with a secondary task, such as a mathematical computation (Turner & Engle, 1989). Complex span measures are thought to place demands on the domain general resources of the central executive whereas simple span tasks only challenge the appropriate slave system (for example, the phonological loop) and there is a substantial body of evidence to support this idea (for reviews see, Gathercole, 2008; Unsworth & Engle, 2007b). There is a growing body of evidence that performance on complex working memory span tasks (and in particular the O-Span task) correlates with inhibition performance on a wide range of low level inhibition paradigms including dichotic listening, the Flanker Task, Paired Associates Task, Brown-Peterson Task, Stroop task, anti-saccade task as well as tests of social inhibition (for review see Redick et al. 2007).

In the 500-800ms epoch, there are three measures taken from left-parietal scalp sites that are of relevance to variations in WMC. These are the left-parietal old/new effects associated with targets and with non-targets, as well as the size of the difference between these effects. The key question of interest is whether the ERP evidence for the degree to which cognitive control is exerted varies with WMC. The ERP evidence in this case is the size of the difference between the target and non-target ERPs. The separate regressions for the target and non-target old/new effects should offer insights into why any reliable differences revealed in the direct contrast between the two come about.

5.2. Method

5.2.1. Participants

193 undergraduate psychology students completed the Barrat Impulsiveness Scale (BIS) and individuals in the upper and lower 25% of scores were invited to participate in an ERP exclusion task. This recruitment method was employed to encourage a range of WMC scores, because BIS correlates negatively with working memory and executive function (for review see, Stanford et al. 2009). 40 students (14 male) took part in the EEG session. Data from 4 participants (2 male) were excluded due to excessive artefacts in the EEG data. Participants were allocated randomly to one of two groups, each of which completed slightly different exclusion tasks, as described in detail below.

5.2.2. Materials

Barrat Impulsiveness Scale: This is a 30-item self-report questionnaire designed to assess impulsiveness. Participants were pre-screened on this item as part of an "Introduction to Research" class for new entrants to the School of Psychology that was held in 2007. The scale contains 30 statements such as "I plan tasks carefully" and "I do things without thinking". Participants are instructed to read each statement and indicate how often they think that statement applies to them via a four alternative forced choice: the alternatives are "Rarely, Occasionally, Often, and Almost Always/Always. Each item is scored 1, 2, 3, or 4 with the most impulsive response attracting the highest score. The maximum total score is 120 (see Appendix 1).

O-span: This task is used widely for measuring WMC (Turner & Engle, 1989). Participants are presented with compound stimuli such as "(3 x 2) + 4 = 11 ? DOG". They are instructed to read each equation aloud, indicate whether the solution is correct, and then read the word aloud. Participants are informed that they will be asked to recall the words at a later point in time. The number of compound stimuli that are presented before recall is required (the 'fan') increases from 2 to 5, and this procedure is repeated 3 times at each fan. The O-Span is scored as one point for every word recalled in the correct serial position on trials where participants give the correct answer for the mathematical equation.

Exclusion task: 412 words were selected from the MRC psycholinguistic database (See General Methods).

5.2.3. Design

400 words were split into 16 equal groups (25 words per group). These were allocated randomly to four task study-test cycles, each comprising four groups of words. These four were

combined in each study-test cycle as follows. One of the four groups in each section was designated as the study word list. All four groups in each section were employed at test, where each item was presented once, with the exception of one group (not the one containing study list words) for which words were presented twice at test, with an average lag of 8 intervening words (range = 7-9) between first and second presentation. Thus each test list in each study-test cycle comprised 125 stimulus presentations: 25 studied words, and 75 words presented at test for the first time, of which 25 were presented for a second time.

One complete task list comprised four study-test cycles, and the word groups designated as study words, new words and repeated test words were rotated, resulting in the development of three complete task lists. A further three task lists were generated by changing the lag between presentation and re-presentation of test words from an average of 8 to an average of 16 (range = 15-17). The task thus comprised short and long lag versions. For the long lag lists, an extra 3 filler items were placed in each test sequence towards the end of the lists to ensure that first and second presentations of test items were distributed relatively evenly throughout the test lists. Thus for these lists, 25 words were shown at study and 103 words (128 stimulus presentations) were shown at test within each study-test cycle.

5.2.4. Procedure

This procedure is identical to that for Experiment 1, except that an equal number of participants (N = 18) completed the short and the long lag lists.

Study phase: Participants were told that 25 words would be presented one at a time on the screen and they were to read each word aloud. They were told at the start of the experiment that their memories for these words would be assessed subsequently.

Test phase: Participants made a binary response on each test trial, pressing one key for words they had read aloud in the study phase and another key for all other words. They were informed before testing that some new (unstudied) test words would repeat, but to always press the "new" key for those words.

5.3. Results

5.3.1. Behavioural data

Behavioural data for the exclusion task are presented in Table 3. As in the previous experiment, discrimination accuracies are calculated as the likelihood of making a correct response to a target item set against the likelihoods of a target response to non-targets and new words. All four individual discrimination scores are reliably above chance (all $t(17) > 14.9$, $p < 0.001$). A mixed model ANOVA with factors of lag group (short: long) and discrimination scores (target: non-target: new) reveal a main effect of stimulus, $F(2, 68) = 468.5$, $p < 0.001$, reflecting the fact that target/non-target discrimination is inferior to target-new discrimination. Across all 36 participants there is no correlation between target accuracy and WMC (Pearson's $r = .01$).

A mixed model 2 x 3 ANOVA on the reaction time data associated with correct responses to each class of stimulus reveals a main effect of stimulus type, $F(2, 68) = 10.1$, $p <$

0.001, reflecting the RT advantage for correct responses to new over old (studied as well as repeated) test words. Reactions times are reliably slower for target items than non-targets items, $t(35) = 2.3$, $p < 0.05$ and new items, $t(35) = 4.3$, $p < 0.001$, reaction times associated with non-targets are slower than for new items, $t(35) = 2.1$, $p < 0.05$.

Table 3: Mean Proportions of Correct Responses to Targets, Non-targets and New words compared by Short lag and Long lag groups and highest (N=18) and lowest (N = 18) WMC

Standard deviations in parenthesis, RT = Reaction time. Target = studied word, Non-target = Repeated test item that repeats after 7-9 intervening items (Short Lag Group) or 15-17 intervening items (Long Lag Group), New = First presentation of a new test word.

WMC		Short Lag Group			Long Lag Group		
		Target	Non-Target	New	Target	Non-Target	New
High	P(correct)	0.87	0.86	0.95	0.68	0.89	0.97
		(0.17)	(0.10)	(0.02)	(0.09)	(0.15)	(0.07)
	RT (ms)	777	736	748	820	830	758
		(133)	(133)	(159)	(243)	(242)	(236)
Low	P(correct)	0.73	0.92	0.98	0.71	0.91	0.97
		(0.10)	(0.07)	(0.02)	(0.06)	(0.06)	(0.04)
	RT (ms)	794	708	691	898	859	808
		(227)	(256)	(215)	(106)	(103)	(101)

5.3.2. Electrophysiological data

Waveforms associated with each class of old item attracting correct responses across groups are presented in Figures 15-18. Across all participants, the distributions of the old/new effects are displayed in Figure 19.

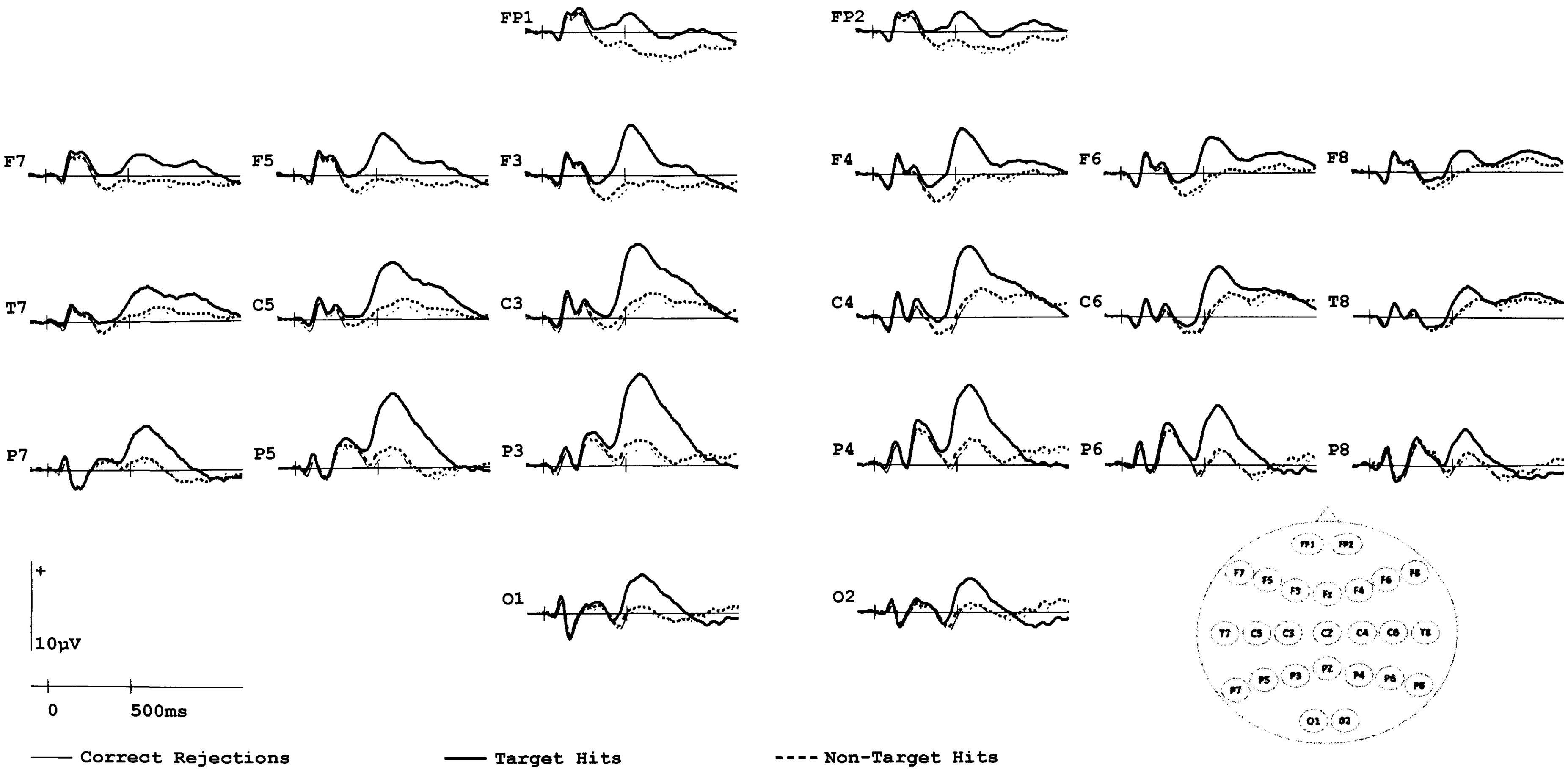


Figure 15: Waveforms across 22 sample electrode sites for 12 participants with highest WMC (N = 12) collapsed across lag.

Data are shown for 22 sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, F4, F6, F8), central (C5, C3, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, P4, P6, P8), and occipital (O1, O2) scalp sites.

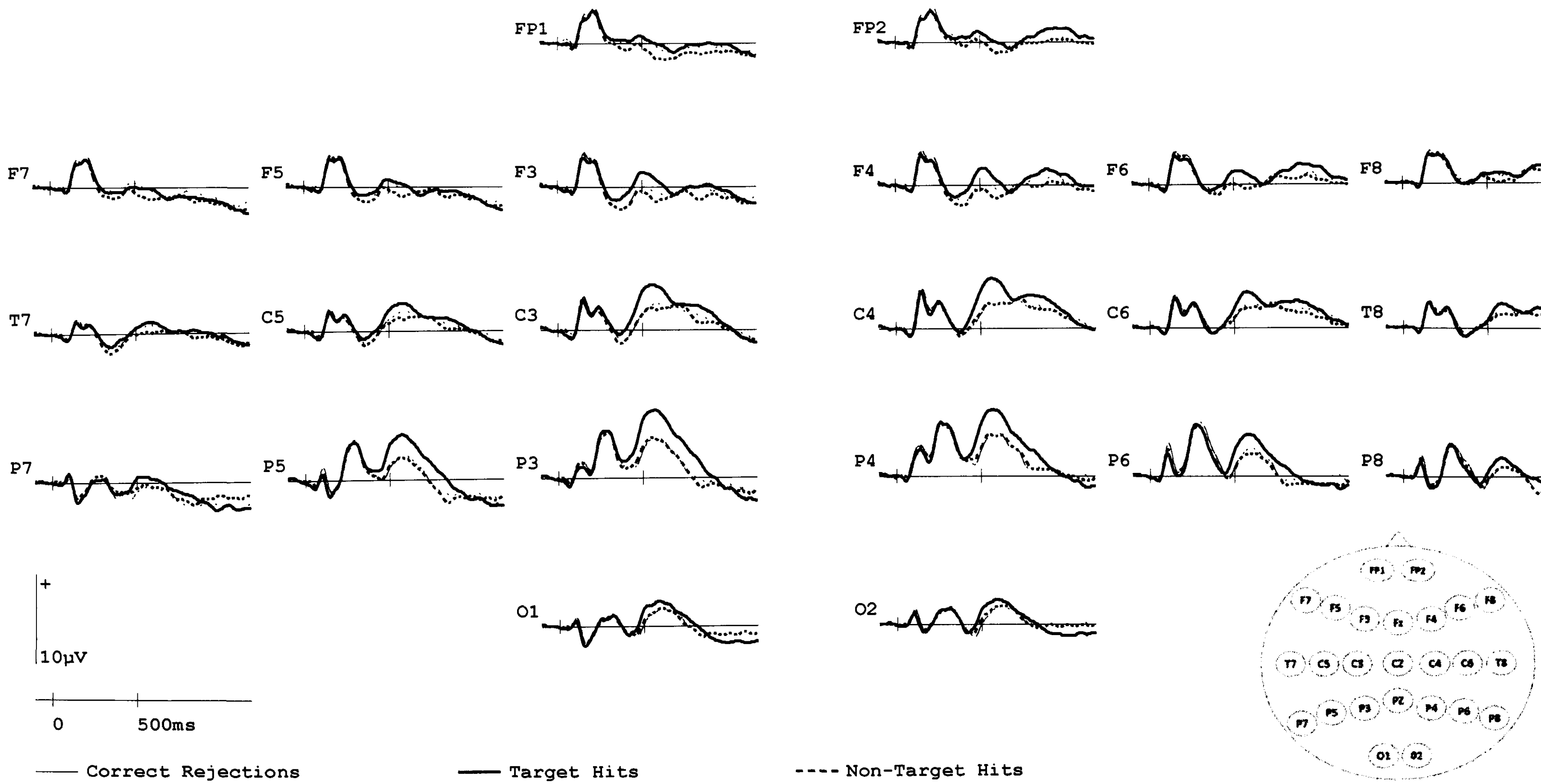


Figure 16: Waveforms across 22 sample electrode sites for 12 participants with lowest WMC collapsed across lag.

Data are shown for 22 sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, F4, F6, F8), central (C5, C3, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, P4, P6, P8), and occipital (O1, O2) scalp sites.

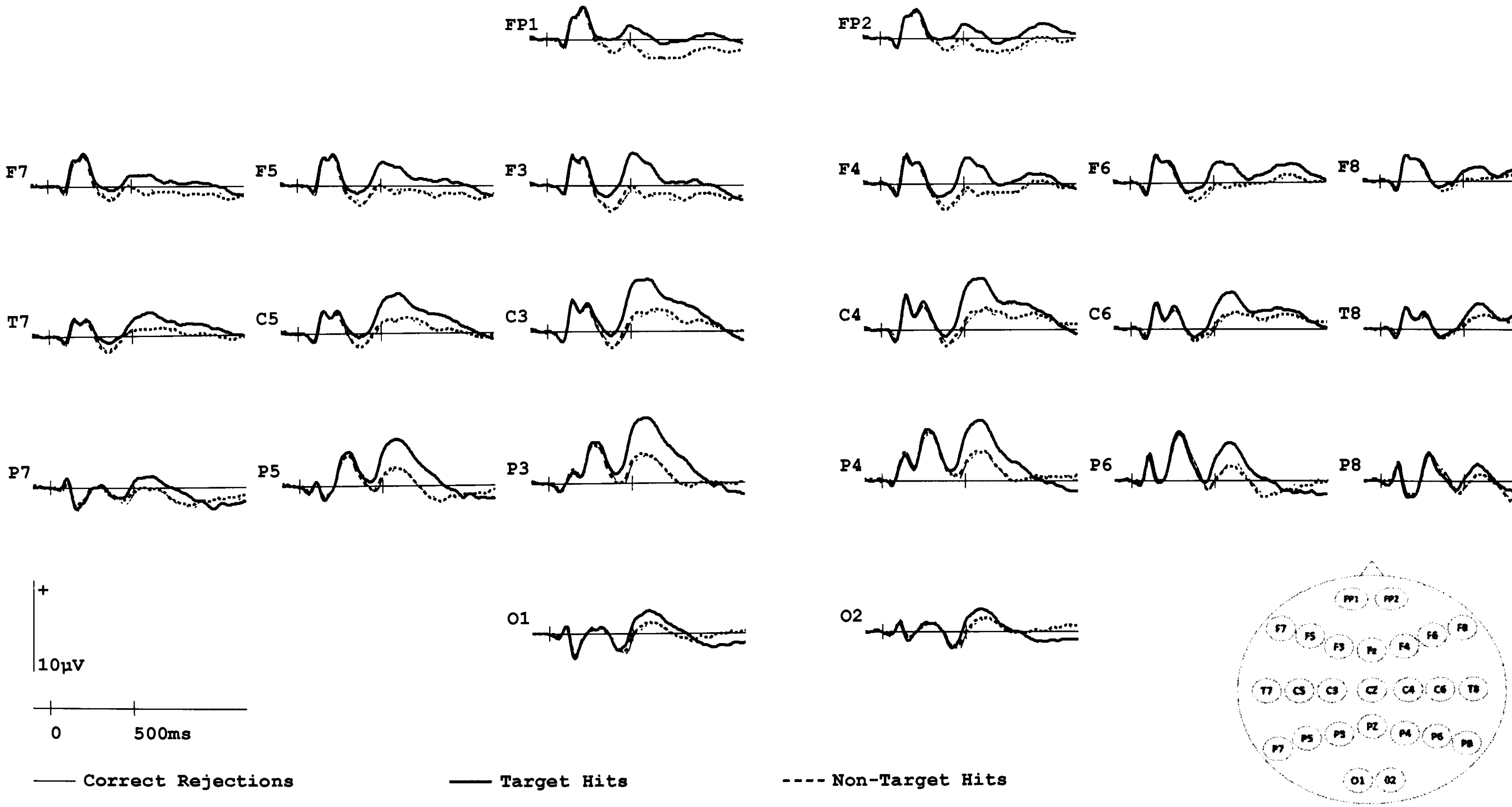


Figure 17: Waveforms across 22 sample electrode sites for 18 participants in the long lag group

Data are shown for 22 sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, F4, F6, F8), central (C5, C3, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, P4, P6, P8), and occipital (O1, O2) scalp sites.

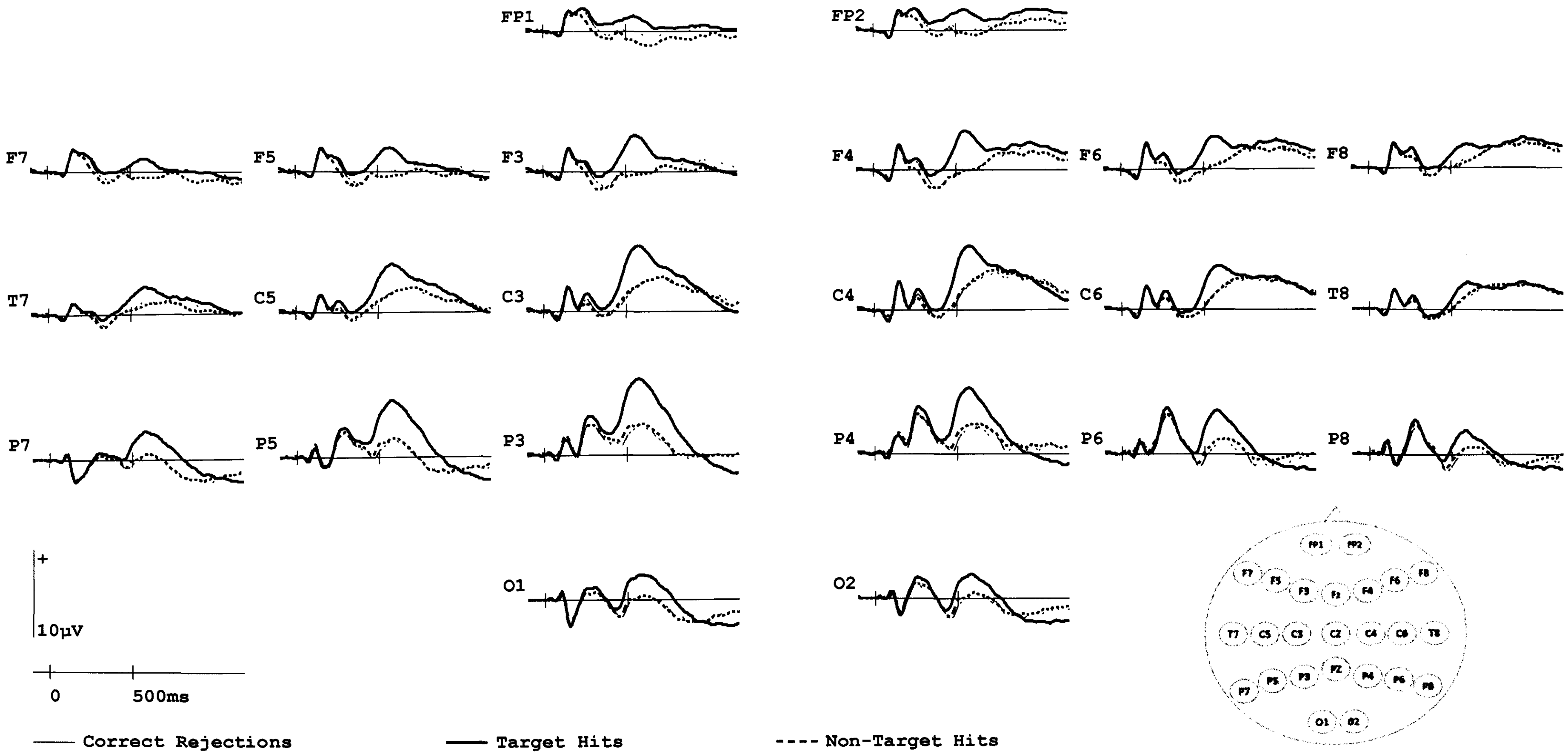


Figure 18: Waveforms across 22 sample electrode sites for 18 participants in the short lag group.

Data are shown for 22 sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, F4, F6, F8), central (C5, C3, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, P4, P6, P8), and occipital (O1, O2) scalp sites.

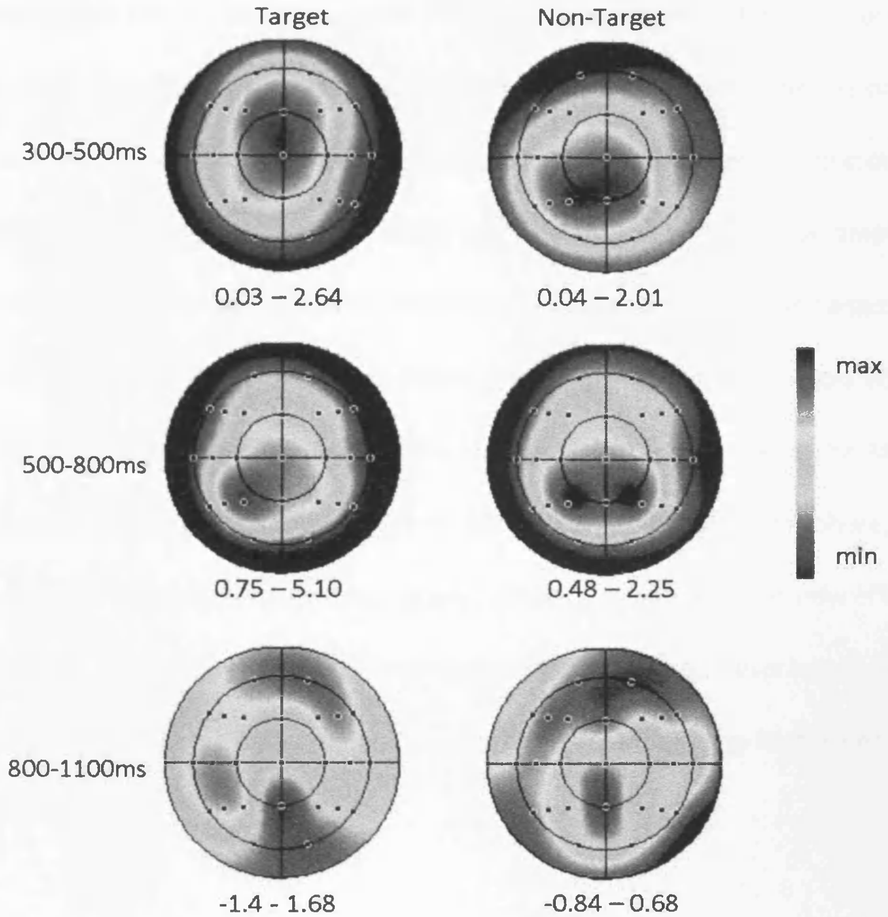


Figure 19: Topographic maps showing the scalp distributions of the old/new effects for each class of old item that attracted a correct judgment collapsed across lag.

Voltage maps are computed on the basis of difference scores obtained by subtracting mean amplitudes for the event-related potentials elicited by new words from each type of old word. Each map is proportionately scaled between the maxima (red) and minima (blue) of the depicted effect and the maximum and minimum values are shown below each map and can be interpreted relative to the colour bar on the right-hand side of the Figure.

5.3.3. The Left-Parietal Old/New Effect: ANOVA

In keeping with the procedure adopted in the previous experiment in this thesis, the initial analyses are focused on the element of the electrical record – the left-parietal ERP old/new effect – that has been used to make inferences about the control of recollection in the exclusion task. An initial ANOVA is conducted on mean amplitudes including data from all participants with factors of stimulus (target: non-target: new), hemisphere (left: right) and lag group (short: long). This is conducted across scalp sites P3, P5 & P7 (left hemisphere) and P4, P6, & P8 (right hemisphere). The ANOVA revealed a significant interaction between response category and hemisphere, $F(2, 68) = 5.7$, $p < 0.05$, indicating that the largest differences between old/new effects are left-lateralised. There is no such interaction with lag group (mirroring the pattern in the behavioural data) and so data are collapsed across lag group for further analyses.

Six Bonferroni corrected t-tests (revised significance level = 0.008) were conducted and demonstrate that at left-parietal scalp sites (data averaged across P3, P5 & P7) amplitudes to targets are reliably greater than non-targets, $t(35) = 3.9$, $p < 0.001$, and new items, $t(35) = 6.3$, $p < 0.001$. There is also a reliable old/new effect for non-targets, $t(35) = 5.4$, $p < 0.001$. On the right hemisphere, the pattern is similar; there are reliable old/new effects for targets $t(35) = 4.4$, $p < 0.001$, and non-targets $t(35) = 4.5$, $p < 0.001$ but in this case target old/new effects are not greater than the non-target old/new effects $t(35) = 1.9$, $p = 0.07$. This outcome is consistent with the presence of the hemisphere interaction term described above.

5.3.5. Left-Parietal Old/New Effect: Regression

The regression analyses are restricted to left-parietal scalp site P3 where the old/new effect is largest (see Figure 20). The left-parietal old/new effect associated with targets (obtained by subtracting mean amplitudes to correctly identified targets from mean amplitudes for correctly identified new items) was entered into a linear regression with target accuracy and O-Span score as predictors. The model accounts for a significant proportion of the variance, $R^2 = 0.2$, $F(2, 33) = 4.2$, $p < 0.05$. There is a significant positive relationship between the size of the left-parietal old/new effect to targets and WMC, $\beta = 0.44$, $t = 2.9$, $p < 0.01$. There is no evidence for such a relationship with target accuracy $\beta = 0.06$, $t = 0.4$. The same analysis strategy is applied to investigate the magnitude of the non-target old/new effect, and in this case the model does not account for a significant proportion of the variance, $R^2 = 0.4$, $F(2, 33) = 2.3$, although there is evidence of a trend towards a negative relationship between target accuracy and the magnitude of the effect, suggesting that as target accuracy improves, amplitudes associated with non-targets are smaller, $\beta = 0.3$, $t = 1.9$, $p = 0.067$.

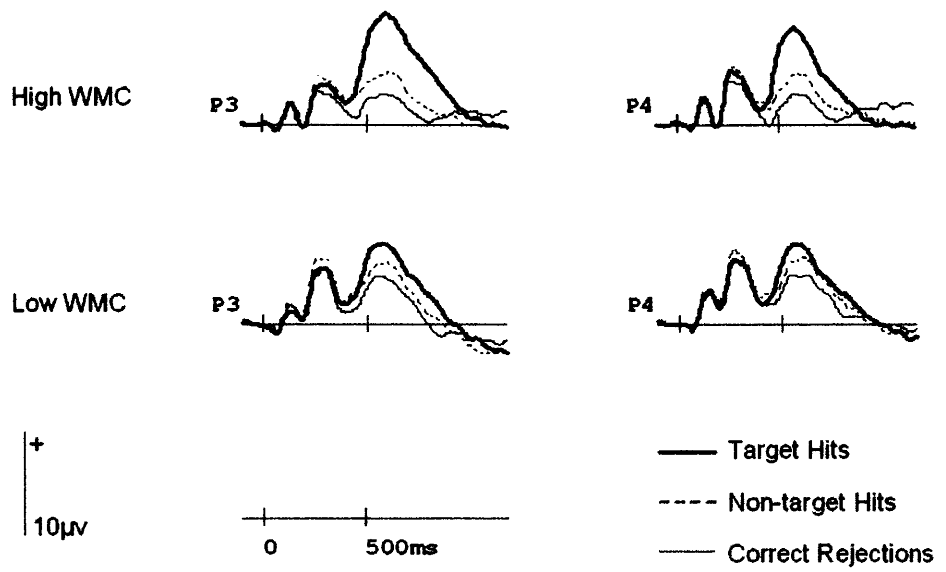


Figure 20: Electrophysiological data accross left (P3) and right (P4) parietal scalp sites compared according to stimulus type Target, Non-Target (repeated test item collapsed across lag) and Correct Rejections.

In further analysis, the left-parietal old/new effects for non-targets are subtracted from those for targets and this difference score is entered into a regression, with target accuracy and O-Span as predictor variables. This model is significant, $R^2 = 0.17$, $F(2, 33) = 3.4$, $p < 0.05$. The difference between amplitudes to targets and non-targets is progressively greater as working memory scores increase, $\beta = 0.4$, $t = 2.6$, $p < 0.05$, see Figure 21. There is no evidence for such a relationship with target accuracy $\beta = -0.07$, $t = -0.4$.

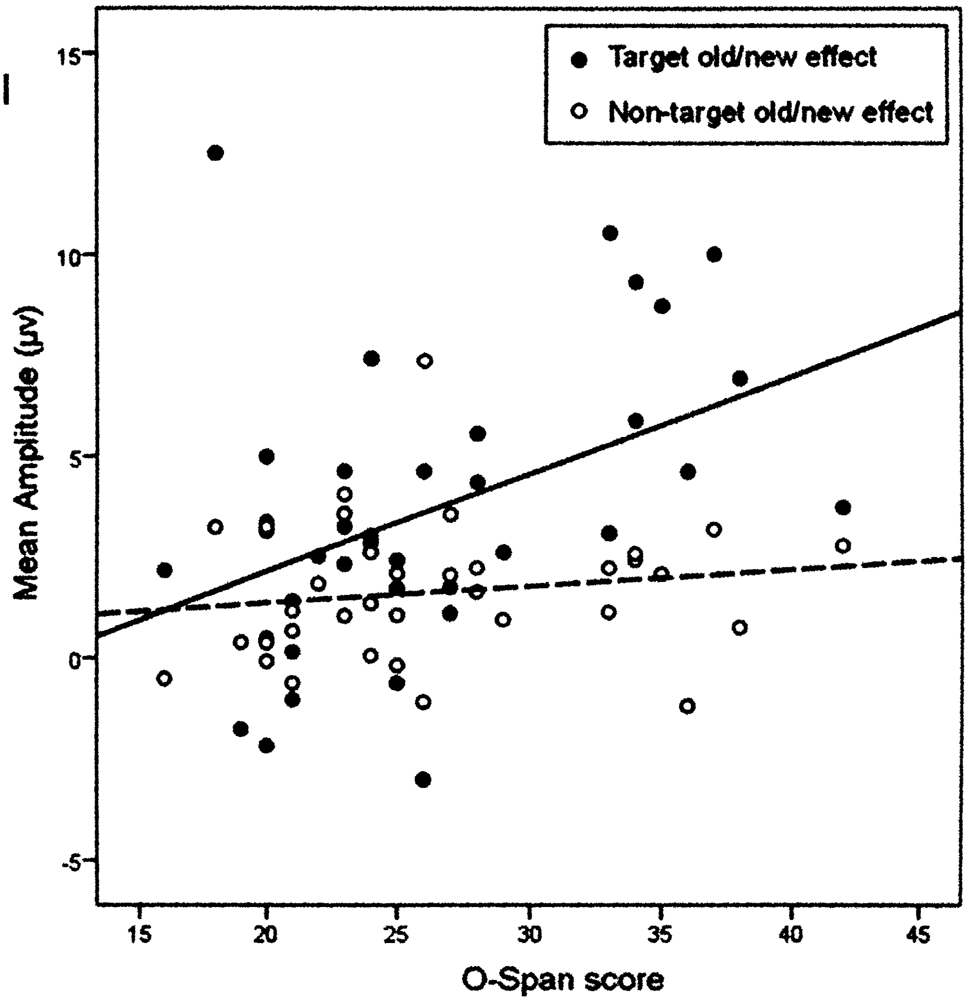


Figure 21: The relationship between WMC capacity as measured by O-Span and the magnitude of the left-parietal old/new effects associated with targets (filled circles) and non-targets (unfilled circles), data acquired 500-800ms post stimulus at scalp site P5.

5.3.6. Subsidiary ERP analyses: Mid-Frontal Old/New Effect

Data from two mid-frontal scalp sites (F3 & F4) are averaged and entered into an ANOVA with factors of stimulus type (target: non-target: new) and lag group (long: short), this reveals a main effect of stimulus type only, $F(2, 68) = 21.9$, $p < 0.001$. Follow-up t-tests revealed that mean amplitudes associated with targets are reliably larger than those for correct rejections, $t(35) = 5.9$, $p < 0.001$, as are non-targets, $t(35) = 3.5$, $p < 0.001$. The old/new effects associated with targets are reliably larger than those associated with non-targets, $t(35) = 3.7$, $p < 0.01$.

The mid-frontal old/new effect associated with targets and non-targets were subject to the same regression analyses as were the parietal old/new effects. In the first of these analyses, the mid-frontal old/new effects were entered as the dependent variable and target accuracy and O-Span scores are entered as predictor variables. The regression is not significant, $R^2 = 0.4$, $F(2, 33) = 2.1$, however, there is evidence of a trend for O-span score to predict the mid-frontal old/new effect, $\beta = -0.3$, $t = 1.9$. This relationship is presented in Figure 22. The same analysis strategy was applied to the mid-frontal old/new effect associated with non-targets, and again no significant trends are revealed, $R^2 = 0.1$, $F(2, 33) = 1.8$. Finally, using the same strategy, there is no evidence for a relationship between the difference between the target old/new effects and the non-target old/new effects and the behavioural data, $R^2 = 0.2$, $F(2, 33) = 0.8$.

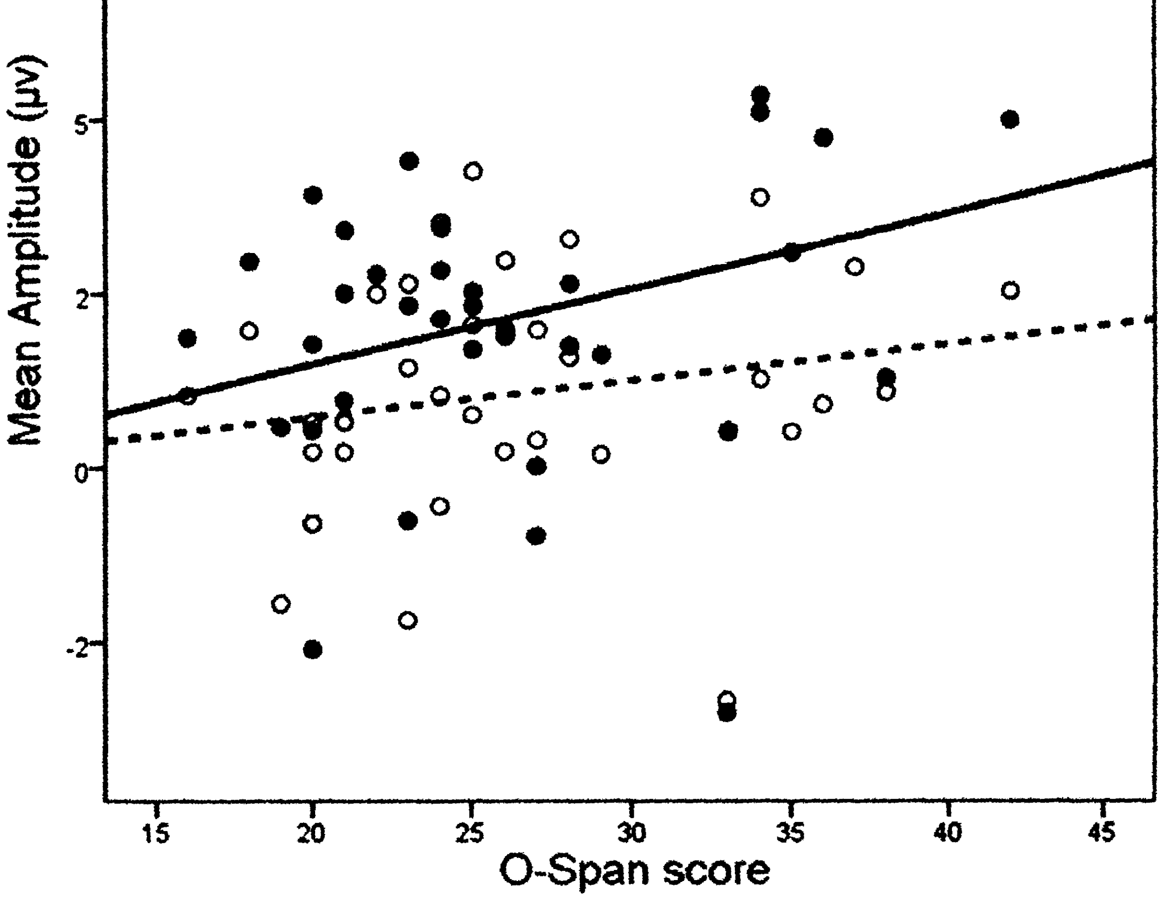


Figure 22: The relationship between magnitude of the mid-frontal old/new effect associated with targets (filled circles) and non-targets (unfilled circles) and O-span score.

5.3.7. Subsidiary ERP analyses: Late Right-Frontal Effect

Data from the 800-1100ms epoch at scalp sites F7, F5, F3, F4, F6 & F8 were subject to a mixed models ANOVA with factors of hemisphere (left: right), stimulus (target: non-target: new) and group (long: short). This revealed a main effect of stimulus, $F(2, 68) = 3.2$, $p < 0.05$. Collapsed across hemisphere and group, paired comparisons reveal reliable old/new effects for targets, $t(35) = 2.3$, $p < 0.05$, and for non-targets, $t(35) = 1.93$, $p < 0.05$. The magnitude of the effect for targets is not reliably greater than the effect for non-targets, $t(35) = 0.89$.

A regression analysis was conducted to investigate whether WMC or target accuracy predicts the size of the late right-frontal effect. The regression was not significant for targets $R^2 = 0.01$, $F(2, 35) < 1$, or for non-targets $R^2 = 0.004$, $F(2, 35) < 1$. Furthermore, neither target accuracy nor working memory scores predict differences between amplitudes to targets and non-targets, $R^2 = 0.001$, $F(2, 35) < 1$. See Figure 23.

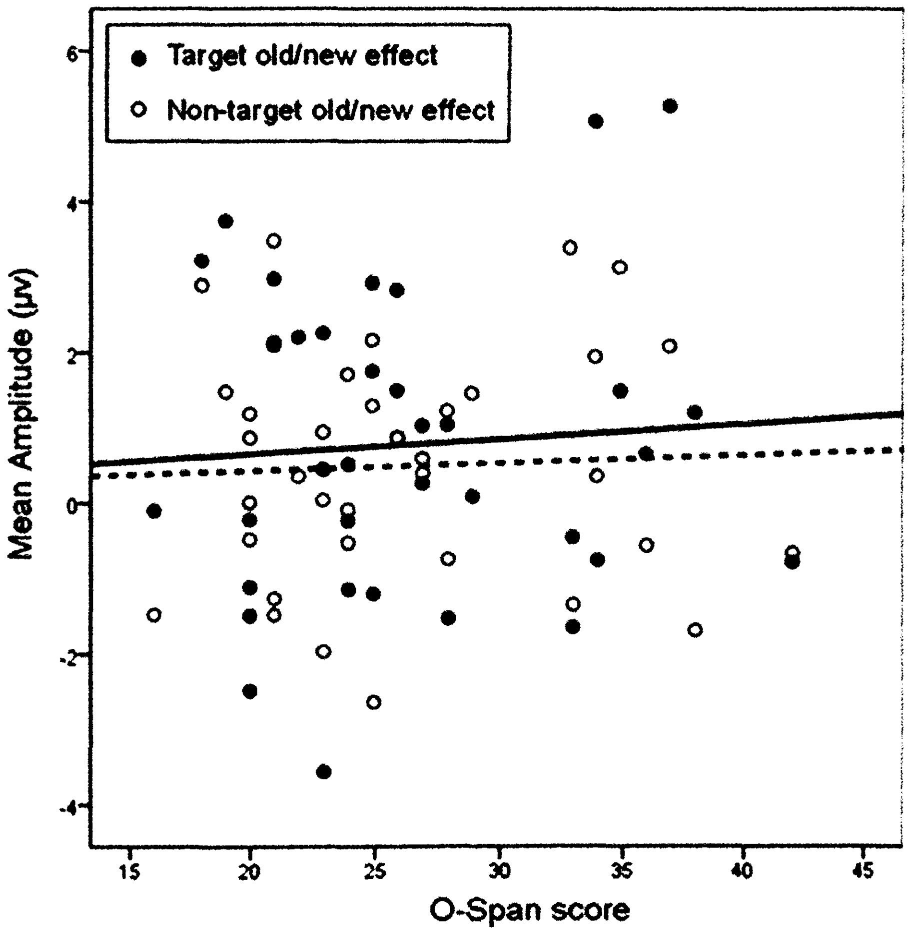


Figure 23: The relationship between the magnitude of the late right-frontal old/new effects associated with targets (filled circles) and non-targets (unfilled circles) and O-Span score.

5.4. Discussion

The principal finding is that working memory predicts a difference between the left-parietal old/new effects for targets and non-targets in the exclusion task. This is consistent with the resource model of inhibition, if it is the case that those with sufficient WMC resources strategically avoid processing non-targets but those with lower WMC resources do not, or at least do not do so to the same degree. In previous work where there have been reliable differences between the left-parietal effects elicited by targets and non-targets this has been interpreted as evidence of strategic recollection, accomplished either by selectively directing processing resources towards the targets or by actively inhibiting recollection of the non-targets (Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding et al. 2005). The pattern of data obtained here is markedly similar to that in other experiments where strategic recollection has been inferred from of ERP data alone. The data in this experiment lends support to this inference, as there is a sound theoretical basis for assuming that working memory should predict the effectiveness of the engagement of cognitive control, of which evidence for strategic recollection is one kind. WMC has been linked to the effective engagement of control strategies in (non-memory) cognitive tasks (for review see Redick et al. 2007) and effective search through long-term memory in clinical populations (Dalgleish et al. 2007).

Larger parietal old/new effects for targets than non-targets have been reported in several papers (Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Dywan et al. 2002; Dywan et al. 1998; Dzulkifli et al. 2006; Dzulkifli & Wilding, 2005; Fraser et al. 2007; Herron & Rugg, 2003; Herron & Wilding, 2005), with the preferred interpretation being that the different sizes of the effects are a consequence of a strategy of relying on recollection of information about targets to a greater degree than information about non-targets. Support for this argument has been adduced from the fact that the degree to which target effects exceed non-target effects increases as the likelihood of recollecting information about targets increases (Wilding & Herron, 2005). In this experiment, by contrast, WMC predicts the size of the differences between the target and non-target ERP old/new effects, but the accuracy of responses to targets do not. This finding suggests, therefore, that the adoption of a selective retrieval strategy is not a consequence of the likelihood of recollection of target information. Rather, it is a strategy adopted – at least in exclusion tasks - when the resources necessary to implement it are available. The possibility that inhibition is the mechanism responsible for the attenuation of non-target left-parietal ERP old/new effects relative to target effects in exclusion tasks has been considered elsewhere (Dzulkifli et al. 2006; Dzulkifli & Wilding, 2005; Herron & Rugg, 2003), but the association with WMC described here is arguably the strongest evidence to date that can be considered consistent with this account in accordance with the Resource Model of Inhibition (Conway and Engle, 1994).

The working memory account accommodates the documented links between the accuracy of target responses and the degree to which non-targets are attenuated relative to targets, if it is assumed that (i) task difficulty increases as response accuracy decreases, and (ii) difficult tasks place greater demands on the resources necessary for exerting cognitive control (see Introduction). It can also accommodate the finding that, when young adults are asked to complete a second task alongside an exclusion task, amplitudes of parietal old/new effects are more similar for targets and non-targets than when there is no dual-task requirement (Dywan et al. 1998). It seems likely that the addition of a second cognitive task would impact negatively on working memory resources, thereby making control over recollection more difficult. In keeping with this account, older adults showed little evidence for control over recollection in the same exclusion task even when there was no dual-task requirement at retrieval (Dywan et al. 2002; Dywan et al. 1998). WMC decreases with advancing age (Park et al. 1996; Salthouse & Babcock, 1991), and some older adults may lack the resources necessary for successful engagement of some classes of controlled retrieval processes. The absence of a direct measure of WMC in the studies of Dywan et al. means, of course, that these observations can be made only tentatively, and the interpretation of their findings remains ambiguous in light of the fact that response accuracy decreased with age, and was also lower in the 'dual' than the 'single' task condition.

Importantly, the size of the left-parietal old/new effect also increased with working memory scores, which may imply that inhibition did not occur at all, but rather the size of the target old/new effects is increased in high (relative to low) working memory participants as they selectively direct resources towards the targets. Working memory resources have not been directly compared to the size of the left-parietal old/new effect before, but in experiments where WMC can be inferred, the pattern of data here fits the literature. Older adults (who at the group level have lower WMC) (Park et al. 1996; Salthouse & Babcock, 1991) tend to show smaller parietal old/new effects than younger adults in the exclusion paradigm (Dywan et al. 2002; Dywan et al. 1998) and when younger adults are given an additional cognitive load at the time of testing, the electrophysiological data resembles those of older adults (Dywan et al. 2002, Experiment 2).

In addition, the size of the left-parietal old/new effect is associated with the maintenance of the products of recollection in an active state (see Introduction and also Vilberg & Rugg, 2008, 2009a; Wilding, 2000; Wilding & Rugg, 1996, 1997), and as such it is likely that those with high WMC are able to hold more information online at any one time. In accordance with this account, it is reasonable to assume that the effects associated with targets are an appropriate baseline against which it is possible to compare those for non-targets. Nonetheless, in future work it will be important to find additional means of assessing the notion that an active inhibition process is taking place, and that this is particularly evident for individuals with high WMC.

According to a competing explanation, however, the correlation reported in this experiment is a reflection of the relationship between WMC and the efficient deployment of memory encoding operations in the episodic buffer (Baddeley, 2000). In keeping with this notion, Oberauer, (2005; Oberauer & Lange, 2009) suggested that people with high WMC are more efficient than participants with low WMC at binding context to content when information is encoded. As a consequence, high WMC individuals may be able to recover more information about these items at test. EEG was not recorded at encoding in this experiment, so there is no electrophysiological data available that speak directly to the issue of whether encoding operations differed according to WMC.

One source of evidence that is connected to this encoding buffer account is the fact that the magnitudes of the left-parietal ERP old/new effects for non-targets attracting correct judgments are uncorrelated with WMC. This outcome indicates that an appeal to encoding efficiency to explain the correlation between target old/new effect amplitudes and WMC scores must include the context in which targets and non-targets are encoded: one would need to argue that (i) the context in which targets are encountered at study enabled efficient encoding operations (as indexed by WMC) to be mobilised, and (ii) this is not the case for the context in which non-targets were encountered.

A second alternative account arises because (in this design) non-targets are first encountered as new (distracter) items in the test phase. Given that WMC is correlated with inhibition of distracter items in perceptual paradigms (Borella, Carretti, & Mammarella, 2006; Dempster & Corkill, 1999; Hedden & Park, 2001; Hogge et al. 2008; Ludwig, Borella, Tettamanti, & de Ribaupierre, 2010; Tomlinson, Huber, Rieth, & Davelaar, 2009; Yonelinas & Jacoby, 1994) it is possible that inhibition is not occurring for the recollection of non-target items, rather, high WMC participants are better able to avoid encoding of non-targets. As a result, it is possible that the processing given these words is comparable to that associated with a relatively shallow encoding task, which might limit the accessibility of these words when they are presented for a second time at test. There is no means of assessing the availability of non-targets within this experiment, but in other very similar experiments there are reports of robust recollection effects for non-targets. Fraser et al. (2007) reported large (~7μV) parietal old/new effects for repeated test words when they were designated as targets and studied words were designated as non-targets in a task that was otherwise highly similar to the one described here. In addition, Bridson et al. (2006) found that repeated test words were associated with robust parietal effects (~5μV) when 'old' responses at test were to be made to both studied and repeated test words. Moreover, Yonelinas & Levy (2002) demonstrated that, at lags between presentation and re-presentation similar to those employed on this task, recollection made a marked contribution to test responses. In combination, these data points argue against the view that there is little evidence for strategic recollection in the ERP data reported here. A stronger within-experiment demonstration, however, would stem from a replication of these findings under conditions where the categories of items associated with the target/non-target designation are varied across participants, or across study-test runs for the same participants. In both of these designs, an estimate of the memorability of items when encountered as non-targets would be available.

In conclusion, the data presented here imply that working memory predicts the use of a controlled recollection strategy in the exclusion paradigm in accordance with a resource model of inhibition, but alternative explanations still remain to be ruled out. A full description of these alternatives, as well as changes made to experiment parameters in light of them, is provided at the start of the next chapter.

CHAPTER 6: WORKING MEMORY & THE INHIBITION OF RECOLLECTION

6.1. Introduction

In Experiment 3, the availability of working memory resources is manipulated with a view to establishing a causal relationship between WMC and the cognitive control of recollection. This is accomplished by having half of the participants complete a resource demanding task prior to the exclusion task, this manipulation is based on previous demonstrations that control resources are limited and can be fatigued (Hagger, Wood, Stiff & Chatzisarantis, 2010). The prediction is that, when working memory resources are compromised, there will be less evidence of the exertion of cognitive control, suggesting that i) cognitive control operations are employed to avoid the recollection of items under some circumstances even in the absence of any instruction to engage in intentional forgetting, and ii) the availability of working memory resources is an important indicator of when cognitive control operations will be employed.

The findings in the previous experiment demonstrate a link between WMC and the magnitude of an ERP index of recollection. One possibility that has been discussed is that this link arises because the inhibition of some kinds of memory contents is possible when the necessary working memory resources are available. The discussion in the previous chapter identified points for consideration that have important implications for this interpretation of the data, particularly to do with an increased ability for high WMC individuals to avoid encoding non-target items in the lag exclusion task. Alternatively, if strategic recollection was taking place, this could have occurred in one of two ways: First, in accordance with the 'Resource Model of Inhibition" working memory resources enable inhibition of the recollection of non-target items; Second, working memory resources enable strong context-content bindings at study which in turn enable the recovery of target items to be prioritised at test. The experiment described in this chapter contains several revisions that permit the merits of these to be addressed and these revisions will now be discussed in turn.

6.1.1. Differential Encoding

The major revision to this experiment in comparison to the previous one is that items designated as targets and non-targets at test will now both be presented at study but in two different contexts (see Introduction), after encoding one of these content will be designated the target context and the other will be designated the non-target context. This design permits an assessment of how well study items were encoded (by varying target/non-target designation at test). In the two previous experiments, only targets were presented at study. Non-targets were repeated test items, and in this version of the exclusion task, it is difficult to assess the memorability of non-targets. In addition, because participants knew the target/non-target designation before completing the study phases, one explanation for the pattern of changes with WMC is that participants with high WMC prioritized encoding of targets over non-targets more so than did participants with lower WMC. Alternatively, it may be that WMC influences primarily encoding that is intentional, and that intentional encoding was applied more so to study words than to first presentations of test words that were then repeated. This is a reasonable assumption since it can be argued that the competing demands of making memory judgments in the test phase reduced the likelihood that participants adopted intentional encoding strategies.

Despite these considerations, as discussed in the previous chapter, there are good reasons to assume that non-targets are relatively well encoded in the lag version of the exclusion task. In previous work using the same design, the left-parietal old/new effect for targets and non-targets was equivalent for young adults under some circumstances (Bridger, Herron, Elward, & Wilding, 2009; Bridson et al. 2006; Fraser et al. 2007). These findings suggest that the repeated test items are not only memorable but also are likely to give rise to recollection. In addition, the short lag between presentation and re-presentation suggests that memory for these items should be reasonable, given the accuracy of memory judgments in other tasks where similar intervals have been employed between presentation and re-presentation (in particular, see Yonelinas & Levy, 2002).

Nonetheless, this revised design will permit an assessment of non-target as well as target memorability, and also allow an assessment of a differential encoding account. To accomplish this, targets and non-targets are presented together at study, and are distinguished by two different encoding tasks. Herron & Rugg (2003) were the first to posit that differences in targets and non-targets may be due to strategic recollection (see Introduction), in their design targets and non-targets were both presented in one test phase but in two different encoding tasks, after study, items that were originally presented in one such encoding task were designated targets and items in the other encoding task were designated non-targets. Unlike the previous work investigating strategic memory in the exclusion task (Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding, Fraser & Herron, 2005), this experiment is not designed in order create a difference in behavioral accuracy across groups and so, using this design, it is possible to completely counterbalance the encoding context associated with targets and non-target items. Critically, participants are only informed which class of items are targets after study. This means that participants are unlikely to prioritise systematically the encoding of one class of items, and any differences between the left-parietal ERP old/new effects at retrieval should not reflect processing differences that might occur at the time of encoding (for an extended discussion of this point see Wilding et al. 2005).

6.1.2. Inhibition of Non-Targets vs. Prioritisation of Targets

A second challenge to an inhibition-based interpretation of the previous dataset is that there are at least two possible ways that strategic retrieval processing can take place. In accordance with the Resource Model of Inhibition (Conway & Engle, 1994), one assumption is that increased working memory resources facilitate the inhibition of non-target items. It is, however, also possible that the higher working memory participants are more able to strategically direct resources towards target items in long-term memory, facilitating the recollection of these items. One way that this might be achieved is if people with high working memory capacity have an increased ability to bind context and content information at study. Baddeley (2000) suggested that the episodic buffer, a component of working memory, plays a crucial role in binding at study, and there is evidence that working memory facilitates context and content binding in older and younger adults (Oberauer, 2005; Oberauer & Lange, 2009). When these bindings are robust, it may be possible to direct resources to one whole class of items that are bound to the same encoding context, which might then facilitate the recollection of these items over others not bound as well to the target context.

The findings in Experiment 2 can be explained in this way. First, the amplitudes of the left-parietal ERP old/new effects for targets correlate positively with WMC, and this might be taken as evidence that the resources devoted to target items are predicted by WMC. Second, if non-targets are being inhibited by high WMC participants, this would predict a negative correlation between WMC and the magnitude of non-target left-parietal ERP old/new effects. This was not observed. There are also, however, good reasons to expect the magnitude of target left-parietal old/new effects to vary in accordance with WMC that are unrelated to strategic retrieval processing. The most commonly accepted functional interpretation of the left-parietal old/new effect is that it represents the active maintenance of recollected information in working memory (Han, Huettel, Raposo, Adcock, & Dobbins, 2010; Vilberg & Rugg, 2009a, 2009b; Wilding, 2000). Furthermore, there is some evidence that older adults typically show much smaller left-parietal old/new effects to target items than younger adults (Dywan et al. 2002; Dywan et al. 1998). This implies that WMC may be an important determinant of the amplitudes of this effect in so far as WMC decreases with increasing age (Park et al. 1996; 2002). As such, those with greater WMC resources might be expected to show larger left-parietal effects than those with fewer WMC resources. As a consequence of this, one way to interpret the magnitude of target old/new effects is that they act as an appropriate baseline against which, for each participant, the relative size of non-target old/new effects can be considered.

In combination, these considerations emphasise that it is difficult to distinguish between inhibition-based and various forms of non-inhibition-based accounts of the data presented in this thesis to this point. One way in which it might be possible to accomplish this, however, is to introduce a memory post-test following completion of an exclusion task. This rationale is based on the independent-probe method devised by Anderson & Green (2001). They reason that if inhibition processing has taken place during a memory retrieval task, then inhibited items should be more difficult to access subsequently than baseline items, even when an independent cue is given memory test (See also Anderson & Green, 2001; Bauml, 2008; Bauml, Pastotter, & Hanslmayr, 2010; Bulevich et al. 2006; for extended discussion of the independent-probe method). For example, in the retrieval induced forgetting paradigm (see Chapter 1) the association Pets-Dog may be trained more times than the association Pets-Cat. Practice facilitates recall of the practiced item at the expense of recall of the unpractised item in that category (Pets-Cat). These items are also less available for subsequent recall than unpractised items in a category where no associations were practised. There is, however, more than one mechanism by which post-test performance can be affected (See Figure 24). (Bauml, 2008) describes that if inhibition/suppression has occurred the inhibited item is deactivated relative to baseline and this deficit will occur regardless of how the item is accessed but his is not the case for mechanisms (a)-(c) in Figure 24).

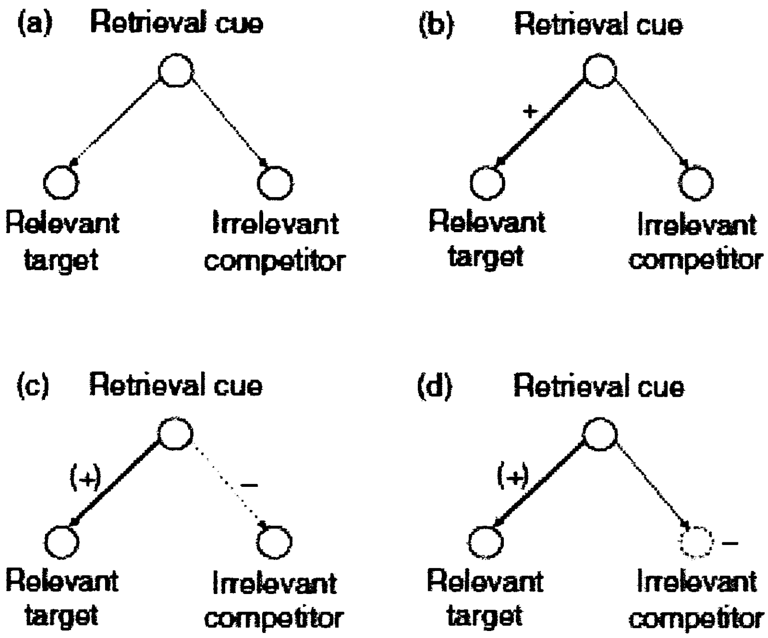


Figure 24: Adapted from Bauml (2008): four methods by which performance may be affected in a post-test.

a) Retrieval Competition, b) Blocking, c) Route Deactivation and d) suppression/inhibition. In the first three examples access to the competitor is only restricted when the original cue is used. When inhibition or suppression takes place the relevant memory trace of the irrelevant competitor is compromised so that it will be less accessible to any retrieval cue.

In order to make a stronger assessment of the role of inhibition in the control of recollection, a free recall post-test was added to this experiment. At the end of the exclusion task all participants were asked to write down any words that they remembered from any part of the exclusion task. They were given five minutes. If inhibition has occurred, then the high working memory participants should recover fewer non-targets than those with lower WMC. This is particularly interesting as working memory is often correlated with improved performance, but in this case the prediction is that the highest functioning young adults will show a selective deficit in the recovery of non-targets.

6.1.3. Establishing a Causal Relationship between Cognitive Resources and Cognitive Inhibition

Although the data in Experiment 2 demonstrate that WMC predicts the magnitude of the differences between left-parietal ERP old/new effects elicited by targets and non-targets, it is not possible to confidently conclude that WMC is causing this modulation. One way to address this issue is to manipulate directly the resources available for inhibition during the exclusion task. If these resources are necessary for the selective recollection of target items, this manipulation should compromise that selective processing.

This approach has not been taken with ERP studies of the exclusion task to date, but there is some evidence that compromising working memory resources has reduced the magnitude of the left-parietal old/new effects associated with both targets and non-targets, hence any evidence of the inhibition of non-targets. Dywan (2002) showed that when participants complete a second task concurrently with the retrieval phase of an exclusion task, the parietal old/new effect associated with targets was markedly smaller and the evidence of selective recollection was no longer present (see extended description in Introduction). If this dual-task requirement reduces resource availability at test, then these findings suggest a causal link between WMC and the control of recollection, although as noted earlier, these data also fit a 'target accuracy' account of the attenuation of non-target parietal old/new effects relative to targets, as the dual-task manipulation also reduced response accuracy.

A different approach to manipulating resource availability was taken here, in this experiment we employed a 'resource depletion' manipulation that has been employed in social psychology studies. This literature demonstrates that acts of self-control consume a 'limited resource' that can be come exhausted. When control has been exerted for some time, subsequent attempts at self-control are compromised (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Baumeister, Muraven, & Tice, 2000; Muraven & Baumeister, 2000; Muraven, Tice, & Baumeister, 1998; Neshat-Doost, 2008; for a meta-analysis of 83 studies see Hagger, Wood, Stiff, & Chatzisarantis, 2010). Importantly, the same fatigue is not demonstrated after performing a demanding and complex task that does not have a control element (such as algebra) for the same amount of time (Muraven et al. 1998, Experiment 3). Using this paradigm, it is possible to manipulate the control resources available to participants before they begin the exclusion task.

In the study by Muraven et al. (1998), participants were erroneously informed that the experiment was designed to investigate the ability to hide emotions. Participants were divided into two conditions. The self-regulation depletion group were asked to write down their thoughts on a piece of paper but to avoid thinking about a white bear for five minutes. This paradigm has been used extensively as a tool for investigating thought suppression and it is typically reported that avoiding thoughts about a white bear is an effortful process; there are often intrusions during the suppression phase and in post-suppression tests there is a rebound effect where white bear thoughts are more prevalent than before suppression (Wegner, Schneider, & White, 1987; for review see Wenzlaff & Wegner, 2000). The second group of participants were asked to complete mathematical equations for five minutes. They were asked to multiply a three digit number by another three digit number. The authors reasoned that this task would be suitably exerting, but would require no self-regulation. Following this, all participants watched a humorous video consisting of skits taken from Saturday Night Live and Robin Williams stand-up comedy. In this phase of the experiment, participants were instructed to avoid showing any amusement while watching the video and their facial expressions were monitored for subsequent encoding (raters were blind to the experimental manipulation and participants were asked to rate their level of arousal and mood before the videotape. There were no differences between these groups). In line with the self-regulation depletion theory, participants who completed the white bear task, which is considered an effortful suppression task, were more likely to smile and laugh than participants in the mathematics condition. There have since been many replications of this effect with various experimental designs (Hagger et al. 2010).

One means of explaining these effects is to assume that the neural networks that support cognitive control are vulnerable to neural adaptation, just as, when cells in the visual system are exposed to a constant stimulus they are less readily perceived. In the case of the kind of tasks described above, the 'after-effect' is a subsequent reduction in the engagement or effectiveness of cognitive control processing. Using this model, Neshat-Doost & Dalgleish (2008) asked young participants with high WMC to complete a Stroop colour-naming task prior to completing an autobiographical memory (AM) test. They then compared the AM scores to those for young adults who had completed a control task, and young adults with naturally low individual WMC. Low WMC individuals generated more over-general responses on this task than those with high WMC who had completed the control task. However, those high WMC individuals who had first completed the Stroop colour naming task were indistinguishable from those with lower WMC. The Stroop task is assumed to require cognitive control, and these findings can be interpreted as evidence that reductions in the resources available for cognitive control via completion of a demanding task can influence subsequent memory judgments for which cognitive control is beneficial.

This is clearly a potentially informative technique for the issues raised in the foregoing discussions. To this end, a resource depletion manipulation was included in this experiment. Participants were split into high and low WMC groups and half of those with high WMC (the resource depletion group) completed a Stroop colour-naming task prior to the exclusion task. If high WMC participants who have completed a Stroop task prior to the exclusion task show a pattern of behavioural and ERP data comparable to that for low WMC participants (little or no evidence of controlled recollection), this would go some way to strengthening the link between the WMC measures and the ERP measures of retrieval control reported in Experiment 2.

6.1.4. Assessing overall PFC function

Another factor to consider with respect to accounts of the data collected so far is that WMC and the ability to engage in cognitive control are both thought to rely on the integrity of the prefrontal cortex (PFC) (Cohen et al. 1997; Desposito et al. 1995; Luria, 1966; MacDonald, Cohen, Stenger, & Carter, 2000; Majerus et al. 2010; Miller & Cohen, 2001; Smith & Jonides, 1999). Older adults show poorer cognitive control, and they also show lower WMC (Hasher & Zacks, 1988; Park et al. 2002; Park et al. 1996; Salthouse & Babcock, 1991) but both of these behavioural effects may be driven by the neural degeneration known to occur in the PFC with advanced age (Spencer & Raz, 1994; Swick, Senkfor, & Van Pettern, 2006). Similarly, it may be that in the experiments reported in this thesis WMC is acting as a proxy for general differences in PFC function. This possibility was also assessed in this experiment, because, in addition to measures of WMC, a battery of tests assumed to index the integrity and effectiveness of PFC was administered to each participant.

6.1.5. Summary and Aims

This experiment represents a considerable extension over the previous study, with a different exclusion task design, additional behavioural memory testing, administration of a neuropsychological battery, and a between groups manipulation intended to influence resource availability. There are three key predictions. First, participants with higher working memory capacity will engage in retrieval processing requiring cognitive control to a greater degree than will participants with lower WMC. Second, high WMC participants in the resource depletion group will produce data (both behavioural and electrophysiological) that will resemble that for lower WMC participants. Finally, if inhibition underlies strategic recollection in the exclusion task, then in a free-recall test administered immediately after the exclusion tasks, those participants who show evidence of high levels of cognitive control (as indexed by the ERP data) will show a selective impairment for the recall of non-targets, relative to those for whom there is less evidence of successful control over retrieval.

6.2. Method

6.2.1. Participants

These were 57 adults recruited through the Cardiff University Experiment Management System. Data from nine participants were rejected due to poor behavioural performance (4), excessive EOG artefact (3) and experimenter error (2). Participants were randomly divided into Resource Depletion and Control groups, and within these groups participants were median split into high and low WMC groups (23 male).

6.2.2. Procedure

OSPAN: In this experiment an automated version of the O-Span test was acquired from the Engle Lab (http://www.psychology.gatech.edu/renglelab/Tasks.htm). The paradigm was administered in E-Prime 2.0. As with traditional OSPAN (used in Experiment 2), participants first see the mathematics operation and after solving it, they see the letter to be recalled at a later time. The number of items presented before recall ranges from 3-7. There are 3 sets of each set-size. This makes for a total of 75 letters and 75 mathematical problems. During recall, mathematics accuracy is presented in the upper right-hand corner. Participants are instructed to keep it above 85%. The program reports OSPAN score at the conclusion of the experiment. OSPAN score is the sum of all perfectly recalled sets. So, for example, if an individual recalled correctly 2 letters in a set size of 2, 3 letters in a set size of 3, and 3 letters in a set size of 4, their OSPAN score would be 5 (2 + 3 + 0). The maximum score is 75.

Resource Depletion: The Resource Depletion group completed a Stroop colour naming task for 6 ½ minutes before completing the exclusion task. Participants were given five A4 cards with 160 colour names (RED, GREEN, BLUE & YELLOW each shown 40 times) printed on each in bold in one of four colours (red, green, blue and yellow). The words were arranged in five columns, and within each column each colour name was printed eight times, twice in each colour. Thus 75% of the words were 'incongruent', such that the verbal label did not match the font colour. The words were pseudo-randomly arranged, in that they were first randomised and then manually adjusted so that not more than four words in the same colour ink were presented consecutively. No two columns were identical. Participants were asked to name the colour of the ink that each word was printed in and to ignore the meaning of each word. They were asked to read as many words as possible in the allocated time and to prioritise accuracy over speed. Participants were made aware that at the end of the test the experimenter would record how many items were completed and also how many errors were made. In the Control group, task and stimulus materials were identical, except all the words were printed in black ink (Neshat-Doost, 2008).

6.2.3. Exclusion Task

Stimuli: 360 words were taken from the MRC psycholinguistic database. Of these, six groups of 60 words were selected at random for a full experiment list. Each experiment list comprised two study-test cycles. Each study phase comprised two word groups (120 words). These were repeated at test together with a third word group to give 180 test words per cycle. No words were repeated across cycles. Word groups were rotated fully across experiment lists, resulting in the formation of 6 complete lists.

Study: The researcher read aloud the exclusion task instructions and participants were also given written descriptions. In each study phase, there were two encoding tasks. In the function task, they were asked to think of a function for the object denoted by the word and make a binary easy/difficult response as to whether it was easy or difficult to think of an appropriate function for that object. In the drawing task, they were asked to consider how easy it would be to draw the object and to make the same binary easy/difficult response. Cues preceding each word signalled which task to complete; 'FUNCTION?' for the function task, 'DRAW?' for the drawing task. Cues remained on the screen for 1000ms, followed by a blank screen for

500ms. Order of encoding task cues was pseudo-randomised; no more than three consecutive words were preceded by the same cue. Each study word was presented for 300ms before the screen was blanked. Participants initiated the next trial by pressing a key on a response pad, and the trial started 2000ms after this response.

Target designation: Immediately following the study phase the experimenter re-entered the room and provided test instructions. Participants were instructed to respond using the index finger of one hand to words from one of the two encoding tasks (targets), and the index finger of the other hand to new test words as well as those from the other task (non-targets). Target designation (function/drawing) changed across study-test cycles. The experimenter asked the participant to read the instructions aloud and confirm that they understood the information. Half of the participants completed the function task designation first. There was a short break between each study-test cycle and between study and test phases.

Free Recall: Although participants were informed that they were taking part in a memory test they were not told about the post-test in advance. Immediately following the exclusion task (and before removal of the EEG cap) participants were given a piece of lines paper with the following instructions printed at the top "In the previous test you were presented with 360 words in total. In the next five minutes, please write down as many as you can remember. Include words from all study lists, including function and draw encoding tasks and new items".

6.2.4. Prefrontal Cortical Function Tests

These were completed after the EEG cap was removed, and after participants were invited to wash and dry their hair as well as take a short break. The following tests were then administered. A brief description of each task is provided here and more details are provided in the appendices.

1. Tower of Hanoi (ToH): The ToH task is a measure of planning ability that requires the formulation of appropriate goals, in accordance with a set of rules, to achieve an externally imposed objective. An automated version of the task was administered. In the practice phase, presented on the screen are three vertical pegs (towers) with three disks on the first peg. The largest disk is at the base of the peg and the smallest is at the top. Participants are instructed that their goal is to move the disks to the third peg and that there are two rules. First, a larger disk must not be placed on the top of a smaller one. Second, only one disk is allowed to move at a time. They are also informed that it is possible to achieve this objective using only 7 moves and are asked to attempt to make as few moves as possible to this end. The number of scores they have made is recorded at the top of the screen. After practice on this task participants are asked to complete a version with 4 disks (possible in 15 moves) and 5 disks (31 moves). A maximum score of 1 is recorded if participants are able to solve the problem in the minimum number of moves and the score is decreased towards 0 with every additional move.

2. Wisconsin Card Sorting Test: The Wisconsin Card sorting test is cited as the most frequently used measure of executive functioning and is regularly used by over 70% of neuropsychologists (Alverez & Emory, 2006). Participants completed an automated version of this task. 128 cards are presented sequentially and participants are instructed to match each card to one of four key-cards. Items could be matched on colour, form, or number. Participants were provided with feedback; when they coded cards correctly, the word "correct" was displayed on the screen, when they responded incorrectly the word "Incorrect" was displayed. The rule to which participants should code the cards was changed at random intervals during the experiment. The percentage of preservative errors (errors where participants incorrectly coded cards according to a previous rule) was recorded.

3. Abstract Reasoning Test: Reasoning depends on the ability to form and manipulate mental representations of relations between objects and events and reasoning abilities are linked to the functional integrity of prefrontal cortex (Kroger et al. 2002; Kyllonen & Chrystal, 1990; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Waltz et al. 1999). Participants were given 25 multiple choice abstract reasoning questions and ten minutes to complete the test. The questions were similar to those found on tests of generalised intelligence and include items such as "which is the odd one out?", "which completes the series" etc. Correct responses were summed to a maximum 25. An example of the Abstract Reasoning Test used is included in Appendix 2.

6.3. Results

Due to the increased complexity of the experimental design here relative to the previous experiment the continuous WMC data are dichotomised by a median split creating a high and low WMC group. Despite the problems associated with dichotomising continuous data (MacCallum, Zhang, Preacher, & Rucker, 2002; Preacher, MacCallum, Rucker, & Nicewander, 2005) the number of groups means that these data would be difficult to interpret with regression analyses. This dichotomisation creates a total of four groups each pertaining to different participants; High WMC Control, Low WMC Control, High WMC Resource Depleted, and Low WMC Resource Depleted.

6.3.1. Behavioural Data: Exclusion Task

The range of WMC scores in the high control group is 68-42, and in the low control group is 12 – 41. The range in the high WMC resource depleted group is also 68 – 42 and in the low resource depleted group it is 12 – 35. Further descriptive statistics and participant characteristics for these four groups are presented in Table 4. A 2x2 ANOVA on each of the subsidiary behavioural measures with factors of WMC and Resource Depletion reveals no reliable between-groups differences according to WMC or Resource Depletion on any of the subsidiary behavioural measures. The outcomes of these analyses are presented in Table 4.

Table 4: Participant characteristics across the Resource Depletion and WMC groups

[1]Stroop score indicates the number of colours named within 6.5mins. [2]Stroop Errors refers to the number of incorrectly identified colours in that time. [3]ToH4 and ToH5 refer to score on the Tower of Hanoi task for 4 and 5 discs respectively- 100% indicates that participants solved the problem in the minimum number of moves possible. [4]WCST refers to the percentage of preservative errors made on the Wisconsin Card Sorting Task, [5]Abstract Reasoning refers to the percentage of correct responses made in the abstract reasoning test. Standard deviations are presented in brackets

	Control Group		Resource Depletion		Main effect: WMC		Main effect: Resource		Interaction	
	High WMC mean (sd)	Low WMC mean (sd)	High WMC mean (sd)	Low WMC mean (sd)	F	p	F	p	F	p
N	12	12	12	12						
O-Span	53 (7.9)	28 (8.8)	52 (8.3)	27 (4.6)	129.7	<0.001	0.03	n.s.	0.99	n.s.
Stroop score[1]	530 (122)	461 (151)	464 (82)	497 (146)	0.23	n.s.	0.17	n.s.	1.88	n.s.
Stroop errors[2]	4.4 (2.4)	6.3 (3.8)	5.5 (3.0)	6.4 (7.7)	1.1	n.s.	0.18	n.s.	0.14	n.s.
ToH4[3]	81% (20%)	67% (20%)	66% (24%)	58% (26%)	2.5	n.s.	2.8	n.s.	0.2	n.s.
ToH5[3]	72% (28%)	64% (21%)	72% (29%)	68% (20%)	0.8	n.s.	0.5	n.s.	0.9	n.s.
WCST[4]	10% (5%)	9% (4%)	8% (3%)	9% (3%)	0.4	n.s.	0.9	n.s.	0.5	n.s.
Abstract Reasoning[5]	50% (19%)	51% (15%)	47% (15%)	49% (16%)	0.5	n.s.	0.2	n.s.	0.002	n.s.

Response accuracy and reaction times associated with each stimulus are presented in Table 5. For all discrimination measures described in previous chapters, participants performed at above chance level. A 2 x 2 x 2 mixed models ANOVA conducted on this discrimination data, with factors of stimulus category (target: non-target), WMC group (High:Low) and Depletion Group (Stroop:Control) reveal no reliable interaction terms and only a main effect of stimulus category $F(1,44) = 403$, $p < 0.001$, reflecting the fact that target/new discrimination was superior to target/non-target discrimination.

Similarly, a 3x2x2 ANOVA conducted on the reaction times associated with correct responses to each class of item, incorporating the WMC and Resource Depletion groups, reveals a main effect of stimulus category, $F(2, 88) = 130$, $p < 0.0001$. Follow up t-tests (collapsed across group) reveal that reaction times are reliably shorter to new items than to targets, $t(47) = 11.1$, $p < 0.001$ or to non-targets, $t(47)\ 13.7 = p < 0.001$. There is no difference in the reaction times to targets and non-targets $t(47) = 1.6$.

Table 5: Behavioural data associated with each class of old item separated according to WMC and Resource Depletion manipulation.

		Control		Resource Depleted	
		High WMC	**Low WMC**	**High WMC**	**Low WMC**
		mean (sd)	**mean (sd)**	**mean (sd)**	**mean (sd)**
N	**12**	**12**	**12**	**12**	**12**
Accuracy	Target	0.71 (0.13)	0.77 (0.08)	0.76 (0.08)	0.72 (0.17)
	Non-target	0.82 (0.14)	0.83 (0.10)	0.80 (0.11)	0.80 (0.09)
	New	0.97 (0.02)	0.96 (0.07)	0.93 (0.08)	0.93 (0.09)
RT (ms)	Target	892 (207)	903 (268)	1019 (231)	925 (314)
	Non-target	959 (252)	937 (263)	1065 (225)	956 (301)
	New	744 (274)	657 (183)	779 (266)	652 (208)

6.3.2. Electrophysiological Data

The presentation of the ERP data in this experiment will follow closely that for the previous experiment, focusing first on analyses of the left-parietal ERP old/new effect across the factors of interest and then on subsidiary analyses of the mid-frontal old/new effect and the right frontal old/new effect. The scalp distributions of the old/new effects associated with targets and non-targets are represented in Figure 25. The electrophysiological data associated with correct rejections and correct responses to targets and non-targets are presented in Figures 26-29.

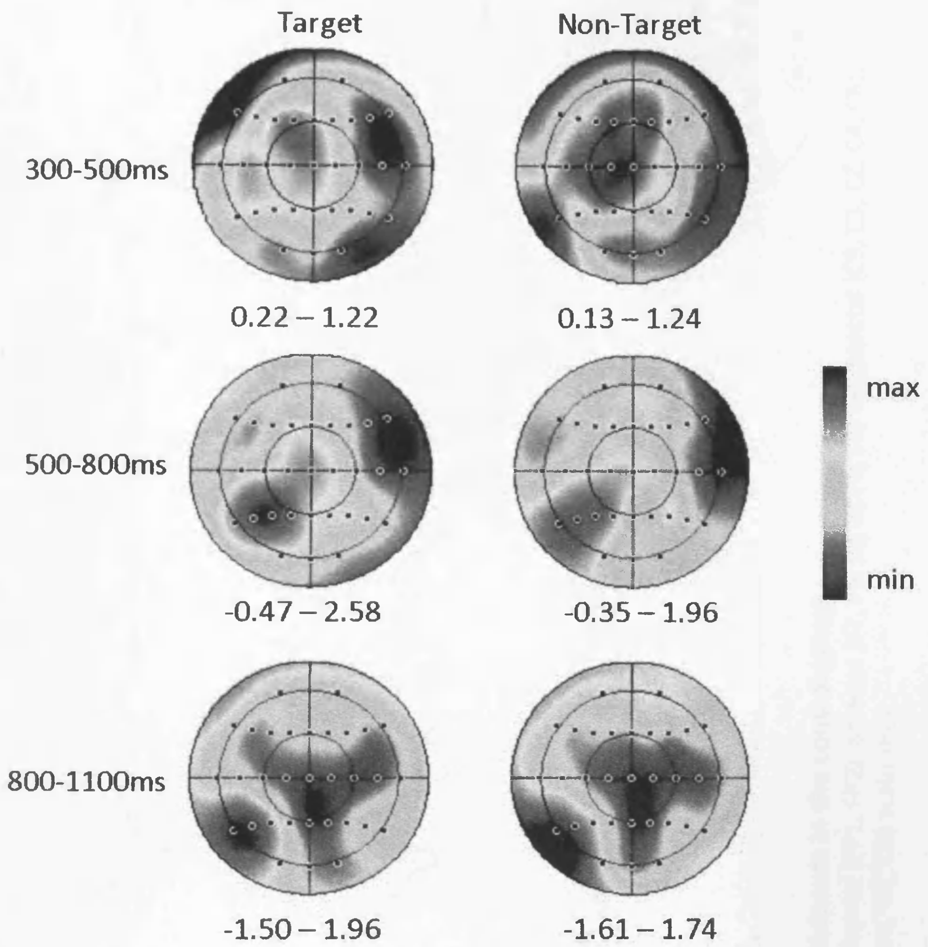


Figure 25: Scalp distributions associated with target and-non-target old/new effects (n=48).

Voltage maps are computed on the basis of difference scores obtained by subtracting mean amplitudes for the event-related potentials elicited by new words from each type of old word. Each map is proportionately scaled between the maxima (red) and minima (blue) of the depicted effect and the maximum and minimum values are shown below each map and can be interpreted relative to the colour bar on the right-hand side of the figure.

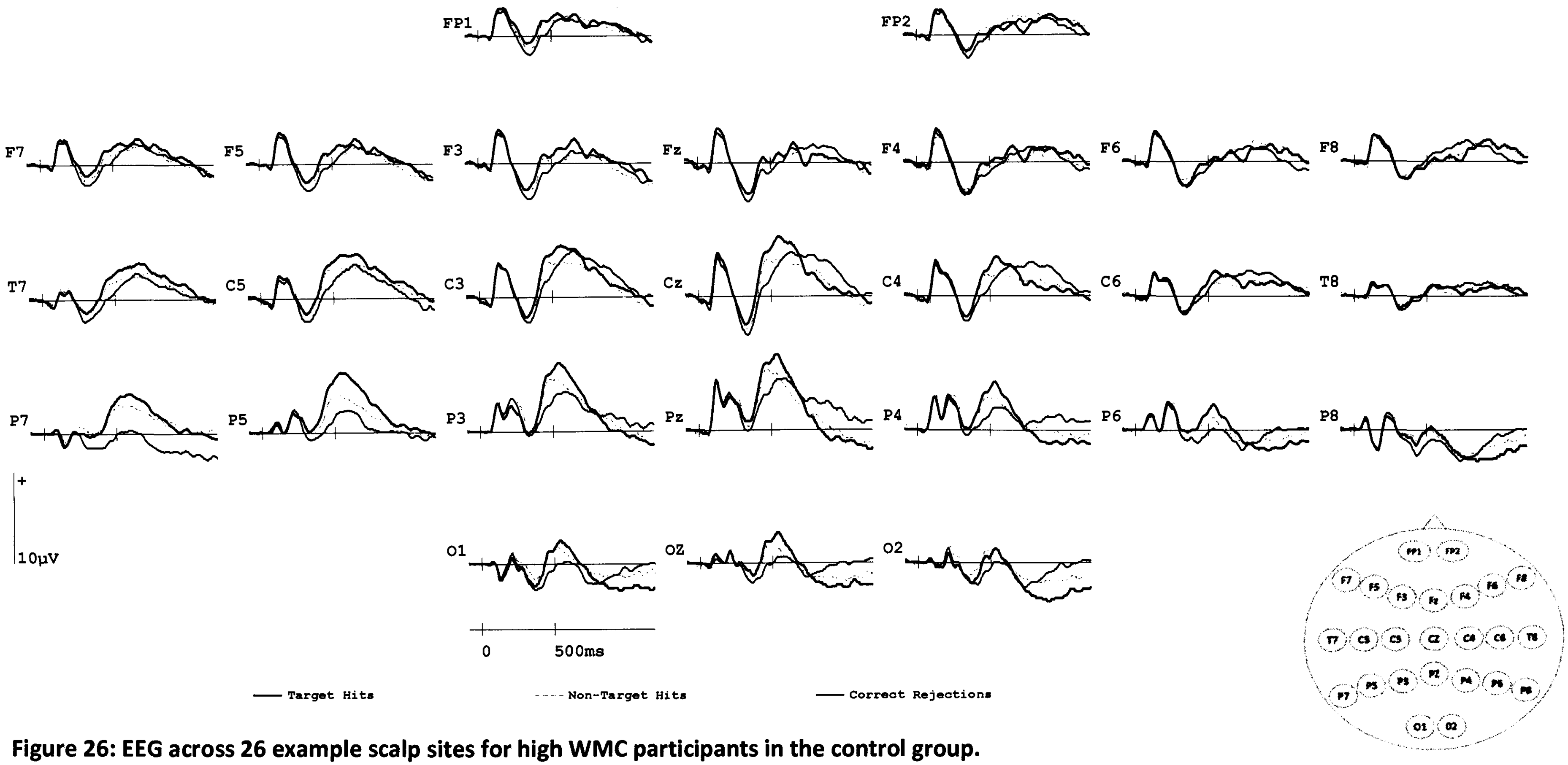


Figure 26: EEG across 26 example scalp sites for high WMC participants in the control group.
Sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, FZ F4, F6, F8), central (C5, C3, CZ, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, PZ, P4, P6, P8), and occipital (O1, OZ, O2) scalp sites.

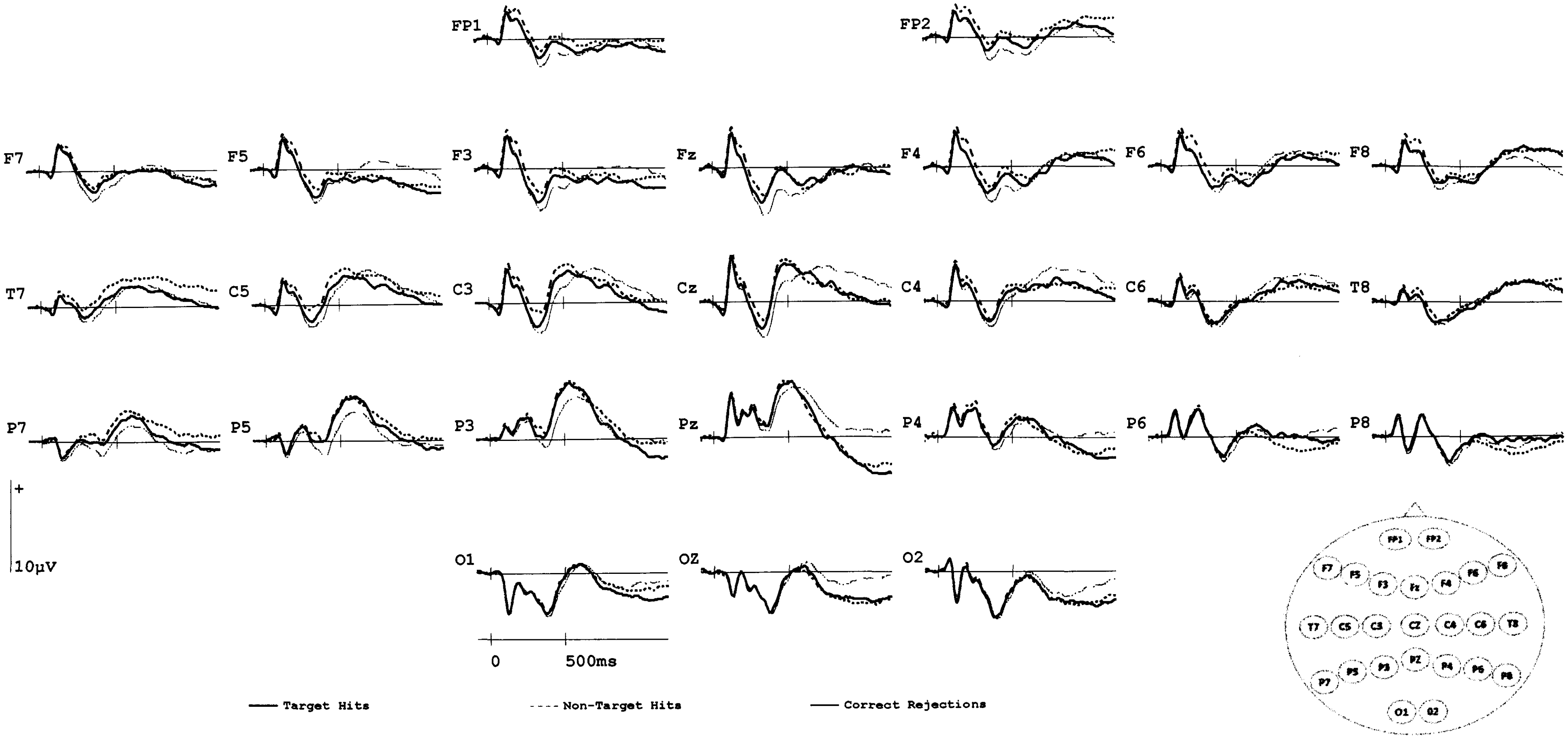


Figure 27: EEG across 26 example scalp sites for low WMC participants in the control group.

Sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, FZ F4, F6, F8), central (C5, C3, CZ, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, PZ, P4, P6, P8), and occipital (O1, OZ, O2) scalp sites..

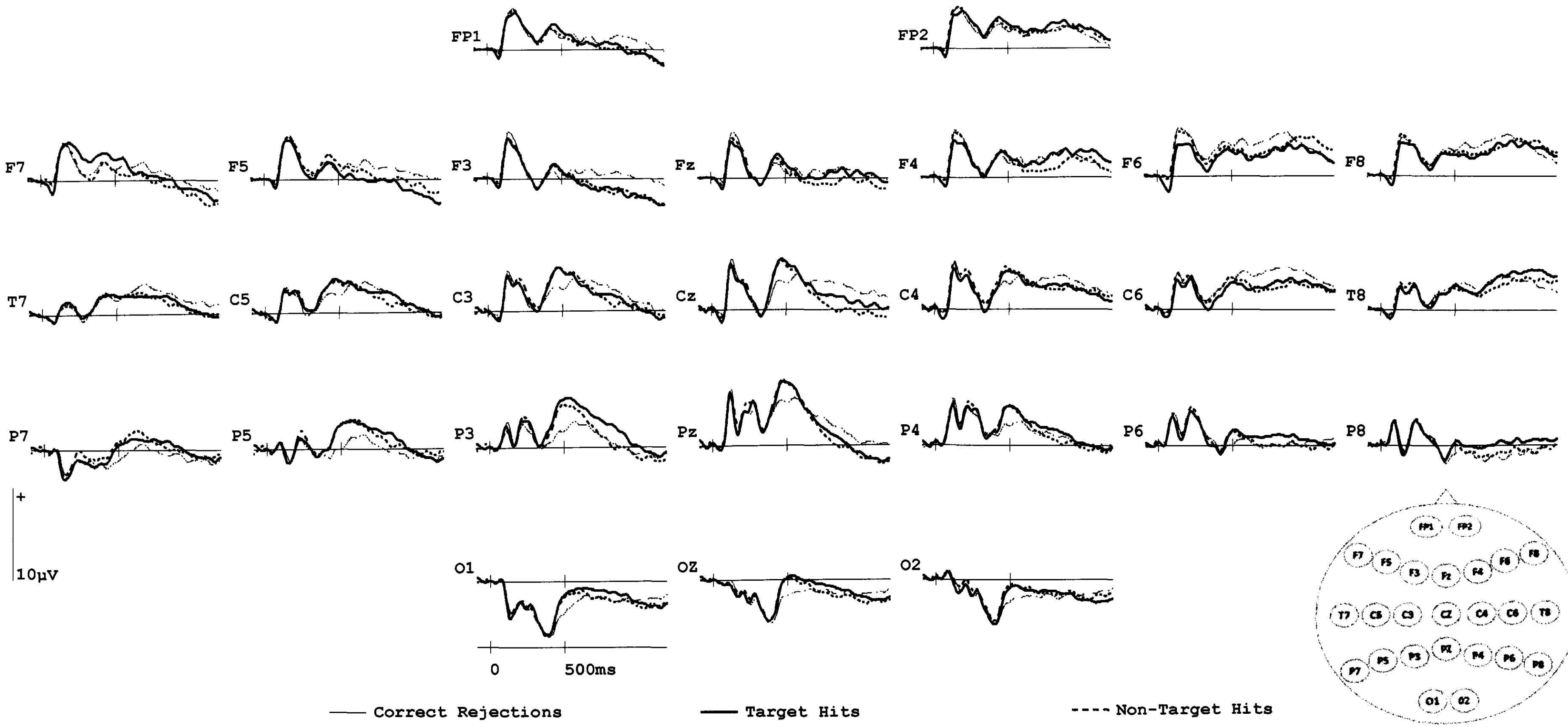


Figure 28: EEG across 26 example scalp sites for high WMC participants in the resource depletion group.

Sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, FZ F4, F6, F8), central (C5, C3, CZ, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, PZ, P4, P6, P8), and occipital (O1, OZ, O2) scalp sites.

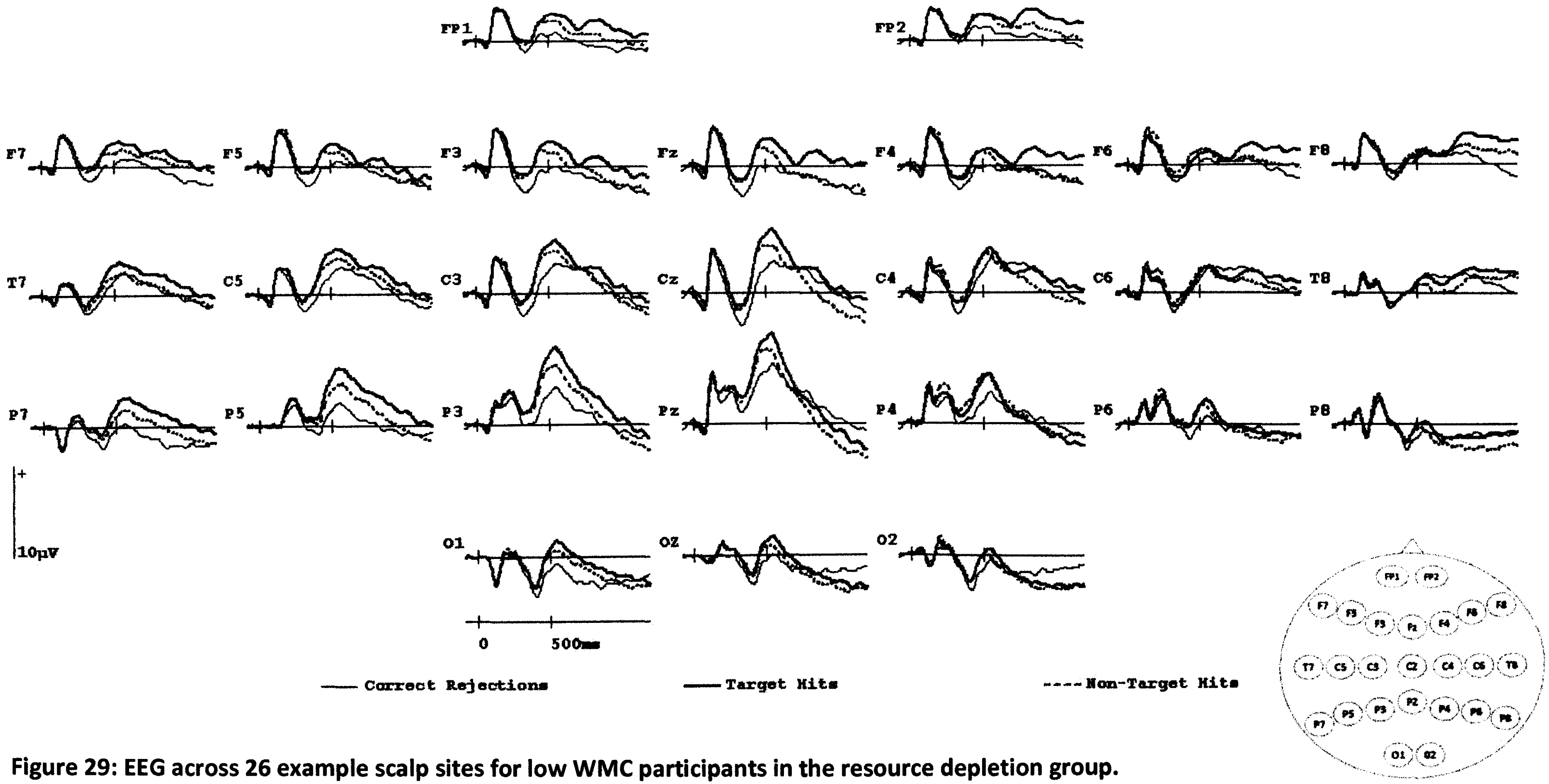


Figure 29: EEG across 26 example scalp sites for low WMC participants in the resource depletion group.

Sample electrode locations at left and right hemisphere sites over prefrontal (FP1, FP2), anterior (F7, F5, F3, FZ F4, F6, F8), central (C5, C3, CZ, C4, C6), temporal (T7, T8), posterior (P7, P5, P3, PZ, P4, P6, P8), and occipital (O1, OZ, O2) scalp sites.

6.3.3. The Left-Parietal Old/New Effect: ANOVA

Focused analyses are conducted in this time window to establish statistical support for the presence of a left-parietal old/new effect that might warrant further between-groups analysis. A 2 x 3 ANOVA of data isolated from P5 and P6 with factors of hemisphere (left:right) and response category (target:non-target:new) (see Figure 30) reveals a reliable interaction, $F(2, 94) = 13.55$, $p < 0.001$. Follow-up tests reveal that the amplitudes associated with targets and non-targets are reliably larger than those associated with new items at both the left and right hemisphere sites (min $t(47) = 2.3$, $p < 0.05$), but are largest on the left for both targets $t(47) = 4.6$, $p < 0.001$, and non-targets $t(47) = 3.4$, $p < 0.01$.

6.3.4. The Left-Parietal Old/New Effect: Median Split ANOVA

Due to the lateralisation described above, subsequent investigations are focused on one left-parietal scalp location: P5, see Figure 30. Mean amplitudes in this time window were subject to a 2x2x2 ANOVA with factors of stimulus (target-new:nontarget-new), WMC group (High:Low) and Resource Depletion group (Resource Depletion:Control) and this reveals a reliable three-way interaction, $F(1, 44) = 5.9$, $p < 0.05$. Follow up t-tests (within-participants) elucidate that this effect is driven by a reliable difference between the amplitudes to targets and non-targets in high WMC participants in the control group only, $t(22) = 2.9$, $p = 0.015$ (two-tailed). No such differences are evident in the other three groups (largest $t(22) = 0.7$).

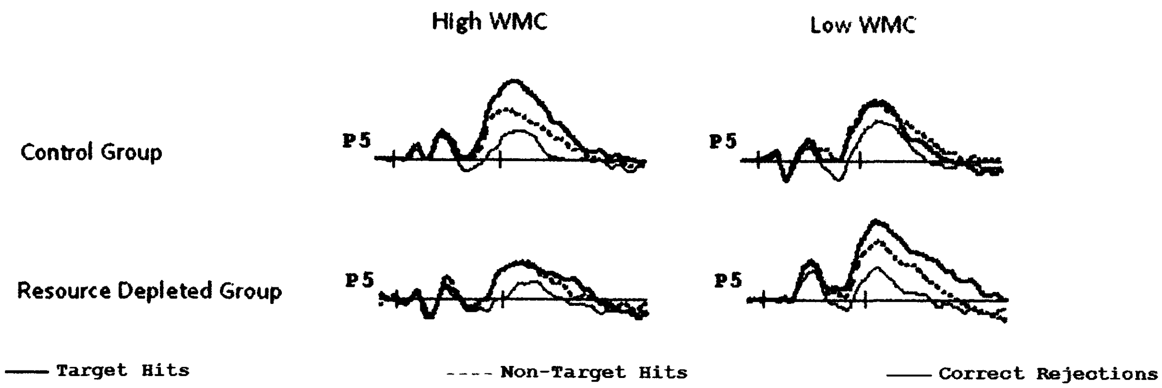


Figure 30: Electrophysiological data accross left parietal scalp site P5 compared according to stimulus type Target, Non-Target and Correct Rejections.

6.3.5. Subsidiary ERP analyses: Mid-Frontal Old/New Effect

Data from frontal scalp sites (F3, F4) in the 300-500ms time-window are subject to an ANOVA with factors of response category (Target:Long:Short:New) and a between-participants factor of WMC. Only ERP data associated with correct responses were entered into this analysis. A main effect of response category was revealed, $F(2, 88) = 4.4$, $p < 0.05$. Pair wise comparisons reveal a reliable old/new effect for non-targets, $t(47) = 2.8$, $p < 0.01$, but no reliable old/new effect for targets, $t(47) = 0.8$. As there is no reliable mid-frontal old/new effect, in accordance with the strategy outlined in Chapter 3: General Methods, the factors that predict the size of this effect will not be investigated.

6.3.6. Subsidiary ERP analyses: Late Right-Frontal Effect

Data from frontal scalp sites (F3, F5, F7, F4, F6 & F8) in the 800-1100ms time-window are subject to an ANOVA with factors of hemisphere (left: right) and response category (Target: Long: Short: New). There is no evidence of a late right-frontal old/new effect. No reliable effects involving response category are evidenced in these analyses.

6.3.7. Post-test Analyses: Free Recall Data

Reponses from the free recall test are divided into 3 categories in accordance with their response category in the exclusion task: items seen at test as targets, items seen at test as non-targets, and items seen at test as new items. The number of items recalled in each category is compared across WMC group and resource depletion group in a 3x2x2 ANOVA and the pattern of data is displayed in Table 6. There was no reliable three-way interaction $F(1, 44) = 2.6$. Due to the three-way interaction in the ERP data, however, the data are separated according to the resource depletion groups at this stage. This analysis revealed a reliable interaction between WMC group and stimulus, $F(1, 22) = 18.8$, $p < 0.001$, for those in the non-resource depleted groups but so such relationship is found for those in the resource depleted groups, $F(1, 22) = 1.6$.

Table 6: The mean number of items recalled in the surprise free-recall test by participants in each group separated according to the status of the item in the exclusion task (Targets, Non-targets or New items). Standard deviations are provided in parenthesis.

	Control		Resource Depleted	
	High WMC mean (sd)	Low WMC mean (sd)	High WMC mean (sd)	Low WMC mean (sd)
Target	19.4 (6.7)	16.5 (6.7)	16.6 (7.6)	15.1 (4.8)
Non-Target	13.5 (6.4)	18.6 (5.9)	13.8 (4.6)	15.4 (5.8)
New	4.8 (2.3)	6.0 (3.6)	4.3 (1.7)	3.9 (2.4)

In the control group, within-participants t-tests demonstrate that proportionally more targets than non-targets are recalled in the high WMC group, $t(11) = 5.9$, $p < 0.001$. This is not the case in the low WMC control group, $t(11) = 1.3$. There are no reliable differences between the number of targets recalled across WMC groups, $t(22) = 1.1$, but the number of non-targets recalled by participants with high WMC is reliably smaller than the number recalled by participants with low WMC, $t(22) = 2.0$, $p < 0.05$ (one-tailed).

6.4 Discussion

The data provided here strongly support the notion that working memory predicts the extent to which inhibition of non-target recollection is employed successfully in the exclusion task. There is electrophysiological evidence for strategic recollection only in those participants with high WMC. Furthermore, in an independent post-test, this high functioning group shows a selective deficit for the recall of non-targets. This provides convincing evidence that non-targets are actively inhibited by the high WMC group. There are no differences in the electrophysiology or the post-test recall scores across stimulus category in the low working memory group. While it is not possible to state confidently that no strategy was employed to prevent the recollection of non-targets in this group, it is reasonable to claim that the extent to which control over recollection (via inhibition) is exerted fell well short of that exerted by those with higher WMC scores.

As in Experiment 2, these claims need to be considered in light of the fact that the left-parietal old/new effect elicited by targets is larger in the high WMC group than in the low WMC group. One interpretation of this outcome is that targets are being selectively prioritised in the high WMC group. Comparable data are obtained in Experiment 2, where WMC predicts the magnitude of the left-parietal effect for targets but not for non-targets. In the free-recall data, the opposite pattern of results was obtained: there are no differences between the number of targets recalled across group but there are fewer non-targets recalled by members of the high WMC group. This outcome is in line with the hypothesis that those participants for whom there is evidence of selective recollection would show a selective deficit in the recall of non-targets on a post-test. This interpretation is consistent with one of the ways in which principles of inhibition are applied, namely that as a consequence of inhibition, items become deactivated relative to baseline and as such will be less accessible later – even when the task demands have changed (Anderson & Green, 2002). This is particularly compelling as the free-recall data suggest a selective deficit in recall in the high WMC participants. Typically, high WMC is associated with a performance advantage on cognitive tests (Gathercole et al. 2003; Jarvis & Gathercole, 2003; Kyllonen & Chrystal, 1990; Prabhakaran et al. 2000; Rosen & Engle, 1997; Swanson et al. 1996; Swanson & Beebe-Frankenberger, 2004) but these data fit with the resource model of inhibition (Aron, 2007; Conway & Engle, 1994; Engle, Conway, Tuholski, & Shisler, 1995; Nigg, 2000; Redick et al. 2007). Overall, the free recall data provide strong support for an inhibition account of the mechanisms responsible for non-target attenuation described earlier.

As has already been noted, high WMC participants show larger left-parietal effects than low WMC participants as a result of having greater capacity to represent and maintain material on-line. This links the left-parietal ERP old/new effect with operations associated with the episodic buffer (Baddeley, 2000), because the left-parietal effect has been considered to index the on-line maintenance of reinstated long-term memory contents (Wilding and Rugg, 1996, Vilberg, Moosavi & Rugg, 2006; Viberg & Rugg, 2009). Hence, the left-parietal effect might reflect operations linked to the engagement of the episodic buffer, and presumably WMC limits the amount of information that can be reactivated/maintained at any one time. According to this account, had inhibition of non-targets not occurred, the magnitude of the left-parietal ERP old/new effects for non-targets would be larger for high than for low WMC participants. Thus the comparable amplitudes for the two WMC groups come about for different reasons: successful inhibition so less information to maintain for high WMC individuals, and a capacity limitation for low WMC individuals.

One important way in which the data provided here go beyond that of the previous experiments is because of the condition introduced to manipulate control resources to investigate the possibility of a causal relationship between the availability of cognitive resources and cognitive control over memory. High WMC participants who completed a Stroop task before the exclusion task became indistinguishable from low WMC controls. This was true for the EEG data as well as the behavioural post-test data. This finding suggests strongly that control resources are necessary for the successful engagement of an effective control strategy, and the behavioural post-test data across high and low WMC groups suggests that this control strategy involves inhibition. When these resources are depleted, controlled recollection is something that cannot be accomplished to the same degree. It is less clear, however, what resources have been depleted by the Stroop task. It is unparsimonious to assume that the Stroop task depleted working memory resources per se, but rather, that the same neural systems that are responsible for response inhibition in the Stroop task became fatigued and this made control in the exclusion task difficult. This issue will be discussed further in the general discussion.

Another important element of the design of this experiment was the inclusion of a battery of prefrontal cortical control data. Working memory and executive control are thought to depend on the integrity of the prefrontal cortex (Badre & Wagner, 2007; Burgess & Shallice, 1996; Chan, Shum, Toulopoulou, & Chen, 2008; Conway & Fthenaki, 2003; MacDonald et al. 2000; Miller & Cohen, 2001;

Prabhakaran et al. 2000; Shallice & Evans, 1978). With advanced age, the prefrontal cortex shows widespread physical degeneration (Raz et al. 1997), if this atrophy occurs indiscriminately over regions that support working memory and inhibition the behavioural data would be expected to show a correlation between measures of inhibition and working memory. To a lesser extent, we might anticipate that there are individual differences in the integrity of the prefrontal cortex in younger adults and this might generate spurious correlations between tasks that rely on disparate but juxtaposed prefrontal cortical networks. To asses these possibilities, a battery of prefrontal cortical function tests was put together. These tests were selected as young adults would show a range of individual differences, thereby increasing the power to detect a relationship between behavioural performance on these tasks and WMC. No such relationship was evident. This adds weight to the notion that WMC is driving the differences between the sizes of indices of recollection for targets and non-targets in the exclusion task.

CHAPTER 7: GENERAL DISCUSSION

7.1. Overview

The experiments in this thesis were designed to contribute to an understanding of the links between WMC and cognitive control over retrieval from long-term memory. Issues concerning these links, and about the mechanisms via which control is exerted, were explored in 3 experiments. In the following sections, a description of the rationale for the progressions between experiments is provided, along with a description of the key experimental findings that motivated the progressions.

7.2. WMC predicts Strategic Recollection in the Exclusion Task

In Experiment 1, participants completed the 'lag' version of the exclusion task, where targets are studied items and non-targets are repeated test items. The study was designed to test a prediction ensuing from what was at the time the dominant account of the way in which completion of the exclusion task differed according to how difficult it was to recollect information about targets. The account, based upon changes in the magnitude of an ERP index of recollection for targets and non-targets, was that the extent to which recollection of target information was prioritised over non-target information varied with the likelihood of recollecting information about targets. This account, outlined initially by Herron & Rugg (2003), held that, when recollection of targets is relatively easy, then succeeding or failing to recollect target information is a good metric for making accurate task judgments. This approach is less good, however, when recollecting target information becomes more difficult, and under these circumstances the common approach is to focus on recollection of information about non-targets as well as on information about targets.

The support for this account was ERP data showing that the left-parietal old/new effect – an index of recollection – is sometimes smaller for non-targets than for targets. This relative attenuation most often occurs when the likelihood of recollecting information about targets is high, and this pattern of data across experiments is consistent with the account offered by Herron & Rugg (2003) if the left-parietal old/new effect is a good index of the extent to which recollection has occurred (or perhaps the proportion of trials on which it has occurred).

The prediction motivating Experiment 1 was that, if this account is correct, then people who are more likely to recollect targets should show a greater relative attenuation of non-target left-parietal ERP old/new effects in comparison to their target parietal effects than should people who are less likely to recollect target content. This prediction is not supported by the outcomes of regression analyses in Experiment 1, and this null result, when considered in combination with published data points that did not fit with Herron & Rugg's (2003) proposal, motivated an alternative explanation for the patterns of left-parietal target and non-target old/new effects that have been observed in exclusion tasks.

According to this alternative account, the circumstances under which ERPs will provide data suggesting that prioritisation of recollection of some contents over others occurred are determined by the availability of the resources necessary to exert control over retrieval, rather than by the likelihood of recollecting information about targets. Individuals with sufficient resources will prioritise recollection of targets over non-targets, whereas those with insufficient resources will not. This account explains the correspondence across studies that motivated Herron & Rugg's account in the following way. Tasks where the likelihood of recollecting targets is high will generally require fewer resources than will tasks where the likelihood of recollection of target content is lower. Consequently, if there is individual variation in resource availability, then a greater proportion of a participant population will have sufficient resources available to exert control in tasks where the likelihood of recollection of target content is high. This account can also explain departures from the pattern predicted by Herron & Rugg (2003), because there will presumably be, at least on occasions, marked differences in the mean and range of resource available for the deployment of cognitive control, so the relationship between target recollection and evidence for control of recollection will sometimes not hold.

This alternative account was tested in Experiment 2, where a similar task to that used in Experiment 1 was employed. In addition, each participant completed the O-Span task, which is considered to be a robust index of working memory capacity (WMC), hence a measure of resource availability. The extent to which target left-parietal ERP old/new effects are attenuated relative to non-target effects as correlated positively with WMC, in line with the predictions of the alternative account outlined after Experiment 1.

There were, however, several caveats that the design of Experiment 2, as well as the pattern of findings, encouraged consideration of. These were due primarily to the use of the lag exclusion task design. A full recount of these issues was provided in Chapters 5 and 6 and they are not recounted here. In Experiment 3, some of these issues were addressed by adopting the more widely employed exclusion task paradigm variant in which items subsequently designated as targets and non-targets are first encountered in different study contexts.

There were also three key additions to Experiment 3 that were introduced to allow an assessment of the strength and the specificity of links between WMC and control of recollection in exclusion tasks, as well as the mechanism by which control might be exerted. The first of these was the introduction of a resource depletion manipulation, whereby half of the participants completed a Stroop task for 6.5mins before completing the exclusion task. In several experiment contexts, the consequence of completing this task has been a subsequent impairment in completing tasks that are assumed to rely on working memory resources. The explanation most often offered for this cost is that completing the cognitively demanding first task (the Stroop task) fatigued resources so that they were less available for some period of time afterwards.

The introduction of this manipulation in Experiment 3, therefore, offered a means of establishing a causal link between WMC and the conditions under which left-parietal ERP old/new effects provide indices of cognitive control. The prediction was that participants with high WMC scores would show little or no evidence for control over recollection in the exclusion task if they had been subject to the resource depletion manipulation prior to completing the memory task. This prediction was confirmed: completing the resource depletion manipulation resulted in the ERP and performance data for these participants resembling closely the data for low WMC participants. While there was no assessment in Experiment 3 following the Stroop task on tasks shown previously to be affected, the changes in ERPs on the exclusion task none-the-less provide evidence for a causal link between WMC and the exertion of control over recollection.

The second key addition in Experiment 3 was the acquisition of performance measures from all participants on a battery of neuropsychological tests that are widely assumed to index the integrity of prefrontal cortex (PFC) function. This addition permitted an assessment of the specificity of the links between WMC and the ERP evidence for the control of recollection, addressing the possibility that the link documented in Experiments 1 and 2 is parasitic upon a link between PFC and the ERP effects, rather than being tied closely to WMC. There was, however, no robust evidence in Experiment 3 for this alternative account.

The final key addition in Experiment 3 was the introduction of a recall task after the exclusion task. All participants were asked to write down (in 5mins) as many words as possible that they had encountered in the exclusion task. The rationale for this addition was that performance on this task would vary with WMC in particular ways if inhibition was the mechanism via which cognitive control was exerted in the exclusion task. Specifically, those participants who had exerted marked control over recollection of non-targets should recall fewer non-targets subsequently than those who did not exert control as effectively. The assumption underpinning this prediction was that inhibition mechanisms have effects that last beyond the time at which they are engaged, with their repercussions evident on subsequent task assessments. The application of this assumption in the way described here is similar to that when post-tests are employed in paradigms such as the retrieval-induced forgetting design, with this work providing some of the motivation for the inclusion of a post-test in Experiment 3. More generally, the inclusion was motivated by the fact that changes in WMC have been shown, in numerous instances, to correlate with performance on a range of tasks that are considered to depend upon inhibition. These links were documented in detail in Chapter 5, and their presence is a strong steer towards considering the possible role of inhibition as a mechanism underpinning the exertion of cognitive control (as indicated by the relative attenuation of non-target left-parietal ERP old/new effects) in the exclusion task.

The critical finding in Experiment 3 was that participants with high WMC did indeed show a reduced likelihood of recalling non-targets than did participants with low WMC. This outcome provides direct evidence for the role of inhibition in the exclusion task. This finding also has important implications for an issue that has been raised earlier in this thesis. Namely, that in Experiments 2 and 3, the reason for the relative attenuation of non-target left-parietal effects in comparison to target effects is was primarily changes in the size of the effect for targets. This outcome prompts consideration of the possibility that the ERP data really indicates prioritisation of targets, rather than active (hence different) processing of non-targets according to WMC. The pattern of post-test data described above argue against this target prioritisation account.

In addition, the Experiment 3 findings extend beyond comparable evidence in prior behavioural work, because of the ERP evidence for the exertion of cognitive control during the completion of the exclusion task. In most prior work, the assumption that control was exerted at an earlier time point is inferred entirely from what happens on the subsequent test.

This assertion does not hold, however, for the study by Bergstrom and colleagues (2009) where ERPs were acquired during the think/no-think stage of the think/no-think paradigm and post-test recall data were also acquired. In that experiment, behavioural evidence for suppression/inhibition (see Chapter 1 for detail) occurred in a condition where there was no evidence from ERPs that control over recollection had been exerted in the think/no-think phase. There was no behavioural evidence for inhibition, however, in the condition where ERP evidence for control over recollection was present.

One immediate explanation for this inconsistency is that it simply reflects the documented difficulties in consistently obtaining evidence for behavioural costs in the think/no-think paradigm. A more intriguing possibility, however, is that the disparities arise because participants in the study reported by Bergstrom et al. were allocated to groups without reference to WMC. One of the general observations that the findings in Experiments 2 and 3 in this thesis permit is that WMC may be an important determinant of the extent to which control of retrieval can be exerted, so in experiments where control might be exerted (either spontaneously or via task instructions), variations in WMC across participant groups could well be a factor to control for.

In summary, building on the foundations of the first pair of experiments, Experiment 3 provides strong evidence for a causal and relatively specific link between WMC and the control of recollection, thereby arguing strongly for the inadequacy of the target accuracy account of the conditions under which ERP evidence for the control of recollection in exclusion tasks might be obtained. In addition, Experiment 3 provides evidence that inhibition is the mechanism by which control over recollection occurs. Alongside findings in the retrieval induced forgetting paradigm, these data points argue strongly for the role of cognitive control during normative memory search, and not simply when control is encouraged explicitly by task instructions. It is also worth emphasising again that, in contrast to the retrieval induced forgetting findings, the behavioural evidence for inhibition here is accompanied by complementary direct evidence – the pattern of ERP old/new effects – that control was in fact exerted.

The remainder of this discussion is split broadly into two sections. The first comprises a brief consideration of various issues that have arisen and which have not yet been addressed, along with a discussion of additional ERP data points reported in the experiment chapters. The second and final section focuses on further implications of the findings in this thesis, set in the context of a consideration of future research directions.

7.3. Further Issues

7.3.1. The Functional Significance of ERP Old/New Effects

The principal claims about the extent to which recollection occurred in this thesis are based on changes in the magnitudes of the left-parietal ERP old/new effect. The findings, therefore, add little directly to knowledge about the functional significance of the effect. It is notable, however, that the recent claim that the effect indexes active maintenance of episodic content in a short term store is consistent with the fact that the magnitude of the target left-parietal old/new effect increased with increases in WMC. A challenge for this account that will need to be addressed in subsequent studies is the relatively consistent duration of this effect across studies with markedly different demands. It might be predicted that the time over which content is maintained would vary to a greater degree than is suggested by published findings to date.

Two other old/new effects – the mid-frontal and right-frontal effects - were also analysed in this thesis, in ways comparable to the analyses of the parietal effect. There was no consistent pattern of effects across the experiment findings that provide novel insights into the functional significance of these effects, although the absence of changes in these effects with WMC provides a previously unreported way in which the two effects are functionally dissociable from the left-parietal ERP old/new effect. Of greater importance for this thesis, the absence of evidence for changes in these modulations with WMC suggests that resource availability was linked here specifically with operations that are tied closely to the process of recollection.

7.3.2. Further Consideration of Non-target Attenuation

In their first description of left-parietal ERP old/new effects in exclusion tasks, Wilding & Rugg (1997) reported that the non-target effect was somewhat smaller than the target effect, despite the fact that the likelihood of correct responses to targets and non-targets was comparable. Wilding & Rugg did not, however, interpret these findings via an appeal to selective recollection strategies. Instead, they noted that correct responses to non-targets were made on the same key as correct responses to new items, so presumably a proportion of the trials contributing to the ERPs associated with correct responses to non-targets were items that had been forgotten. Since ERPs associated with forgotten items (misses) typically resemble those associated with correct rejections, the likely impact of these trials would be an attenuation of the non-target parietal old/new effect relative to the target effect.

Can this argument explain the findings in the experiments described here, or does this consideration at least complicate interpretations? It seems unlikely, because the extent to which relative attenuation of the non-target effect occurs decreases along with response accuracy on the task overall. This is not the outcome that would be predicted according to the explanation offered by Wilding & Rugg (1997), where non-target effects should diminish relative to target effects as the memorability of non-targets declines.

7.3.3. Resource Depletion

The findings in Experiment 3 demonstrated that depleting resources before completing the exclusion task influenced the retrieval strategy that was employed on the task. It is not clear, however, what resources were depleted by the Stroop task. It is unparsimonious to assume that the Stroop task depleted working memory resources *per se*, and an alternative is that the neural systems that are responsible for response inhibition in the Stroop task became fatigued and this made control in the exclusion task difficult because selective retrieval strategies depend in at least part of the same neural system. In keeping with this perspective, Neshat-Doost, Dalgleish & Golden (2008) suggested that "self-regulation resources" and "working memory resources" are overlapping constructs. Schmeichel (2007) investigated this suggestion across a series of experiments where performance on working memory span and response inhibition tests was negatively influenced by participant's prior completion of executive control as well as working memory tasks. In the first of four experiments, participants were asked to watch a video in which words appeared at the bottom of the screen. Half of the participants were asked to avoid looking at or reading any words appearing on the screen, and participants in this group subsequently showed impaired performance on the O-Span test of WMC. Schmeichel (2007) also demonstrated that inhibiting handwriting by writing a story without using the letters a or n reduces subsequent performance on a digit span test, in comparison to participants who were able to write freely. Moreover, completing the O-Span task (versus the completion of mathematical equations) impaired later performance on an emotion regulation test in which participants were shown a gruesome film of an animal slaughterhouse and asked to inhibit any outward emotional response. Participants in the O-Span condition rated themselves to be more distressed after viewing the clip, and (according to independent judges blind to the purpose of the experiment) expressed more facial emotion while watching the video. In the fourth experiment, participants were asked to exaggerate their expression of negative emotions, and this too negatively impacted performance on a subsequent working memory test. Schmeichel reasoned that exaggerating emotionality would also depend on self-control. Importantly, the after-effects in each of these experiments did not extend to attention and memory tasks that did not require a component of executive control. Taken together, this work suggests that executive control operates like a limited resource that is vulnerable to depletion, and furthermore, that previous demonstrations of depleted 'self-regulatory' resources may more precisely be considered instances of reduced resources available for general executive control.

This evidence implies that working memory is necessary for successful inhibition processes in the exclusion task because inhibition and working memory both require executive resources. When these resources are unavailable, or depleted due to a previous resource demanding task, inhibition mechanisms will be less effective.

7.3.4. Memory Suppression Effects Across the Lifespan

The working memory account presented here is largely consistent with findings from older individuals. There is evidence that WMC reduces with age (Park, et al. 1996), and correspondingly evidence of selective retrieval on the exclusion task has not been reported. There are also, however, reports of ERP and behavioural data from the exclusion task where participants were children, and the findings in these studies do not sit entirely comfortably with the framework advocated in this thesis.

In a study by Czernochowski, et al. (2005), children were poorer at the target/non-target discriminations than were adults, but the degree to which non-target old/new effects were attenuated appeared to be greater for the children, although this was not tested directly. de Chastelaine et al. (2007) also reported a target/non-target discrimination advantage for adults in comparison to children. Parietal old/new effects were larger for children, but the degree to which the non-target effects were attenuated was roughly equal for children and adults. If children have lower WMC than adults, these outcomes are a challenge to the WMC account for when non-target effects will be attenuated relative to target effects, although the reasons why the findings across these two studies do not converge also need to be addressed. Furthermore, neither Czernochowski et al. (2005) nor de Chastelaine et al. (2007) measured working memory capacity directly, so comparisons involving these studies can only be made tentatively, which is of course also true of the work by Dywan and colleagues (2002; 2005).

Furthermore, the data points in the two studies with children were obtained in versions of the exclusion task where study items were encountered in different contexts, and items from one study context were denoted as targets at test. One reason for selecting the variant on this exclusion procedure that was used in Experiments 1 and 2 in this thesis (where non-targets were repeated test items) was because this variant was first introduced as one that is well-suited for use with different populations and participants of different ages. Jennings & Jacoby (1997) argued that the use of the test repetitions provided a key benefit when comparing performance across different populations. They noted that by comparing response accuracy for non-targets at short repetition lags (for which most responses should be correct) it is possible to assess whether all participants understood the task instructions equally well. It may be that some of the inconsistencies across the findings for children stem from failures to adhere to task instructions.

7.3.5. The General Implications of the Findings for the Field.

The principal implication of the data reported in this thesis is that people engage in selective cognitive control strategies spontaneously during memory tasks, even when there is no explicit requirement to do so. There has been much research that suggests that cognitive control operations support memory by selecting between competing representations, and perhaps preventing too many forms of competing information coming to mind (Bartlett, 1932; Anderson & Green, 2001; Anderson et al. 2004; Bergström, Velmans, de Fockert, & Richardson-Klavehn, 2007; Bjork, LaBerge, & Legrand, 1968; Golding & MacLeod, 1998; See Chapter 1 for a more lengthy description). Individuals with damage to the pre-frontal cortex have difficulties associating memories with the appropriate context, and one potential account for this deficit is that it is a failure to exert sufficient control over competing contextual elements and their bindings to specific memories (Fletcher & Henson, 2001; Rugg, Fletcher, Chua, & Dolan, 1999; Spencer & Raz, 1994). In line with this account, patients with Korsakoff's amnesia often display confabulation, which is characterised by gross inaccuracies in memory judgments (Berlyne, 1972). One explanation for this phenomenon is that an executive deficit causes a difficulty selecting accurate internal representations from inaccurate ones. Consistent with this account is work demonstrating that when cognitive control processes associated with the prefrontal cortex become damaged predictable memory errors occur

(Burgess & Shallice, 1996; Moscovitch, 1989). This work suggests that, in healthy adults, control processes commonly occur as part of memory search, and the work in this thesis support this view, by providing evidence that young adults engage in cognitive control processes to avoid recollecting unnecessary information.

Other work with healthy adults has demonstrated that cognitive control processes to guide memory retrieval. There are, however, methodological issues associated with some of these experiments that limit the conclusions that can be drawn, and these limitations do not apply to the work described in this thesis (Anderson, 1983; Anderson, Bjork, & Bjork, 2000; Anderson, Bjork, & Bjork, 1994; Anderson & Green, 2001; Anderson et al. 2004; Anderson & Spellman, 1995; Bergström, de Fockert, & Richardson-Klavehn, 2009; Bergström et al. 2007; Bjork & Bjork, 2003; Bjork, 1972; Bjork et al. 1968). In two common approaches, participants are instructed to forget a subset of memory items (Brown, 1954; Golding & MacLeod, 1998; Johnson, 1994) or they are instructed to avoid thinking about one class of items (Anderson et al. 2004; Anderson & Spellman, 1995; Bergström, de Fockert, & Richardson-Klavehn, 2009; Bergström et al. 2007. In these cases, the extent to which participants *spontaneously* engage in such selective retrieval strategies in the absence of a specific instruction is not clear. The data presented in this thesis, however, supports strongly the conclusion that healthy young adults typically engage in cognitive control processes to restrict memory processing despite no explicit requirement to do so.

7.3.6 Limitations of the Experiments, in terms of Analysis, Methodology and Possible Interpretation.

As well as the methodological benefits associated with the exclusion paradigm, there are also several caveats that must be considered. One alternative possibility that has been addressed at various points throughout the thesis is that inhibition is not the most parsimonious explanation for the mechanism by which control in the exclusion task is exerted. An alternative is that participants encode items designated as targets better than they do items designated as non-targets, and that WMC enables superior encoding, hence larger old/new effects for targets relative to non-targets as WMC increases. This alternative explanation can apply to Experiments 1 & 2 in this thesis, because targets were presented at study, while non-targets were items presented once and then re-presented at test. Under these circumstances it is straightforward to envisage how the extent to which targets and no-targets are encoded might not be equivalent.

The selective encoding account is less convincing in Experiment 3, however. In this case, items were encoded under two different encoding conditions at study, but participants were not informed which class of item would subsequently be designated as 'target' until immediately before the subsequent test phase. This means that there is no obvious benefit to prioritizing one class of items at the time of encoding, nor any reason to believe that a population of participants would show a systematic bias. Furthermore, at least in the experiments in this thesis, changes in

WMC did not predict changes in response accuracy, which also argues against a selective encoding account for the overall pattern of data reported here.

A related consideration is there are at least two ways in which cognitive control could be operationalized at the time of retrieval. It is possible that the recovery of target items is 'enhanced' relative to that of non-targets or that the recovery of information about non-targets is inhibited. The strongest evidence in this thesis that inhibition of non-targets is part of an accurate explanation comes from Experiment 3, where participants were given a surprise post-test after the exclusion task. The reason for the post-test was the argument that when inhibition occurs, a suppressed item will be less accessible for recovery on a subsequent test (Anderson & Green 2007; Bauml 2008). For the control group in Experiment 3, WMC did not predict target accuracy, but high WMC participants were less likely to recall non-targets than were low WMC participants. Because the high WMC participants were the ones for which there was ERP evidence for the exertion of greater degrees of cognitive control, this outcome suggests that part of exerting control in the exclusion task involves inhibition of non-targets. For the three experiments overall, it is reasonable to argue that strategic encoding of targets in Experiments 1 & 2 is as likely to be correct as is a cognitive control at retrieval account. This argument cannot be applied to Experiment 3, however, where the post-test data not only argues for the use of cognitive control at the time of retrieval, but also fits with one mechanistic account of how that control comes about.

It is always the case in experimental psychology that power should be optimized and one of the ways that this is achieved is to ensure there are suitably large sample sizes in each experimental condition. Although the experiments in this thesis have relatively large samples for EEG research, as the design becomes more complex so more participants are required to keep the statistical power optimal. In Experiment 3, there were only 12 participants in each group and there are several points in this experiment where increased statistical power may have aided the interpretation of the results. In particular, in the free-recall data the three-way interaction between Stimulus, WMC and Resource Depletion group was not significant (see page 166). When the groups were separated according to resource depletion group, the two-way interactions with Stimulus and WMC were remarkably different (for the control group the interaction was very ($F = 18.8$), for the resource depletion group it was not significant ($F = 1.6$)). Given this, on the basis of our specific hypotheses and the related three-way interaction involving group that was present in the electrophysiological data, the data are reported split across the resource depletion groups. It is important to note that, however, that while there is some justification for this approach, the absence of the reliable higher-level interaction encourages a degree of caution for the conclusions that have been drawn. Further work with larger samples to unpick the role of WMC in the inhibition of items from LTM is needed to address this issue.

On a related note, power is optimised in the thesis by focusing on a very selective portion of the EEG data. The reasoning here was that the left-parietal old/new effect is a reliable correlate of the process of recollection. The aim of the work in this thesis, and particularly in Experiments 2 and 3, was to identify individual difference variables that moderate this effect. Within each experiment, the scalp locations where the left-parietal effect was largest were identified, and values from that scalp site (or sites) were entered into correlational analyses with behavioural measures of interest. This analysis strategy was used to optimise the power of the regression analyses. It can be argued, however, that by selecting data points in this way other interesting findings may be missed. More importantly, the approach is subject to the concern that the directed analyses have provided significant results that are not an accurate reflection of the data overall. In defence of the selective strategy that was employed, inspection of multiple data sets across published and unpublished experiments commonly reveals left-lateralised parietal distributed old/new effects that vary to some degree in their specific maximum, presumably due to factors including variations in head shape as well as variations in the specific placement of electrodes relative to their intra-cranial generators. In addition, small differences in experiment design can have some effect on the maxima of parietal effects, but what is common is the fact that left-lateralised parietal locations are those that index recollection and the degree to which recollection has occurred (see Wilding 2000). For these reasons, the analysis decisions taken are unlikely to have encouraged spurious correlations.

7.4. Conclusions and Future Directions

The experiments in this thesis suggest strongly that working memory capacity plays an important role in long-term memory retrieval, and particularly with respect to the ways in which recollection may be subject to top-down control influences. Starting with the earliest conceptualizations of long-term memory retrieval, it has been considered as an active 'constructive' process (Bartlett, 1932; Burgess & Shallice, 1996; Schacter, et al. 1998) and contemporary cognitive neuroscience accounts articulate 'construction' and related processes as those that depend upon the prefrontal cortex (Berlyne, 1972; Bonhoeffer, 1901; Burgess & Shallice, 1996; Fletcher & Henson, 2001; Janowsky, et al. 1986; Moscovitch, 1989; Rafal & Henik, 1994; Spencer & Raz, 1994; Swick, et al. 2006). One way in which the prefrontal cortex is considered to be responsible for long-term memory retrieval is via the active suppression of competing memory representations, thereby enabling memory search to access task-appropriate memories (Anderson, et al. 2004; Bergström, et al. 2009; Bergström, et al. 2007; Bjork, et al. 1968; Burgess & Shallice, 1996; Moscovitch, 1989). It has, however, been difficult to obtain strong and consistent evidence for the suppression of memories (Bulevich, et al. 2006; Johnson, 1994; MacLeod, 1999; MacLeod, et al. 2003).

The approach to addressing this issue in this thesis depended in part on exploiting the fact that a considerable body of research has identified an electrophysiological correlate of recollection, to the degree where changes in the magnitude of this correlate can be used as an index of the extent to which recollection has occurred (Donaldson, et al. 2002; Donaldson & Rugg, 1999; Vilberg, et al. 2006; Vilberg & Rugg, 2009a, 2009b; Wilding, 1999; Wilding, et al. 1995; Wilding & Rugg, 1996, 1997; Wilding & Sharpe, 2003). One instantiation of this approach is employing this neural correlate to make inferences about when recollection is being strategically avoided (Bergström, et al. 2009; Bergström, et al. 2007; Herron & Rugg, 2003; Herron & Wilding, 2005; Wilding, et al. 2005). The experiments in this thesis were designed to achieve this, using the recognition memory exclusion task because of findings in previous work. The novel insights that are provided by the outcomes of the experiments of this thesis are two-fold. First, a new account of the factors responsible for selective retrieval in exclusion tasks has been developed and tested: WMC rather than the likelihood of target recollection is the key determinant. Second, one mechanism by which control over recollection is achieved is inhibition.

Obvious extensions to this work involve work with older populations, where long-term memory tasks are coupled with assessments of working memory capacity. It may be that returning to the lag version of the exclusion task is a sensible strategy in this regard, for the reasons to do with understanding and adhering to the task that were outlined earlier. In addition, the similarities between the findings in Experiments 2 & 3 (where different versions of the exclusion task were employed) suggest that this approach is not unreasonable. More generally, another way of looking at the findings in this thesis is that they point to the possible protective effect of maintaining working memory resources for the efficient operation of human long-term memory. If it is possible to increase the capacity of working memory, or the efficiency with which resources are deployed (for encouraging preliminary findings, see Hagger, et al. 2010) it may also be possible to ameliorate or retard the time course of some of the cognitive deficits associated with normal and/or pathological aging. The introduction to this thesis started with an exclamation from Romeo: "*oh teach me how I should forget to think*"'. A first step towards this might be increasing working memory resources.

REFERENCES

Allan, K., Wilding, E., & Rugg, M. D. (1998). Electrophysiological evidence for dissociable processes contributing to recollection. *Acta Psychologica, 98*(2-3), 231-252.

Allan, K., & Rugg, M. D. (1997). An event-related potential study of explicit memory on tests of cued recall and recognition. *Neuropsychologia, 35*(4), 387-397.

Alverez, J. A., & Emory, E. (2006). Executive Function and the Frontal Lobes: A Meta-Analytic Review. *Neuropsychology Review, 16*(1), 17-41.

Anderson (personal communication, August, 2010)

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA.: Harvard University Press.

Anderson, M. C., Bjork, E. L., & Bjork, R. A. (2000). Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychonomic Bulletin & Review, 7*(3), 522-530.

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering Can Cause Forgetting: Retrieval Dynamics in Long-Term Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(5), 1063-1087.

Anderson, M. C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Nature, 410*, 366-369.

Anderson, M. C., Ochsner, K. N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S. W. et al. (2004). Neural Systems Underlying the Suppression of Unwanted Memories. *Science, 303*, 232-235.

Anderson, M. C., & Spellman, B. A. (1995). On the Status of Inhibitory Mechanisms in Cognition: Memory Retrieval as a Model Case. *Psychological Review, 102*(1), 68-100.

Andres, P., Van der Linden, M., & Parmentier, F. B. R. (2004). Directed forgetting in working memory: Age-related differences. *Memory, 12*(2), 248-256.

Aron, A. R. (2007). The neural basis of inhibition in cognitive control. *Neuroscientist, 13*(3), 214-228.

Atkinson, R. C., & Juola, J. F. (1974). Search and decision processes in recognition memory In D. H. Krantz, R. C. Atkinson, R. D. Luce & P. Suppes (Eds.), *Contemporary developments in mathematical psychology: Learning, memory, & thinking*.

Au Young, C., Dalgleish, T., Golden, A. M., & Schartau, P. (2006). Reduced specificity of autobiographical memories following a negative mood induction. *Behaviour Research and Therapy, 44*, 1491-1490.

Azaimian-Faridani, N., & Wilding, E. L. (2006). The Influence of Criterion Shifts on Electrophysiological Correlates of Recognition Memory. *Journal of Cognitive Neuroscience, 18*(7), 1075-1086.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-424.

Baddeley, A., & Hitch, G. J. (Eds.). (1974). *Working memory* (Vol. 8). New York: Academic Press.

Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia, 45*, 2883-2901.

Bartlett, F. C. (1932). *Remembering*. Cambridge: Cambridge University Press.

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology, 74*, 1252-1265.

Baumeister, R. F., Muraven, M., & Tice, D. M. (2000). Ego depletion: A resource model of volition, self-regulation, and controlled processing. *Social Cognition, 18*, 130-150.

Bauml, K. H. (2008). Inhibitory processes. In H. L. Roediger (Ed.), *Cognitive Psychology of Memory: A Comprehensive Reference* (Vol. 2). Oxford: Elseviver.

Bauml, K. H., Pastotter, B., & Hanslmayr, S. (2010). Binding and inhibition in episodic memory-Cognitive, emotional, and neural processes. *Neuroscience and Biobehavioral Reviews, 34*(7), 1047-1054.

Bergström, Z. M., de Fockert, J., & Richardson-Klavehn, A. (2009). Event-related potential evidence that automatic recollection can be voluntarily avoided. *Journal of Cognitive Neuroscience, 21*(7), 1280-1301.

Bergström, Z. M., Velmans, M., de Fockert, J., & Richardson-Klavehn, A. (2007). ERP evidence for successful voluntary avoidance of conscious recollection. *Brain Research, 1151*, 119-133.

Berlyne, N. (1972). Confabulation. *British Journal of Psychiatry, 120*, 31-39.

Binnie, C. D., Dekker, E., Smit, A., & Van der Linden, G. (1982). Practical considerations in the positioning of EEG electrodes *Electroencephalography and Clinical Neurophysiology, 53*(4), 453-458.

Bjork, E. L., & Bjork, R. A. (2003). Intentional forgetting can increase, not decrease, residual influences of to-be-forgotten information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(4), 524-531.

Bjork, R. A. (1972). Theoretical implications of directed forgetting. In A. W. Melton & E. Martin (Eds.), *Coding processes in human memory* Washington, D. C.: Winston.

Bjork, R. A., LaBerge, D., & Legrand, R. (1968). The modification of short-term memory through instructions to forget. *Science, 10*, 55-56.

Bonhoeffer, K. (1901). *Die akuten Geisteskrankheiten der Gewohnheitstrink*. Jena: Gustav Fischer.

Borella, E., Carretti, B., & Mammarella, I. C. (2006). Do working memory and susceptibility to interference predict individual differences in fluid intelligence? *European Journal of Cognitive Psychology, 18*(1), 51-69.

Brewin, C. R., & Smart, C. R. (2005). Working memory capacity and suppression of intrusive thoughts. *Journal of Behavior Therapy and Experimental Psychiatry, 36*(1), 61-68.

Bridger, E. K., Herron, J. E., Elward, R. L., & Wilding, E. L. (2009). Neural Correlates of Individual Differences in Strategic Retrieval Processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(5), 1175-1186.

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.

Brown, J. (1954). The nature of set-to-learn and of intra-material inference in immediate memory. *Quarterly Journal of Experimental Psychology, 6*, 141-148.

Bulevich, J. B., Roediger, H. L. I., Balota, D. A., & Butler, A. C. (2006). Failures to find suppression of episodic memories in the think/no-think paradigm. *Memory & Cognition, 34*(8), 1569-1577.

Burgess, P. W., & Shallice, T. (1996). Confabulation and the control of recollection. *Memory, 4*(4), 359-411.

Burock, M. A., Buckner, R. L., Woldorff, M. G., Rosen, B. R., & Dale, A. M. (1998). Randomized event-related experimental designs allow for extremely rapid presentation rates using functional MRI. *NeuroReport, 9*(16), 3735-3739.

Chan, R. C. K., Shum, D., Toulopoulou, T., & Chen, E. Y. H. (2008). Assessment of executive functions: Review of instruments and identification of critical issues. [Review]. *Archives of Clinical Neuropsychology, 23*(2), 201-216.

Cohen, J. D., Perlstein, W. M., Braver, T. S., Nystrom, L. E., Noll, D. C., Jonides, J. et al. (1997). Temporal dynamics of brain activation during a working memory task. *Nature, 386*(6625), 604-608.

Coles, M. G. H., & Rugg, M. D. (1995). Event-Related Potential. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of Mind: Event-Related Brain Potentials and Cognition*. New York: Oxford University Press.

Conway, A. R. A., & Engle, R. W. (1994). Working Memory and Retrieval: A Resource-Dependent Inhibition Model. *Journal of Experimental Psychology: General, 123*(4), 354-373.

Conway, M. A., & Fthenaki, A. (2003). Disruption of inhibitory control of memory following lesions to the frontal and temporal lobes. *Cortex, 39*, 667-686.

Curran, T., & Cleary, A. M. (2003). Using ERPs to dissociate recollection from familiarity in picture recognition. *Cognitive Brain Research, 15*(2), 191-205.

Curran, T., & Hancock, J. (2007). The FN400 indexes familiarity-based recognition of faces. *Neuroimage, 36*(2), 464-471.

Curran, T., & Hintzman, D. L. (1995). Violations of the independence assumption in process dissociation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*(3), 531-547.

Curran, T., & Hintzman, D. L. (1997). Consequences and causes of correlations in process dissociation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(2), 496-504.

Czernochowski, D., Mecklinger, A., Johansson, M., & Brinkmann, M. (2005). Age-related defferences in familiarity and recollection: ERP evidence from a recognition memory study in children and young adults. *Cognitive, Affective & Behavioral Neuroscience, 5*(4), 417-433.

Dalgleish, T., Williams, J. M. G., Golden, A. J., Perkins, N., Feldman Barrett, L., Barnard, P. J. et al. (2007). Reduced Specificity of Autobiographical Memory and Depression: The Role of Executive Control. *Journal of Experimental Psychology: General, 136*(1), 23–42.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review, 3*, 422-433.

Dempster, F. N., & Corkill, A. J. (1999). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica, 101*(2-3), 395-416.

Depue, B. E., Banich, M. T., & Curran, T. (2006). Suppression of emotional and nonemotional content in memory - Effects of repetition on cognitive control. *Psychological Science, 17*(5), 441-447.

Depue, B. E., Curran, T., & Banich, M. T. (2007). Prefrontal regions orchestrate suppression of emotional memories via a two-phase process. *Science, 37*, 215–219.

Desmdt, J. E., Chalkin, V., & Tomberg, C. (1990). Emulation of somatosensory evoked potential (SEP) components with the 3-shell head model and the problem of 'ghost potential fields' when using an average reference in brain mapping. *Electroencephalography and clinical neurophysiology, 77*, 243-258.

Desposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378*(6554), 279-281.

Donaldson, D. I., Allan, K., & Wilding, E. L. (2002). Fractionating episodic retrieval using event-related potentials. In A. Parker, E. L. Wilding & T. J. Bussey (Eds.), *The Cognitive Neurosicence of Memory*. London: Psychology Press.

Donaldson, D. I., & Rugg, M. D. (1999). Event-related potential studies of associative recognition and recall: electrophysiological evidence for context dependent retrieval processes. *Cognitive Brain Research, 8*, 1-16.

Duzel, E., Yonelinas, A. P., Mangun, G. R., Heinze, H., & Tulving, E. (1997). Event-related brain potential correlates of two states of conscious awareness in memory. *Proceedings of the National Academy of Sciences of the United States of America, 94*, 5973-5978.

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 Nontarget Information in Older Adults. *Brain and Cognition, 36*, 390-430.

Dzulkifli, M. A., Herron, J. E., & Wilding, E. L. (2006). Memory retrieval processing: Neural indices of processes supporting episodic retrieval. *Neuropsychologia, 44*, 1120-1130.

Dzulkifli, M. A., & Wilding, E. L. (2005). Electrophysiological indices of strategic episodic retrieval processing. *Neuropsychologia, 43*, 1152-1162.

Ellis, H. C., & Ashbrook, P. W. (1988). Resource allocation model of the effects of depressed mood states on memory. In K. Fiedler & J. Forgas (Eds.), *Affect, Cognition and Social Behaviour*. Hogrefe, Germany: Gottingen.

Engle, R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 972-992.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6*(2), 122-125.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory and general fluid intelligence a latent variable approach. *Journal of Experimental Psychology: General, 125*, 309-331.

Evans, L. H., Wilding, E. L., Hibbs, C. S., & Herron, J. E. (2010). An electrophysiological study of boundary conditions for control of recollection in the exclusion task. *Brain Research, 1324*, 43-53.

Fletcher, P. C., & Henson, R. N. A. (2001). Frontal lobes and human memory - insights from functional imaging. *Brain, 124*, 849-881.

Fraser, C. S., Bridson, N. C., & Wilding, E. L. (2007). Controlled retrieval processing in recognition memory exclusion tasks. *Brain Research, 1150*, 131-142.

Freud, S. (1940/2005). *The Unconscious (Penguin Modern Classics Translated Texts)* (G. Frankland, Trans.). London: Penguin Classics.

Gardiner, J. M. (1988). Recognition failures and free-recall failures: implications for the relation between recall and recognition. *Memory & Cognition, 16*(5), 446-451.

Gathercole, S. E. (2008). Working Memory. In H. L. Roediger (Ed.), *Cognitive Psychology of Memory: A comprehensive reference* (Vol. 2). Oxford: Elseviver.

Gathercole, S. E., Adams, A.-M., & Hitch, G. J. (1994). The Children's Test of Nonword Repetition: A test of phonological working memory. *Memory & Cognition, 22*, 201-207.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2003). Working memory skills and educational attainment: evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*(1), 1-16.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology, 88*, 121-151.

Geiselman, R. E., Bjork, R. A., & Fishman, D. L. (1983). Disrupted Retrieval in Directed Frogetting: A link with posthypnotic amnesia. *Journal of Experimental Psychology: General, 112*(1), 58-72.

Golding, M., & MacLeod, C. M. (Eds.). (1998). *Intentional forgetting: interdisciplinary approaches*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Gotlib, I. H., & Joormann, J. (2010). Cognition and depression: current status and future directions. *Annual Review of Clinical Psychology, 27*(6), 286-312.

Grech, R., Cassar, T., Muscat, J., Camilleri, K. P., Fabri, S. G., Zervakis, M. et al. (2008). Review of Solving the Inverse Problem in EEG source analysis. *Journal of Neuroengeneering and Rehabilitation, 5*(25).

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin, 136*(4), 495-525.

Han, S., Huettel, S. A., Raposo, A., Adcock, R. A., & Dobbins, I. G. (2010). Functional Significance of Striatal Responses during Episodic Decisions: Recovery or Goal Attainment? *Journal of Neuroscience, 30*(13), 4767-4775.

Hartalage, S., Alloy, L. B., Vazquez, C., & Dykman, B. (1993). Automatic and effortful processing in depression. *Psychological Bulletin, 113*, 247-278.

Hasher, L., Quig, M. B., & May, C. (1997). Inhibitory control over no-longer relevant information: Adult age differences. *Memory & Cognition, 25*(3), 286-295.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193-225). San Diego, CA: Academic Pres.

Hedden, T., & Park, D. (2001). Aging and interference in verbal working memory. *Psychology and Aging, 16*(4), 666-681.

Herron, J. E., & Rugg, M. D. (2003). Strategic influences on recollection in the exclusion task: Electrophysiological evidence. *Psychonomic Bulletin & Review, 10*(3), 703-710.

Herron, J. E., & Wilding, E. L. (2005). An Electrophysiological Investigation of Factors Facilitating Strategic Recollection. *Journal of Cognitive Neuroscience, 17*(5), 777-789.

Hertel, P. T., & Calcaterra, G. (2005). Intentional forgetting benefits from thought substitution. *Psychonomic Bulletin & Review, 12*(3), 484-489.

Hertel, P. T., & Gerstle, M. (2003). Depressive deficits in forgetting. *Psychological Science, 14*(6), 573-578.

Hintzman, D. L., & Curran, T. (1994). Retrieval Dynamics of Recognition and Frequency Judgments: Evidence for Separate Processes of Familiarity and Recall. *Journal of Memory and Language, 33*(1), 1-18.

Hitch, G. J., Towse, J. N., & Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology: General, 130*, 184-198.

Hogge, M., Adam, S., & Collette, F. (2008). Directed Forgetting and Aging: The Role of Retrieval Processes, Processing Speed, and Proactive Interference. *Aging Neuropsychology and Cognition, 15*, 471-491.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*, 513-541.

Jacoby, L. L. (1998). Invariance in automatic influences of memory: toward a user's guide for the process-dissociation procedure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 3-26.

Jacoby, L. L., Begg, I. M., & Toth, J. P. (1999). Ironic effects of repitition: Measuring age-related differences in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(1), 3-22.

Jacoby, L. L., & Shrout, P. E. (1997). Toward a psychometric analysis of violations of the independence assumption in process dissociation. *Journal of Experimental Psychology: Learning, Memory, and Cognition., 23*(2), 505-510.

Jacoby, L. L., Yonelinas, A. P., & Jennings, J. M. (1997). The relation between conscious and unconscious (automatic) influences: A declaration of independence. In J. D. Cohen & W. Schooler (Eds.), *Scientific approaches to consciousness*. Hillsdale, NJ.: Erlbaum.

Janowsky, J. S., Shimamura, A. P., & Squire, L. R. (1986). Source memory impairment in patients with frontal lobe lesions. *Neuropsychologia, 27*(8), 1043-1056.

Jarvis, H. L., & Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Journal of Memory and Language, 51*, 623-643.

Jasper, H. A. (1958). The ten-twenty system of the international federation. *Electroencephalography and clinical neurophysiology, 10*, 371-375.

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

Johnson, H. M. (1994). Processes of Successful Intentional Forgetting. *Psychological Bulletin, 116*(2), 274-292.

Joormann, J., Hertel, P. T., F., B., & Gotlib, I. H. (2005). Remembering the good, forgetting the bad: Intentional forgetting of emotional material in depression. *Journal of Abnormal Psychology, 114*, 640-648.

Kroger, J. K., Saab, F. W., Fales, C. L., Bookheimer, S. Y., Cohen, M., & Holyoak, K. J. (2002). Recruitment of anterior dorsolateral prefrontal cortex in human reasoning: A parametric study of relational complexity. . *Cerebral Cortex, 12*, 477-485.

Kutas, M., & Dale, A. M. (1997). Electrical and magnetic readings of mental functions. In M. D. Rugg (Ed.), *Cognitive Neuroscience* Cambridge, MA.: MIT Press.

Kyllonen, P. C., & Chrystal, R. E. (1990). Reasoning ability (little more than) working memory. *Intelligence, 14*, 389-433.

Loftus, E. F. (1975). Leading questions and eyewitness reports. *Cognitive Psychology, 7*, 560-572.

Loftus, E. F. (1996). *Eyewitness Testimony*. Cambridge, MA: Harvard University Press.

Loftus, E. F. (2003). Our changeable memories: legal and practical implications. *Nature Neuroscience, 4*, 231-234.

Lucas, H. D., Voss, J. L., & Paller, K. A. (2009). Familiarity or Conceptual Priming? Good Question! Comment on Stenberg, Hellman, Johansson, and Rosén (2009). . *Journal of Cognitive Neuroscience, 22*(4), 615-617.

Lucas, H. D., Voss, J. L., & Paller, K. A. (2010). Familiarity or Conceptual Priming? Good Question! Comment on Stenberg, Hellman, Johansson, and Rosén (2009). . *Journal of Cognitive Neuroscience, 22*(4), 615-617.

Luck, S. (2005). *An Introduction to the Event-Related Potential technique*. Cambridge, MA.: MIT Press.

Ludwig, C., Borella, E., Tettamanti, M., & de Ribaupierre, A. (2010). Adult age differences in the Color Stroop Test: A comparison between an Item-by-item and a Blocked version. *Archives of Gerontology and Geriatrics, 51*(2), 135-142.

Luria, A. R. (1966). *Higher Cortical Functions in Man*. London: Tavistock.

Lustig, C., Hasher, L., & Zacks, R. T. (2007). Inhibitory Deficit Theory: Recent Developments and "New View". In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in Cognition*. Washington DC: American Psychological Association.

MacCallum, R. C., Zhang, S., Preacher, K. J., & Rucker, D. D. (2002). On the Practice of Dichotomization of Quantitative Variables. *Psychological Methods, 7*(1), 19-40.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*(5472), 1835-1838.

MacLeod, C. M. (1999). The item and list methods of directed forgetting: Test differences and the role of demand characteristcs. *Psychonomic Bulletin & Review, 6*(1), 123-129.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In Opposition to Inhibition. *Psychology of Learning and Motivation, 43*, 163-214.

Majerus, S., D'Argembeau, A., Perez, T. M., Belayachi, S., Van der Linden, M., Collette, F. et al. (2010). The Commonality of Neural Networks for Verbal and Visual Short-term Memory. *Journal of Cognitive Neuroscience, 22*(11), 2570-2593.

Malmstrom, T., & LaVoie, D. J. (2002). Age differences in inhibition of schema-activated distractors. *Experimental Aging Research, 28*(3), 281-298.

Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review, 87*(3), 252-271.

McCarthy, G., & Wood, C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology, 62*(3), 203-208.

Mecklinger, A. (2000). Interfacing mind and brain: a neurocognitive model of recognition memory. *Psychophysiology, 37*, 565-582.

Mecklinger, A., Parra, M., & Waldhauser, G. (2009). ERP correlated of intentional forgetting. *Brain Research, 1255*, 132-147.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Miltner, W., Braun, C., Johnson, R., Simpson, G. V., & Ruchkin, D. S. (1996). A test of brain electrical source analysis (BESA): A simulation study. *Electroencephalography and clinical neurophysiology, 91*(1), 295-310.

Moscovitch, M. (1989). Confabulation and the frontal systems: Strategic versus associative retrieval in neuropsychological theories of memory. In H. L. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 133-160). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Muraven, M., & Baumeister, R. F. (2000). Self-Regulation and Depletion of Limited Resources: Does Self-Control Resemble a Muscle? *Psychological Bulletin, 126*(2), 247-259.

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-Control as Limited Resource: Regulatory Depletion Patterns. *Journal of Personality and Social Psychology, 74*(3), 774-789.

Näätänen, R., & Picton, T. W. (1987). The N1 wave of the human electric and magnetic response to sound: a review and an analysis of the component structure. *Psychophysiology 24*, 375-425.

Neshat-Doost. (2008). Reduced specificity of emotional autobiographical memories following self-regulation depletion. *Emotion, 8*(5), 731-736.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220-246.

Nunez, p. L. (1981). *Electrical fields of the brain: The neurophysics of EEG.* New York: Oxford Universiry Press.

Oberauer, K. (2005). Binding and Inhibition in Working Memory: Individual and Age Differences in Short-Term Recognition. *Journal of Experimental Psychology: General, 134*(3), 368-387.

Oberauer, K., & Lange, E. B. (2009). Activation and binding in verbal working memory: A dual-process model for the recognition of nonwords. *Cognitive Psychology, 58*, 102-136.

Orne, M. T. (1962). The demand characteristics of an experimental design and their implications. *American Psychologist, 17*, 776-783.

Paller, K. A. (1990). Recall and stem-completion priming have different electrophysiological correlates and are modified differentially by directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(6), 1021-1032.

Paller, K. A., & Kutas, M. (1992). Brain Potentials during Memory Retrieval Provide Neurophysiological Support for the Distinction between Conscious Recollectionand Priming. *Journal of Cognitive Neuroscience, 4*(4), 375-391.

Paller, K. A., Voss, J. L., & Boehm, S. G. (2007). Validating neural correlates of familiarity. *Trends in Cognitive Sciences, 11*(6), 243-250.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal vemory across the adult life span. *Psychology and Aging, 17*(2), 299-300.

Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J. L., Frieske, D., Zwahr, M. et al. (1996). Mediators of Long-Term Memory Performance Across the Life Span. *Psychology and Aging, 11*(4), 621-637.

Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles *Clinical Neurophysiology, 110*(11), 1842-1857.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R. et al. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology, 37*, 127-152.

Picton, T. W., Lins, O. G., & Sherg, M. (1995). The recording and analysis of event-related potentials. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology*. Amseterdam: Elsevier Science.

Piolino, P., Coste, C., Martinelli, P., Mace, A., Quinette, P., Guillery-Girard, B. et al. (2010a). Reduced specificity of autobiographical memory and aging: Do the executive and feature binding functions of working memory have a role? *Neuropsychologia, 2010*(48), 429-440.

Piolino, P., Coste, C., Martinelli, P., Mace, A., Quinette, P., Guillery-Girard, B. et al. (2010b). Reduced specificity of autobiographical memory and aging: Do the executive and feature binding functions of working memory have a role? *Neuropsychologia, 48*, 429-440.

Prabhakaran, V., Narayanan, K., Zhao, Z., & Gabrieli, J. D. E. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience, 3*(1), 85-90.

Preacher, K. J., MacCallum, R. C., Rucker, D. D., & Nicewander, W. A. (2005). Use of the Extreme Groups Approach: A Critical Reexamination and New Recommendations. *Psychological Methods, 10*(2), 178-192.

Rafal, R., & Henik, A. (Eds.). (1994). *The neurology of inhibition: Integrating controlled and automatic processes.* San Diego, CA.: Academic Press.

Rakover. (1976). Voluntary forgetting: The effect of items to be remembered on those to be forgotten. *American Journal of Psychology, 89*(2), 241-252.

Ramponi, C., Barnard, P. J., & Nimmo-Smith. (2004). Recollection deficits in dysphoric mood: An effect of schematic models and executive mode? *12*(655-670).

Raz, N., Gunning, F. M., Head, D., Dupuis, J. H., McQuain, J., Briggs, S. D. et al. (1997). Selective aging of the human cerebral cortex observed in vivo: differential vulnerability of the prefrontal gray matter. *Cerebral Cortex, 7*(3), 268-282.

Redick, T. S., Heitz, R. P., & Engle, R. W. (2007). Working memory capacity and inhibition: Cognitive and social consequences. In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 81-102). Washington: American Psychological Association.

Roediger, H. L. (1974). Inhibiting the effects of recall. *Memory & Cognition, 2*(2), 261-269.

Rosen, B. R., Buckner, R. L., & Dale, A. M. (1998). Event-related functional MRI: Past, present, and future. *Proceedings of the National Academy of Sciences of the United States of America, 95*(3), 773-780.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General, 126*(3), 221-227.

Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences, 11*(6), 251-257.

Rugg, M. D., Fletcher, P. C., Chua, P. M.-L., & Dolan, R. (1999). The Role of Prefrontal Cortex in Recognition Memory and Memory for Source: An fMRI Study. *Neuroimage, 10*(5), 520-529.

Rugg, M. D., Schloerscheidt, A. M., & Mark, R. E. (1998). An Electrophysiological Comparison of Two Indices of Recollection. *Journal of Memory and Language, 39*, 47-69.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27*(5), 763-776.

Savoy, R. L. (2001). History and future directions of human brain mapping and functional neuroimaging. *Acta Psychologica, 107*(1-3), 9-42.

Schacter, D. L., Koutstaal, W., & Norman, K. A. (1997). False memories and aging. *Trends in Cognitive Sciences, 1*(6), 229-236.

Schacter, D. L., Norman, K. A., & Koutstaal, W. (1998). The cognitive neroscience of constructive memory. *Annual Review of Psychology, 49*, 289-318.

Scherg, M. (Ed.). (1990). *Fundementals of Dipole Source Potential Analysis* (Vol. 6).

Senkfor, A. J., & Van Pettern, C. (1998). Who said what? An event-related potential investigation of source and item memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 1005-1025.

Shallice, T., & Evans, M. E. (1978). The involvement of the frontal lobes in cognitive estimation. *Cortex, 14*, 294-303.

Smith, E. E., & Jonides, J. (1999). Neuroscience - Storage and executive processes in the frontal lobes. *Science, 283*(5408), 1657-1661.

Speer, N. K., & Curran, T. (2007). ERP correlates of familiarity and recollection processes in visual associative recognition. *Brain Research, 1174*, 97-109.

Spencer, K. M., Vila Abad, E., & Donchin, E. (2000). On the search for the neurophysiological manifestation of recollective experience. *Psychophysiology, 37*, 494-506.

Spencer, W. D., & Raz, N. (1994). Memory for Facts, Source, and Context: Can Frontal Lobe Dysfunction Explain Age-Related Differences. *Psychology and Aging, 9*(1), 149-159.

Stanford, M. S., Mathias, C. W., Dougherty, D. M., Lake, S. L., Anderson, N. E., & Patton, J. H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review *Personality and Individual Differences, 47*(5).

Steinmetz H; Fürst G; Meyer B U (1989) Craniocerebral topography within the international 10-20 system.*Electroencephalography and clinical neurophysiology, 72*(6):499-506.

Sternberg, G., Hellman, J., Johansson, M., & Rosen, I. (2009). Familiarity or Conceptual Priming: Event-related Potentials in Name Recognition. *Journal of Cognitive Neuroscience, 21*(2), 447-460.

Swanson, H. L., Ashbaker, M. H., & Lee, C. (1996). Learning-disabled readers' working memory as a function of processing demands. *Journal of Experimental Child Psychology, 61*, 242-275.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for math disabilities. *Journal of Educational Psychology, 96*, 471-491.

Swick, D., Senkfor, A., & Van Pettern, C. (2006). Source memory retrieval is affected by aging and prefrontal lesions: Behavioral and ERP evidence. *Brain Research, 1107*, 161-176.

Tomlinson, T. D., Huber, D. E., Rieth, C. A., & Davelaar, E. J. (2009). An interference account of cue-independent forgetting in the no-think paradigm. *Proceedings of the National Academy of Sciences of the United States of America, 106*(37), 15588-15593.

Tulving, E. (1983). *Elements of Episodic Memory*. Oxford: Oxford University Press.

Tulving, E. (1985). How many memory systems are there? *American Psychologist, 40*, 385-398.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127-154.

Ullsperger, M., Mecklinger, A., & Muller, U. (2000). An electrophysiological test of directed forgetting: The role of retrieval inhibition. *Journal of Cognitive Neuroscience, 12*(3), 924-940.

Unsworth, N., & Engle, R. W. (2007a). The Nature of Individual Differences in Working Memory Capacity: Active Maintenance in Primary Memory and Controlled Search From Secondary Memory. *Psychological Review, 114*(1), 104-132.

Unsworth, N., & Engle, R. W. (2007b). On the Division of Short-Term and Working Memory: An Examination of Simple and Complex Span and Their Relation to Higher Order Abilities. *Psychological Bulletin, 133*(6), 1038-1066.

Vilberg, K. L., Moosavi, R. F., & Rugg, M. D. (2006). The relationship between electrophysiological correlates of recollection and amount of information retrieved. *Brain Research, 1122*, 161-170.

Vilberg, K. L., & Rugg, M. D. (2008). Memory retrieval and the parietal cortex: A review of evidence from a dual-process perspective. *Neuropsychologia, 46*, 1787-1799.

Vilberg, K. L., & Rugg, M. D. (2009a). Functional Significance of Retrieval-Related Activity in Lateral Parietal Cortex: Evidence from fMRI and ERPs. *Human Brain Mapping, 30*, 1490-1501.

Vilberg, K. L., & Rugg, M. D. (2009b). Left parietal cortex is modulated by amount of recollected verbal information. *NeuroReport, 20*, 1295-1299.

Waltz, J. A., Knowlton, B. J., Holyoak, K. J., Boone, K. B., Mishkin, F. S., de Menezes Santos, M. et al. (1999). A system for relational reasoning in the human prefrontal cortex. *Psychological Science, 10*(2), 119-125.

Wegner, D. M., Schneider, D. J., R., C. S., & White, T. L. (1987). Paradoxical effects of thought supression. *Attitudes & Social Cognition, 53*(1), 5-13.

Wenzlaff, R. M., & Wegner, D. M. (2000). Thought Supression. *Annual Review of Psychology, 2000*(51), 59-91.

Wessel, I., Wetzels, S., Jelicic, M., & Merckelbach, H. (2005). Dissociation and memory suppression: A comparison of high and low dissociative individuals' performance on the Think-No Think task. *Personality and Individual Differences, 39*(8), 1461-1470.

Wheeler, M. A., & Roediger, H. L. (1992). Disparate effects of repeated testing: Reconciling Ballard's (1913) and Bartlett's (1932) results. *Psychological Science, 3*, 240-245.

Wilding, E. L. (1999). Separating retrieval strategies from retrieval success: an event-related potential study of source memory. *Neuropsychologia, 37*, 441-454.

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

Wilding, E. L., Doyle, M. C., & Rugg, M. D. (1995). Recognition memory without retrieval of context: An event related potential study. *Neuropsychologia, 33*(6), 743-767.

Wilding, E. L., Fraser, C. S., & Herron, J. E. (2005). Indexing strategic retrieval of colour information with event-related potentials. *Cognitive Brain Research, 25*, 19-32.

Wilding, E. L., & Rugg, M. D. (1996). An event-related potential study of recognition memory with and without retrieval of source. *Brain, 119*, 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., & Sharpe, H. (2003). Episodic Memory Encoding and Retrieval: Recent Insights from Event-Related Potentials. In Z. Alberto, P. Alice Mado & I. P. Michael (Eds.), *The Cognitive Electrophysiology of Mind and Brain* (pp. 169-196). San Diego: Academic Press.

Williams, J. M. G., Barnhofer, T., Crane, C., Hermans, D., Raes, F., Watkins, E. et al. (2007). Autobiographical memory specificity and emotional disorder. *Psychological Bulletin, 133*(1), 122-148.

Williams, J. M. G., & Broadbent, K. (1986). Autobiographical memory in suicide attempters. *Journal of Abnormal Psychology, 95*, 144-149.

Williams, J. M. G., Chan, S., Crane, C., & Barnhofer, T. (2006). Retrieval of autobiographical memories: The mechanisms and consequences of truncated search. *Cognition and Emotion, 20*(3/4), 351-382.

Wood. (1987). Generators of event-related potentials. In A. M. Halliday, S. R. Butler & R. Paul (Eds.), *A textbook of clinical neuropsysiology*. Chichester, UK: Wiley.

Woodruff, C. C., Hayama, H. R., & Rugg, M. D. (2006). Electrophysiological dissociation of the neural correlates of recollection and familiarity. *Brain Research, 1100*(1), 125-135.

Yonelinas, A. P. (2002). The Nature of Recollection and Familiarity: A review of 30 Years of Research. *Journal of Memory and Language, 46*, 441-517.

Yonelinas, A. P., & Jacoby, L. L. (1994). Dissociations of processes in recognition memory: effects of interference and of response speed. *Canadian Journal of Experimental Psychology, 48*(4), 516-535.

Yonelinas, A. P., & Jacoby, L. L. (1995). Dissociating automatic and controlled processes in a memory-search task: beyond implicit memory. *Psychological Research, 57*(3-4), 156-165.

Yonelinas, A. P., & Levy, B. J. (2002). Dissociating familiarity from recollection in human recognition memory: Different rates of forgetting over short retention intervals. *Psychonomic Bulletin & Review, 9*(3), 575-582.

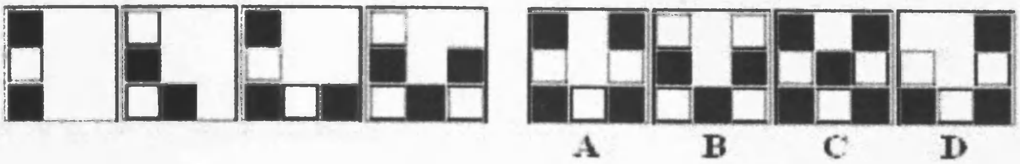
Zacks, R. T., Radvansky, G., & Hasher, L. (1996). Studies of directed forgetting in older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(1), 143-156.

APPENDIX 1: BARRAT IMPULSIVENESS SCALE

Barratt Impulsiveness Scale Please Indicate how often each statement accurately describes you by ticking the appropriate box		Never	Rarely	Occasionally	Often
1	I squirm at plays or lectures				
2	I am restless at the theatre or lectures				
3	I don't pay attention				
4	I concentrate easily				
5	I am a steady thinker				
6	I act on impulse				
7	I act of the spur of the moment				
8	I buy things on impulse				
9	I make my mind up quickly				
10	I do things without thinking				
11	I spend or charge more than I earn				
12	I am happy-go-lucky				
13	I am a careful thinker				
14	I plan tasks carefully				
15	I am self-controlled				
16	I plan trips well ahead of time				
17	I plan for job security				
18	I say things without thinking				
19	I like to think about complex problems				
20	I like puzzles				
21	I save regularly				
22	I am more interested in the present than the future				
23	I get easily bored when solving thought problems				
24	I change residences				
25	I change jobs				
26	I am future oriented				
27	I can only think about one problem at a time				
28	I often have extraneous thoughts while thinking				
29	I have racing thoughts				
30	I change hobbies				

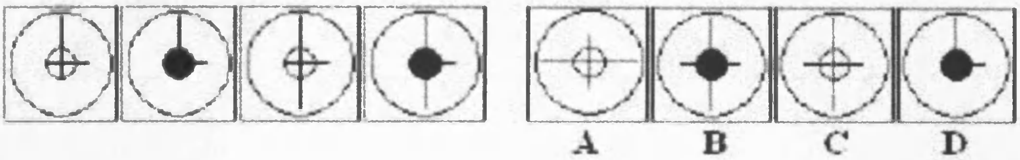
APPENDIX 2: ABSTRACT REASONING TEST

1) Which figure completes the series?



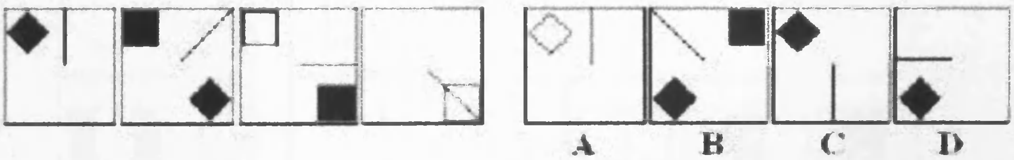
A B C D

2) Which figure completes the series?



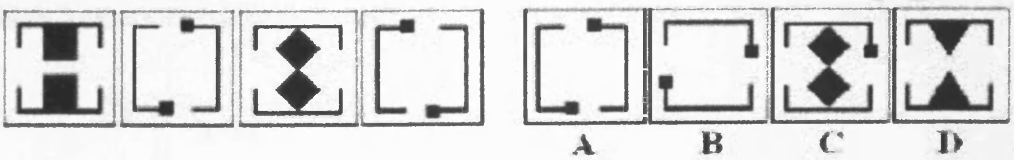
A B C D

3) Which figure completes the series?



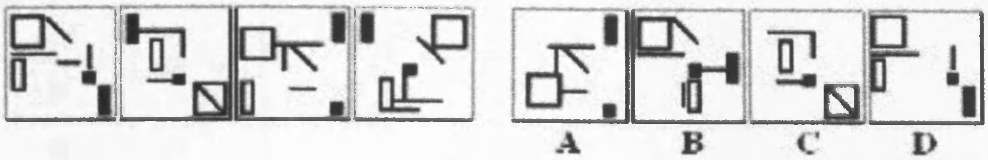
A B C D

4) Which figure completes the series?



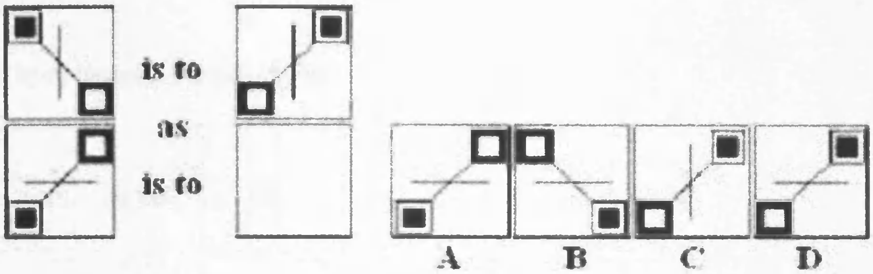
A B C D

5) Which figure completes the series?



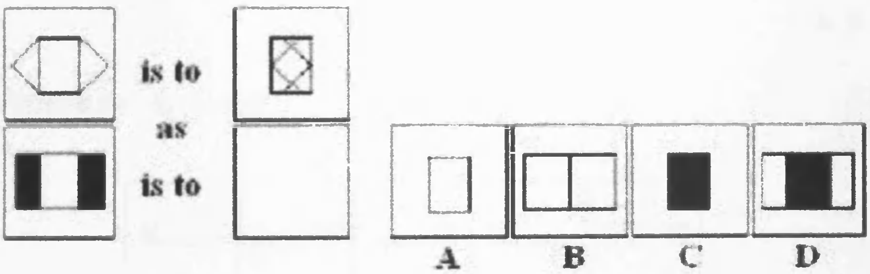
A B C D

6) Which figure completes the statement?



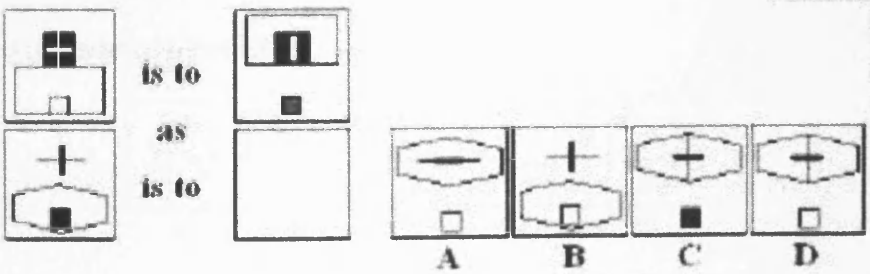
A B C D

7) Which figure completes the statement?



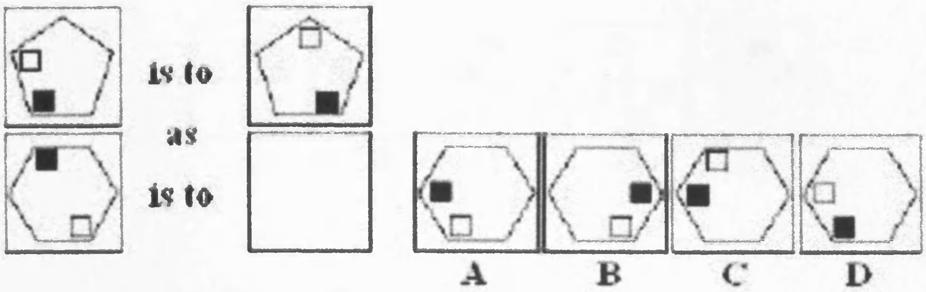
A B C D

8) Which figure completes the statement?



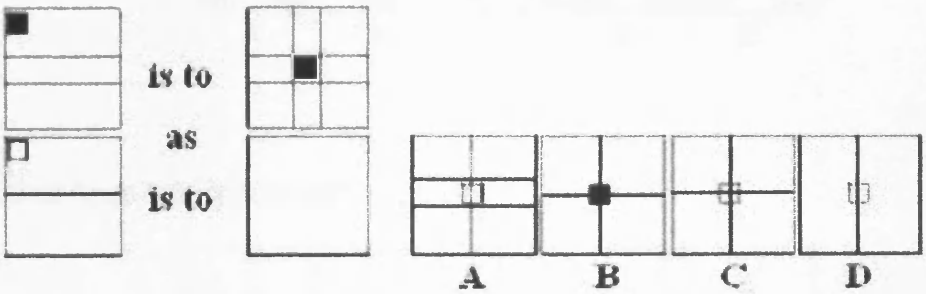
A B C D

9) Which figure completes the statement?



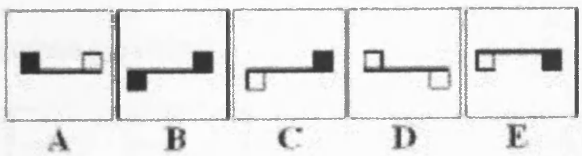
A B C D

10) Which figure completes the statement?



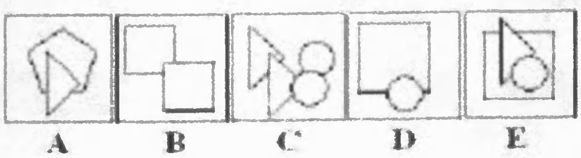
A B C D

11) Which figure is the odd one out?



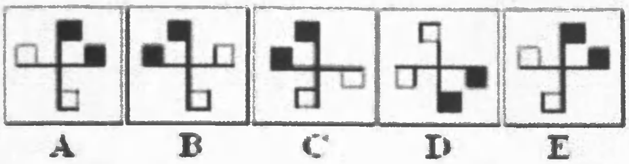
A B C D E

12) Which figure is the odd one out?



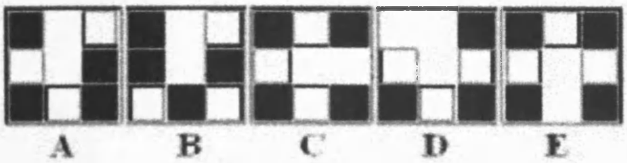
A B C D E

13) Which figure is the odd one out?



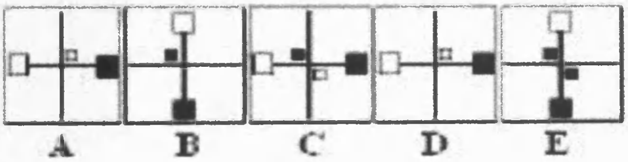
A B C D E

14) Which figure is the odd one out?



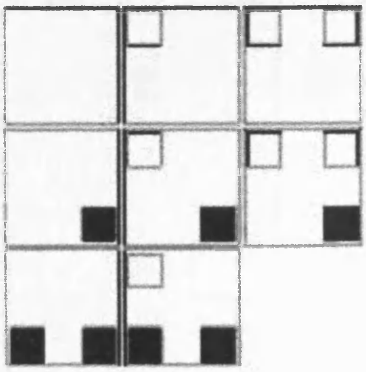
A B C D E

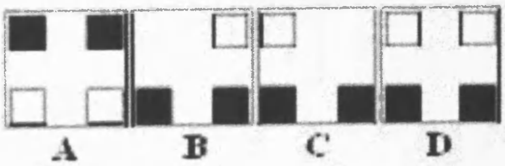
15) Which figure is the odd one out?



A B C D E

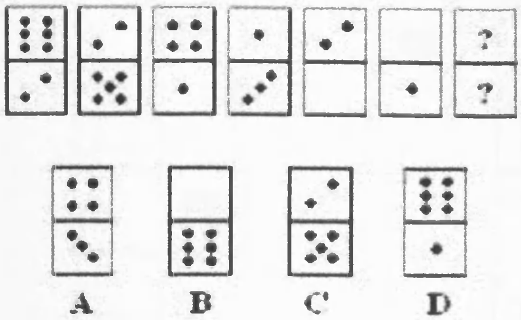
16) Which figure completes the series?





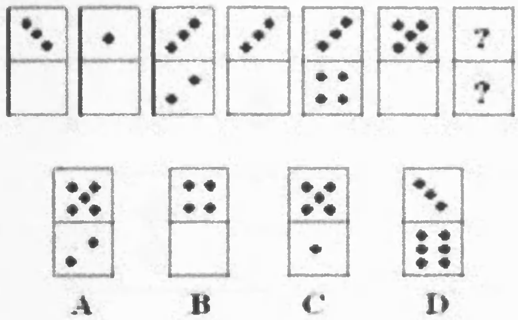
A B C D

20) Which figure is next in the series?



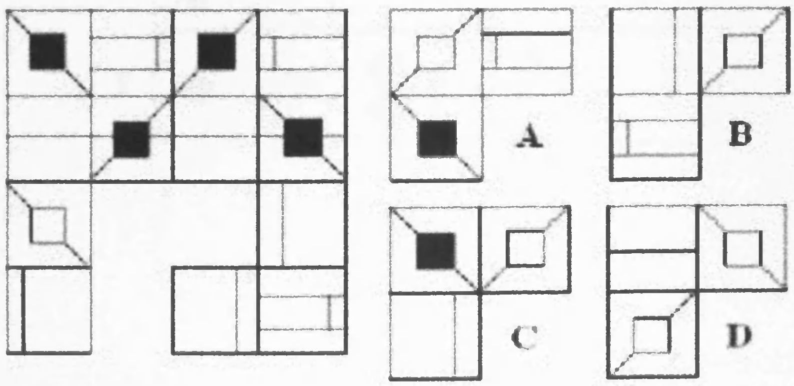
A B C D

21) Which figure is next in the series?



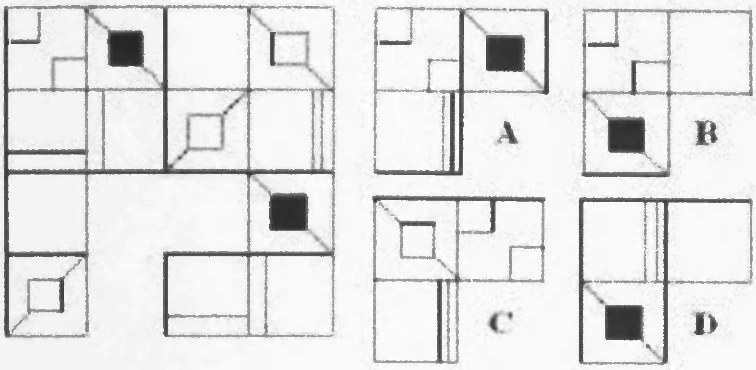
A B C D

22) Which figure completes the grid?



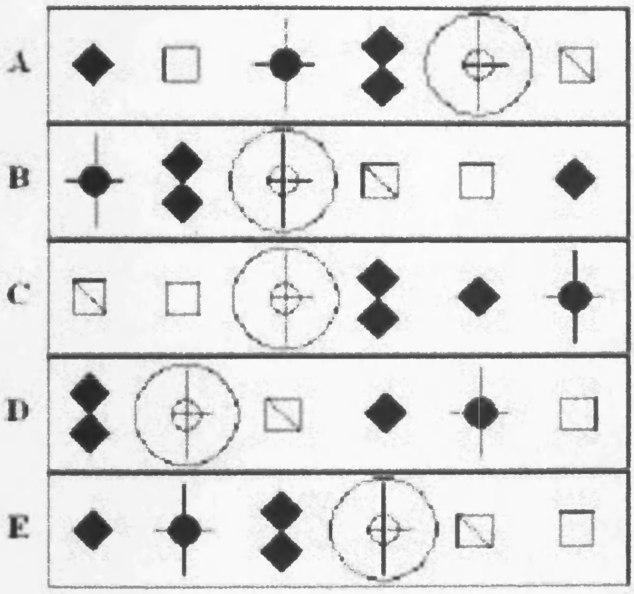
A B C D

23) Which figure completes the grid?



A B C D

24) Which figure is the odd one out?



A B C D E