The Control of Task Sets and Long-Term Memory

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Thesis submitted for the degree of

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SHORT ABSTRACT

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The current thesis explores the complex relationship between cognitive control and memory. A series of experiments combined task-switching paradigms with recognition memory tests to measure how switching between tasks influences effective control over long-term memory. In these experiments, participants were presented with compound stimuli consisting of a picture and an overlaid word, and were cued in each trial whether the word or the picture was relevant (attended) or irrelevant (unattended). Participants were then tested for their memory of items presented during task switching. Experiments 1-2 indicated that switching between tasks reduces the selectivity of processing: Switching was associated with impaired task performance as well as more similar memory ratings for attended and unattended items. Experiments 3-5 extended these findings by showing that enhanced top-down control positively affected task-performance as well as memory, in both cases by increasing the selectivity of processing toward task-relevant information. Experiments 6-7 replicated key effects with simple switches of visual attention, and explored the neural correlates of successful task performance and encoding using EEG. The key finding here was that previously observed “subsequent memory” effects reflect, at least in part, selective encoding processes. The last chapter extended the focus of the investigation to explore the role of control in long-term memory retrieval. FMRI meta-analyses indicated considerable overlap in neural activation found during task switching and during the adoption of different retrieval sets. The results of Experiment 8 indicated that switching during task performance and later memory retrieval were both associated with decreased selectivity of processing. Collectively, the results of this thesis suggest that selectivity of processing is a critical factor in effective task performance and successful memory, with potentially very similar mechanisms underlying the two. This work demonstrates the fruitfulness of combining research on cognitive control and memory to study questions relevant for both fields.

LONG ABSTRACT

The Control of Task Sets and Long-Term Memory

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Cognitive control is of central importance for successful task performance. As such, the topic of cognitive control has been a major research focus in experimental psychology. In recent years, an increasing amount of work has assessed the role of control processes in long-term memory. The main objective of the research presented in this thesis was to investigate how control processes support effective task performance and successful memory. In this thesis, these questions were investigated by combining task-switching paradigms, traditionally used to study executive processes in the cognitive control literature, with recognition-memory tests. During task switching, participants were presented with a series of word and object stimuli, and a cue indicated which of two tasks to perform. When participants had to respond to the same task as in the previous trial they performed a *repeat trial*, and when the task was changed, they performed a *switch trial*. This switching was associated with a cost in reaction times (RTs) and error rates, referred to as *switch cost*. In the recognition memory test, participants were then presented with items they had encountered in the previous task-switching phase, together with new items, and had to indicate on a rating scale whether they believed the item presented was old (i.e., seen during task switching) or new (i.e., not seen during task switching).

A key debate in the existing literature concerns the nature of cognitive control. Historically, control has often been described to be bound by capacity limitations

(Broadbent, 1958; Norman, 1968). This view has been challenged in recent years, and the idea that control serves to increase selectivity in processing has been proposed instead. However, notions of resource limitations are still central in many modern accounts of control and memory. The current thesis aimed to explore the specific relationship between control and memory.

In theories of memory, it is has been proposed that increased control demands impair memory by preventing the effective selection of task-relevant information for further encoding into memory (cf. Uncapher & Wagner, 2009). In contrast, other theories have argued that control resources are limited and that increased control demands during encoding should lead to a decrease in resources available for memory, so that less information will be encoded (Otten & Rugg, 2001; Reynolds, Donaldson, Wagner, & Braver, 2004). Critically, a similar discussion has also been held in the literature on control processes in the task-switching paradigm. Here, it has on the one hand been suggested that switch costs are the result of interference from the previous task. Specifically, this view suggests that switching results in impaired performance due to competition between current and previous tasks that is caused by a carryover of activity from the previous trial. This view implies that decreased selectivity of processing is a main reason for switch costs. An alternative set of theories argues, in contrast, that switch costs are the result of time- and resource-consuming reconfiguration processes that are specifically necessary in switch trials (Rubinstein, Meyer, & Evans, 2001). This view is more consistent with a resource-limitation account of control, as it suggests that reconfiguration imposes a demand on cognitive resources and therefore impairs the processing of information during task performance.

Chapter 2 describes the development of the main paradigm used in this thesis to study the relationship between cognitive control and memory. In this chapter, it was explored how switching between word and object classification tasks affected later recognition memory for the items presented in these tasks. A critical methodological element of the design was that participants were presented with compound stimuli comprised of a superimposed word and object: The use of these compound stimuli made it possible to separately assess the processing and memory of attended and unattended information, which was a key feature in all subsequent analyses.

The research presented in Chapter 2 revealed that task switching during the encoding phase resulted in less selective memory in the later recognition test, evident in lower memory ratings for attended stimuli combined with higher memory ratings for unattended stimuli in switch compared to repeat trials. This finding indicated that the selectivity of processing was reduced by switching. Further analyses in this chapter demonstrated that it is possible to use later performance in the memory test as an indicator of processes that underlie successful performance in the prior task-switching phase. The difference in rating scores given to the attended and unattended item of a trial (termed *memory selectivity* in subsequent analyses) “post-dicted” performance during the earlier task- switching phase, specifically in switch trials. Here, an increase in RTs and error rates was observed with decreasing memory selectivity. This result indicated that later memory was directly related to earlier task-switching performance, which provided some evidence that selective processing improved earlier task-switching performance and simultaneously later memory. Another key finding in Chapter 2 was that one of the factors influencing task performance and later memory was the salience of the stimuli presented. This finding suggested a role of bottom-up processes in task performance and memory. Follow-up analyses indicated that the effects of memory selectivity were at least partly independent of those of salience. An interesting limitation of the memory selectivity and salience analyses results was that these measures were correlated with performance only in switch trials, which suggests that repeat trial performance is more stable, possibly due to a more secure establishment of task sets (cf. Dreisbach & Haider, 2008).

The effects of stimulus salience in Chapter 2 clearly indicated bottom-up effects on task performance and memory. Top-down control was, however, not systematically varied in Chapter 2 and was assessed only indirectly by assessing the effect of fluctuations of control across trials. Chapter 3 aimed to assess the effect of variations in top-down control directly: If top-down control affects task performance and memory via similar mechanisms, then systematic variations in top-down control should lead to differences in task performance and later memory. To test this prediction, three methods were used in Chapter 3 to influence top-down control. A manipulation of preparation time (by varying the cue-stimulus interval, CSI, Experiment 3) was chosen as one of the best documented manipulations of top-down control in task-switching research. A voluntary task-switching condition (Experiment 4) introduced a motivational component, and enabled study of the nature of task control in voluntary task- switching paradigms. Lastly, a reward condition was introduced, in which reward could only be obtained with very accurate and fast performance. This condition was the most control-demanding of all three conditions, and therefore provided a crucial test of the question of whether enhanced use of top-down control induces competition between task control and encoding, or, alternatively, whether it increased the selectivity of processing.

The results of Chapter 3 showed that manipulations of top-down control during the task-switching encoding phase were not only associated with performance improvements in task switching, but also in the later memory test. The key finding was that top-down control improved memory by increasing the selectivity of encoding, not by affecting overall encoding success of both attended and unattended items. Importantly, the effects of increased control during task switching were mirrored in parallel improvements in memory. This result suggested that memory and task-switching performance were affected by top-down control in a similar way, indicating that similar processes underlie the successful performance of tasks and memory encoding. Critically, this finding is not consistent with the idea that the relationship between memory and cognitive control is characterised by competition, but much more in agreement with the notion that control increases the selectivity of processing.

Chapter 4 investigated two main questions regarding the neural correlates of task switching and memory encoding. First, it was explored whether evidence of selective processing could also be found in the neural correlates of task-switching and memory encoding as measured with EEG. A second main analysis focussed on the nature of *subsequent memory* effects during the encoding phase; that is, differences in the neural correlates of items that are later remembered compared to forgotten. In particular, differences over frontal scalp regions have previously been associated with elaborative encoding, which is usually more successful than other types of encoding such as rote encoding strategies. However, the reasons why elaborative encoding is superior have not been clearly determined. Therefore, Experiment 7 assessed the question whether frontal subsequent memory effects reflect selective encoding or general encoding success.

Although subsequent memory EEG effects in the preparation phase (i.e., before stimulus presentation) were rather weak, notable descriptive similarities were observed between switch-related control processes in the task-switching paradigm and memory-selectivity based subsequent memory effects in this phase. This similarity suggested that both effects (successful preparation for a switch and successful selective encoding) may in fact share similar underlying mechanisms. In the stimulus-phase only memory selectivity was associated with significant subsequent memory effects, suggesting that previously reported frontal subsequent memory effects in this phase might be driven by selective encoding processes. Overall, the EEG data were also consistent with the behavioural data of the experiment which indicated that the measures of selective encoding (memory selectivity) and overall encoding success (global memory) were not correlated with each other, and showed differential associations with task performance: Whereas memory selectivity predicted earlier task performance in switch trials, global memory did not show a significant association with earlier task performance.

The investigation of the behavioural data of experiments presented in Chapter 4 also addressed the question whether variations in the selectivity of processing associated with switching that were described in previous chapters could be replicated when the switching requirement was simplified. In previous experiments, the attended material and the rule with which this material was classified were switched simultaneously. The behavioural data of Chapter 4 demonstrated that the effects of switching found in the earlier experiments were not dependent on this combined switching between classification rule and attention. Such an effect was replicated when only attention was switched, but the classification rule for the objects and words remained the same.

In Chapter 5, the theoretical and methodological approach of previous chapters was extended by additionally investigating the effect of control processes on successful memory. This chapter explored the similarity between the concept of mental sets during task switching (task set) and in memory retrieval (retrieval sets). Task sets in this context constitute a set of stimuli, a set of responses, as well as rules that associated stimuli with specific responses. Retrieval sets similarly consist of a set of relevant memories (rather than stimuli), as well as responses that are mapped to these memories via specific rules.

Similarities between task sets and retrieval sets were investigated using two methods. First, activation likelihood estimation meta-analysis was conducted on published functional magnetic imaging studies of task switching and memory retrieval. Comparison of the results of these meta-analyses demonstrated substantial overlap in areas consistently activated in studies of retrieval set and those consistently activated in studies of task switching. Importantly, the memory studies displayed activity in key regions frequently identified in neuroimaging studies on task switching, the inferior frontal junction and superior parietal lobe. The finding that similar neural correlates are associated with studies of task sets and retrieval sets suggests overlap in underlying mechanisms.

Experiment 8 investigated task switching and retrieval switching in the same paradigm with the same participants. The goal of this behavioural experiment was to explore similarities in the behavioural correlates of task switching and retrieval switching. The main methodological difference to the experiments presented in previous chapters was that participants in this experiment switched between two tasks not only in the task-switching encoding, but also in the memory-retrieval phase. The tasks were conducted on pictures of famous people and their corresponding names, which was important for the later memory test: In this memory test, participants not only needed to remember which persons they had seen during the earlier task-switching phase, but also in which format this person had been presented (i.e., whether they had seen their face or name).

The findings of this experiment indicated that switching between two different retrieval tasks leads to switch cost in reaction times as well as the accuracy of performance in the retrieval test. Importantly, the results suggested that switching again reduced the selectivity of processing, in terms of more similar memory rating to task-relevant and task-irrelevant items in the memory test when the retrieval task switched. This effect demonstrated that selective processing is not only a key feature of successful task performance and encoding, but also relevant during the memory-retrieval phase. These results suggest the possible involvement of similar mechanisms in task switching and retrieval switching.

Overall, the findings reported in this thesis suggest that selectivity of processing is a key factor in successful task performance as well as later memory, and that this selectivity is a key factor for both the encoding and the successful retrieval of memories. These findings suggest that control and memory do not compete for processing resources when it is possible to selectively focus control on task- and memory-relevant information. These findings are consistent with the view that control processes should not be described as a limited resource, but are best described as enabling selectivity of processing that benefits both task performance and memory.

Chapter 1:

General Introduction

1.1 Cognitive Control and Memory: Similarities in Concepts and Theories

In our everyday lives, it is of critical importance that we attend to relevant information and ignore irrelevant information. To do this successfully we often have to change our focus of attention rapidly between different sources of information. Attention and cognitive control are central to the successful performance of flexible and accurate cognition and behaviour. In cognitive tasks, control allows the efficient filtering of relevant information, which helps to optimise processing of this information. In the context of behaviour, cognitive control has been described as the mechanisms and processes that allow us to adjust our actions depending on our current goals (Cohen, Dunbar, & McClelland, 1990; Desimone & Duncan, 1995; Norman & Shallice, 1986). It involves a broad range of cognitive operations that help us to manage and coordinate information, response execution, stimulus representations, and that allow us to flexibly adapt our processing (cf. Monsell, 1996). In this thesis I will use cognitive control as an umbrella term for a broad class of control processes that includes for example selective attention, inhibition and monitoring, all of which are believed to optimise performance of cognition and action.

The research presented in this thesis studies the role of cognitive control in long-term memory (LTM). I will focus on the role of control in encoding of information into LTM, as well as retrieval processes, and will try to draw parallels between the research on cognitive control and memory. For this reason, the following sections will review research on control as well as on memory. I will highlight similarities and differences that have emerged in the ideas and findings of both fields. Specifically, I will review the theoretical background of both fields, behavioural findings, and findings from neuropsychology and neuroimaging, before I highlight open questions that are the focus of this thesis.

Ideas related to the concept of cognitive control have been studied in psychology as long ago as the 19th century when William James (1980) discussed the differences between quick, non-deliberate “reflexes” and slower, choice-based “voluntary actions”. In 1910, Ach similarly distinguished between “habits”, defined as automatic stimulus-response associations, and capacity-limited “will”, referring to non-automatic stimulus-response associations. Willed actions, according to Ach’s theory, could be transformed into automatic actions via learning. This distinction between automatic and willed, or non-automatic actions has since become popular in psychological models of action control. Norman and Shallice (1986) distinguished between controlled and automatic actions in their influential *attention to action* model. Their theory proposes that well-learned “automatic” actions rely on “contention scheduling”, a mechanism that allows action selection between different action schemata. Contention scheduling can, however, be influenced by higher-level control, if required. This higher-level mechanism is provided by the “supervisory attentional system”, a system recruited for any complex non-routine tasks, as well as novel tasks that cannot be successfully dealt with by contention scheduling. In a similar model, Posner and colleagues (Posner, Snyder, & Davidson, 1980) suggested that automatic processes can occur without awareness and do not interfere with other processes, while controlled processes (similar to those that require the supervisory attentional system) run on limited resources and therefore restrict the operations that can be performed.

These theories highlight critical assumptions about automatic and controlled processes: On the downside, automatic processes are less flexible once they have been learned (Shiffrin & Schneider, 1977), but on the upside, automatic behaviour is faster and requires less control than “willed action”. Thus, according to these theories, whenever control is needed to successfully perform a task, this puts strain on what is believed to be a capacity-limited system.

As can be seen from the examples above, control has often been described in terms of a resource limitation. This view has been criticised as such limitations are almost exclusively described for situations in which two closely related tasks are performed simultaneously (e.g., dichotic listening, Cherry, 1953). In this case, problems with fulfilling two tasks concurrently might stem from the fact that the tasks are confused with each other, and participants neglect one of them to increase performance in the other task rather than being the result of capacity limitations. Supporting this argument, capacity limitations are not observed when different tasks are performed, such as sight reading piano music and shadowing speech at the same time (Allport, Antonis, & Reynolds, 1972). In contrast to resource-limitation models, contemporary theories of control have shifted to describe control according to the mechanisms by which it operates. The next paragraphs will review more recent theories on control that focus on such mechanism-based accounts of cognitive control.

A crucial way in which control is argued to operate is by selective focusing on information that is currently relevant. “Selective attention” or “attentional biasing” refers to the idea that attention selects relevant inputs from all information that is available to the cognitive system at a given point. Selective attention thereby describes the top-down focussing of control processes towards a stimulus. This idea is reflected in attention-biasing models (Desimone & Duncan, 1995; Posner & DiGirolamo, 1998) or the guided-activation theory by Cohen and colleagues (Cohen, et al., 1990; Miller & Cohen, 2001). These models suggest interactions between competing sources of information, and that the neural representations of this information can mutually inhibit or excite each other. Attention can be selectively allocated to relevant information in a top-down manner and strengthen the representation that is currently important.

Selective processing, or specifically selective attention is, for example, evident in performance enhancements when participants are cued to features of the relevant stimulus, such as its location in the Posner task (Posner, et al., 1980). If participants are, for example, presented with two stimuli, one of which is irrelevant for the task, they can improve task performance by focussing attention selectively on the relevant stimulus (Posner & Dehaene, 1994). At the neural level, selective attention is proposed to be achieved via amplification of cortical representations of relevant material (and perhaps also the inhibition of irrelevant information, see below). Evidence for amplification stems mainly from neuroimaging, for example from findings that event-related potentials (ERPs) to stimuli appearing in a cued attended location are enhanced compared to stimuli appearing in an unattended location (Hillyard, Vogel, & Luck, 1998; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Luck, Fan, & Hillyard, 1993).

Whereas there is thus a consensus on the idea that control in the form of attention can be selectively directed to relevant information, there are other ways in which control can be exerted. Cognitive control is often studied in situations of high interference or conflict. In these situations, cognitive control has also been argued to work in the form of the inhibition of irrelevant information or processes (Kastner & Ungerleider, 2000).

Such inhibition may be used when the processing of irrelevant information like distractors needs to be reduced, an action has to be stopped or suppressed, or when irrelevant or unwanted information needs to be kept out of awareness (Aron, 2007; Koch, Gade, Schuch, & Philipp, 2010). Inhibition is held to be apparent, for example, in the stop signal task (e.g., Logan & Cowan, 1984), in which participants perform a primary task until a predefined “stop signal” (auditory tone, visual signal etc.) tells them to withhold the response for the current trial. Participants are usually able to withhold or inhibit their response when the signal is presented shortly after the stimulus, which is taken as a sign of inhibitory control.

Amplification and inhibition are often difficult to separate from each other in behavioural and neuroimaging data, and they are likely to occur simultaneously in difficult cognitive tasks. One criticism of inhibition accounts is that the same task can either be resolved via the amplification of the relevant stimulus, and/or the inhibition of irrelevant information (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Moreover, some theories that emphasise amplification propose an indirect lateral inhibition mechanism that is automatically activated when material is amplified. In this case, inhibition would simply be a by-product of amplification rather than an independent control mechanism (Miller & Cohen, 2001). Thus, it is still the subject of debate whether amplification and inhibition are both occurring, and if so, whether inhibition is best described as a subset of amplification mechanisms, such as, for example, selective attention. This debate aside, the relevance of the degree of activation of relevant and irrelevant information is a central theme in the control literature.

A further characteristic of cognitive control is that the way it operates may be influenced by task and situational characteristics. The load theory of attention and cognitive control (Lavie, Hirst, de Fockert, & Viding, 2004) discusses the influence of situational factors on the reliance on control processes. This theory suggests that interference from irrelevant information may depend on the overall load on the cognitive system. Perceptual load determines in which of two ways the cognitive system responds: When perceptual load is high, resources are directed to the relevant information, so that no capacity is available to process potentially interfering distractors, keeping the overall conflict from these distractors low. If load is limited, however, not all resources are required for the processing of the relevant information. In this case, any spare perceptual capacity automatically “spills over” to the processing of distractors. As a result, cognitive control mechanisms need to come into place to keep distractor interference low. Thus, situations of low load put a strain on control resources. For this reason, in situations of low load, distractors can be more interfering than in situations of high load, demonstrating how situational factors influence how information is processed.

A last characteristic that has been proposed for the control of behaviour is that behaviour needs to be organised in a somewhat hierarchical fashion (Badre, 2008; Lashley, 1951; Reed, Montgomery, Palmer, & Pittenger, 1995). This kind of control process is somewhat different from the processes usually studied when investigating cognitive control, and refers to a higher level of organisation. The idea that behaviour is organised hierarchically implies that there are superordinate goals, which can be obtained by reaching a number of subgoals. These subgoals do not have to be achieved in a linear fashion. Consider, for example, the goal of preparing a peanut butter sandwich. You take the bread and the peanut butter from the cupboard, open the jar of peanut butter, and spread it onto the bread. In this sequence, different elements can be flexibly interchanged in their order: For example, it does not matter if you first take the bread out of the cupboard or whether you first take the peanut butter. If actions were strictly linear, the order of different elements could not be interchanged: It would be necessary to finish all of the subgoals in a specific order. An important role of high-level control processes is therefore the organisation of actions in hierarchical structures.

As indicated in the last paragraphs, involvement of control processes is well established for the control of current performance. However, control is also necessary for performance of memory tasks. Memory encoding describes the establishment or formation of new memories. Memory retrieval conversely describes the recovery of information that has previously been stored. Whereas cognitive control is clearly not the only factor that determines the success of encoding and retrieval (see below), there are several steps during the encoding and retrieval of memories that have been proposed to draw on control processes. In the next paragraphs I will discuss the role of control in theories of memory, before I will discuss behavioural and neural findings on control and memory.

In early theories of memory, the need for control in encoding and retrieval has been suggested. Shiffrin and Atkinson (1969) proposed that the successful storage of information into LTM requires control processes that bias sensory channels, manage rehearsal mechanisms, and regulate transfer of information from sensory to short-term to long-term stores (a distinction that is made less strictly today, cf. Cowan, 1995; Crowder, 1982; Postle, 2006; Ranganath & Blumenfeld, 2005; Ruchkin, Grafman, Cameron, & Berndt, 2003).

During encoding, cognitive control has been argued to support the maintenance of perceived, but no longer available, information in sensory areas (cf. Ranganath, DeGutis, & D'Esposito, 2004). It has been argued that control shields this provisionally-stored information from interfering or conflicting processes, and blocks out irrelevant sensory input (cf. Jonides et al., 2008). Consistent with this idea, interfering with the maintenance of information in working memory by introducing a secondary task at early stages of encoding (1 second after the stimulus is presented) has a detrimental effect on later LTM.

When interference occurs at a later stage of encoding (7 seconds after the stimulus is presented), however, it does not seem to impair LTM to the same degree (Ranganath, Cohen, & Brozinsky, 2005).

If a broader interpretation of the term “cognitive control” is adopted (i.e., one that also encompasses organisation and the use of strategies), another indication for the use of control mechanisms in memory is that memory is known to benefit from the organisation of study material.

Organisational processes are evident, for example, in chunking pieces of information rather than learning pieces of information as separate entities (Miller, 1956; Simon, 1974), in the organising of to-be memorised lists (Segal & Mandler, 1967), or in the clustering of such lists (Bousfield, 1953). If required to learn a large amount of information, people usually revert to such organisational strategies themselves, but patients with lesions in frontal cortex, an area associated with control (see below), often fail to do so (e.g., Gershberg & Shimamura, 1995).

Elaborative or deep processing of information further enhances the likelihood for this information to be remembered. This “depth of processing” effect (Craik & Lockhart, 1972) is, for example, evident when comparing remembering rates for words upon which a shallow orthographic judgement (does this word contain the letter “e”?) versus a deeper semantic judgement (does this word describe something living or non-living?) has been made. The latter task requires processing the information in a meaningful manner, which is assumed to help establish links to already stored information, which improves memory (Bradshaw & Anderson, 1982).

Moreover, whereas rehearsal is not typically described as a very control-demanding process (but see e.g., Shiffrin & Atkinson, 1969), it is also viewed as an important encoding mechanism. Rehearsal has been shown to improve memory for encoded information (Rundus, 1971), but it has also been shown not to be sufficient for accurate memory (Nickerson & Adams, 1979).

During retrieval, control processes might be expected to help the reconstruction of partial memory traces (Kolodner, 1983), to direct searches in memory (Norman, 1968; Shiffrin & Atkinson, 1969), and to filter out also-remembered but currently irrelevant information (Levy & Anderson, 2002). Control processes may play a role in ensuring that the relevant information is recalled, irrelevant information is suppressed, or that partial information is reconstructed and recombined in an adequate way.

The retrieval of information is thought to be initiated by a “retrieval cue” (Tulving & Thomson, 1973) which activates an associative network structure (cf. Anderson, 1983a; Raaijmakers & Shiffrin, 1981) and finally re-activates the relevant memory trace. This cue may either be self-generated (e.g., re-establishing the situation you last had your key, to then remember where you left it), or provided by the environment (e.g., a question in everyday life, or a stimulus in a memory test). Accordingly, monitoring how such a memory cue is processed is an important aspect at the initial stage of retrieval (Rugg & Wilding, 2000). Sometimes only weak retrieval cues are available. In this case, control processes are thought to support retrieval, for example, by monitoring the activation of information, prioritising potentially helpful information, or guiding strategic search processes to lead to a successful retrieval of the memory trace (e.g., Wheeler et al., 2006).

In situations in which no strong retrieval cue is provided, irrelevant memories may also be retrieved. These irrelevant memories can then lead to conflict and may need to be controlled or filtered out to prevent interference with the relevant memory trace. Such interference is evident, for example, in increased reaction times (RTs) in interference situations (Anderson, 1983b). Interference is thought to necessitate control mechanisms such as biasing of relevant information (Anderson et al., 2004; Anderson & Reder, 1999) or inhibition of irrelevant information (Anderson & Spellman, 1995; Healey, Campbell, Hasher, & Ossher, 2010). Attentional biasing for one kind of information has, for example, been suggested to be evident in the fact that brain activity to the same kind of new items (e.g., words) in a memory test differs when participants try to retrieve different kinds of information, such as words or pictures (e.g., Johnson & Rugg, 2006). That is, orienting retrieval attempts to different kinds of memories changes brain activity, even though the perceptual stimulation is the same. Inhibition has been argued to be evident in the finding that consistently remembering a specific aspect of associative information, reduces (or inhibits) memory for other associated information, compared to a control condition (Anderson, Bjork, & Bjork, 1994). More detailed evidence for both processes will be reviewed in later sections of this chapter.

Another way to control memory when a retrieval cue is weak is to rely on further search operations, either to elicit better retrieval cues, or, ideally the relevant memory. This memory search has also been suggested to be initiated and navigated through the successful allocation of cognitive control. Support for this notion, for example, stems from findings that patients with lesions in frontal control-related areas show difficulties in memory search processes (Shimamura, 2002), as well as from neuroimaging findings (Ranganath & Paller, 2000; Rugg & Wilding, 2000).

As with encoding, there are of course also factors independent of cognitive control that improve retrieval performance. For example, retrieval performance is expectedly most efficient when strong retrieval cues are available. The most effective retrieval cues are often available when there is an overlap of the encoding and retrieval situation (Smith, Glenberg, & Bjork, 1978) and encoding and retrieval processes (transfer appropriate processing, see Morris, Bransford, & Franks, 1977).

To conclude, cognitive control has been postulated to play an important role in the performance of cognitive tasks in situations of conflict, interference, or unautomatised processes. Control processes have not only been proposed for current performance, but also for memory encoding and retrieval, as reflected in the large number of theories and concepts in the memory literature that refer to memory control. As discussed above, not all improvements in memory performance are necessarily related to the use of control processes, but there is broad agreement that cognitive control enhances memory performance just as it improves performance in other tasks. Accordingly, there is substantial overlap in theories and ideas regarding the relevance of cognitive control in general task performance, as well as in memory. In a next step, I will extend this theoretical account and will describe behavioural and neural correlates for control processes in task performance as well as memory encoding and retrieval.

1.2 Behavioural Studies of Control and Memory

This section reviews behavioural studies that investigate cognitive control and memory, to draw comparisons between them. The following paragraphs will first review the task-switching paradigm – a method commonly used to study cognitive control that will also be employed in the current thesis. Then behavioural evidence for similarities in research on memory and control will be presented. As described in the previous section, memory processes have long been postulated to draw on control processes. Successful allocation of control is often studied with RTs and error rates in other cognitive tasks. The role of control on memory has similarly been demonstrated with behavioural measures, such as memory accuracy or recall performance, as described below.

1.2.1 Control in Task Switching

Task-switching designs are used in psychology to study control processes and flexible behaviour. In a typical task-switching paradigm, a participant is presented with a series of stimuli, and switches between two or more simple tasks, such as a magnitude versus parity judgement on numbers. Either a cue or the predefined task order (e.g., each task is repeated twice then switched) indicates when a switch is required. When the same task as in the previous trial is performed, this is referred to as a *repeat trial*, if the task changes in comparison to the previous trial, this is referred to as a *switch trial*. Switches compared to repetitions are associated with performance decrements such as increased RTs and error rates, referred to collectively as *switch costs*. Task switching is believed to be a useful method to study cognitive control, as flexible switching is assumed to be a central aspect of optimised task performance in most cognitive tasks (e.g., Kiesel et al., 2010).

Task-switching has been studied in detail since Jersild (1927) published some of the first work on this topic (cf. Kiesel, et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010). Over the years, different methodologies and variations of the design have been developed. A detailed review of the task-switching literature is beyond the scope of this thesis. Here, I will only review some theoretical and methodological points that are of relevance for the work presented in later chapters.

Cued Task-Switching Design. In the cued task-switching design, the task required on a given trial is usually determined at random and indicated by a cue. The trial sequence is not predictable for the participants, and they have no prior knowledge about the task to come. For this reason, participants need to use the cue to prepare effectively for the task.

The cued task-switching paradigm also allows manipulation of the time participants have to prepare a given task, by varying the cue-stimulus interval (CSI). This paradigm has therefore been an important tool in studying preparation processes. Switch costs typically reduce with increasing CSIs (Meiran, 1996; Monsell & Mizon, 2006). Even if long preparation times are used, however, switch costs almost never completely disappear, a finding referred to as residual switch costs.

Voluntary Task-Switching Design. One of the more recent developments in the study of task switching is the voluntary task-switching design. In this design, participants voluntarily decide which task to perform on each trial, within certain constraints such as attempting to conduct both tasks equally often, and to switch and repeat tasks randomly (cf. Arrington & Logan, 2004; Arrington & Logan, 2005). Similar to the other task-switching designs, voluntary task-switching is also associated with switch costs. Arrington and Logan argued that voluntary task-switching could measure top-down control more directly, as it necessarily requires an act of active executive control, in contrast to cued task switching (Arrington & Logan, 2004). This claim has since proven controversial (Arrington & Rhodes, 2010; Demanet, Verbruggen, Liefooghe, & Vandierendonck, 2010; Liefooghe, Demanet, & Vandierendonck, 2010; Mayr & Bell, 2006; Orr & Weissman, 2011; Yeung, 2010).

The Switch Cost

Switch costs, that is, the difference in RT and error rates between switch and repeat trials, are the main measure of control processes in the task-switching design. Since the development of task-switching designs, considerable discussion has arisen regarding the nature of the switch cost. The most common distinction is between the *reconfiguration* account and the *interference* account, though various other explanations and combinations of these two originally opposing models have been proposed (cf. Kiesel, et al., 2010; Vandierendonck, et al., 2010).

The reconfiguration account was initially proposed by Rogers and Monsell (1995). It argues that the switch cost reflects a delay in the onset of response selection in switch trials, due to the duration of control processes that support the changing of the current task set to adopt a new one. The task-set reconfiguration view has been formalised by Rubinstein et al. (2001), who argued that task processing is postponed on switch trials while the task goal is switched and new stimulus-response associations are retrieved. Models that are designed along the lines of reconfiguration processes (Meiran, 2000; Rubinstein, et al., 2001) in general propose time-consuming control mechanisms (reconfiguration processes) that are only necessary in switch, but not in repeat trials. As reconfiguration is believed to take place only in switch trials, these trials take longer than repeat trials, thus resulting in the switch cost. Reconfiguration processes have been postulated to take place either before stimulus identification (Meiran, 2000) or response selection (Rubinstein, et al., 2001).

An alternative view has been proposed by Allport, et al. (1994), who suggested that task performance is not delayed, but rather, is prolonged in switch trials. According to this view, switching leads to less successful performance, in particular slowed response selection, due to competition between current and previous tasks. This competition is due to a carryover of activity from the last trial. In this context, “task-set inertia” describes the tendency to continue to activate tasks performed on previous trials (Allport, et al., 1994). This idea of task-set inertia has also been implemented in several formal models on task-switching performance (Gilbert & Shallice, 2002; Yeung & Monsell, 2003).

Many researchers today argue for a combination of both views, and most models assume, or can easily incorporate, the existence of both reconfiguration and interference processes (e.g., Altmann & Gray, 2008; Brown, Reynolds, & Braver, 2007; Gilbert &

Shallice, 2002; Meiran, 1996; Ruthruff, Remington, & Johnston, 2001; Sohn & Anderson, 2001; Yeung & Monsell, 2003).

The theoretical accounts of the switch costs reviewed in this section demonstrate the number of different processes that have been proposed to explain performance differences in switch and repeat trials. The variety of explanations suggests that task-switching performance is the result of complex interactions between proactive top-down control and reactive adjustments in control to counteract interference caused by control failures.

1.2.2 Control of Encoding

A prominent demonstration of the role of control in memory comes from studies of divided attention and dual-task performance. In these studies, participants perform a primary encoding task (e.g., encoding auditorily presented words) while simultaneously performing a second reaction-time task (e.g., pressing a button to stimuli appearing on the computer screen). Such dual-task studies have shown that performing a secondary task during encoding has a detrimental effect on later memory (Anderson, Craik, & Naveh-Benjamin, 1998; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin & Guez, 2000; Naveh-Benjamin, Guez, & Marom, 2003). It has been suggested that encoding requires capacity-limited executive mechanisms such that performing a second task in addition to encoding causes a decline in task performance and later memory. More generally, the idea that attention and control limit what will be encoded due to capacity limitations has often been suggested in this context (Chun & Turk-Browne, 2007; Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008; Otten & Rugg, 2001b). Accordingly, it has been argued that task processing, as well as encoding are diminished as a result of a sharing of limited resources.

The role of attention in encoding can be seen when comparing memory for attended versus unattended information. If participants are presented with compound stimuli, for example, overlapping face-house pictures, and are instructed to perform a task on only one of these two stimuli, the attended stimulus is remembered well, but even if the unattended information is repeated several times, it often does not receive higher memory ratings than new information (cf. Rock & Gutman, 1981; Yi, Kelley, Marois, & Chun, 2006).

Bottom-up attention can similarly enhance encoding success. Especially salient memories do not require any rehearsal, deep processing, or intentional encoding to be remembered for decades. People seem to be able to store so called “flashbulb memories”, for example what they were doing when Kennedy was murdered (Brown & Kulik, 1977), or, more recently, the attacks from September 11th, 2001 (Hirst et al., 2009), without rehearsal or encoding strategies. These examples provide a powerful demonstration of the effect of attention on encoding, as salient events like 9/11 are said to “capture” attention in a bottom-up manner, which could explain their superior encoding. Thus, successful encoding is not only the result of top-down processing, but bottom-up attention can similarly aid the formation of memories.

To conclude, encoding often requires the allocation of cognitive control. This is evident from the research on divided attention, which demonstrates that divided attention has a detrimental effect on memory. Moreover, the beneficial effects on encoding from selective attention, and similarly the enhancement of memory related to bottom-up attentional capture demonstrate that cognitive control, here specifically selective attention, is beneficial for encoding.

1.2.3 Control of Retrieval

In contrast to the encoding of memories, the retrieval of memories seems to be less affected by divided attention. (Baddeley, Lewis, Eldridge, & Thomson, 1984; Naveh-Benjamin, Craik, Guez, & Dori, 1998; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000). As examples for situations in which retrieval is sensitive to manipulations of attention, recognition memory may be impaired by a secondary task when there are similarities between the distractor and target material (Fernandes & Moscovitch, 2000), and retrieval is also more often impaired when recall compared to recognition tests are used (Baddeley, et al., 1984). Even if studies on divided attention are somewhat inconclusive, retrieval does seem to require control processes. Irrelevant information can interfere with the retrieval of relevant information. Interference from irrelevant information is believed to be a frequent cause of the need for executive control during retrieval (Anderson, 2003). In this context, control is believed to be needed to filter out (or inhibit) irrelevant information that is retrieved when a shared retrieval cue is activated, and to bias the processing towards relevant information.

An example of interference from irrelevant information is the *fan effect* (Anderson, 1974, 1975): This effect is evident when participants encode different sentences of a similar type (e.g., about different persons and different locations, such as “A hippie is in the park.”, “A policemen is in the park.”). If they are later asked to recognise old sentences that were either identical to the earlier presented ones (“A hippie is in the park.”), overlapped with them (either person or location was repeated, e.g., “A hippie is in the church.”), or were completely new (e.g., ”A fireman is in the bank.”), participants’ RTs increase the more associations have been made between either the location, or the person, presented in the probe sentence (Anderson, 1974). This effect is thought to demonstrate interference from irrelevant items which are elicited by the same retrieval cue (in this case the probe sentence).

Proactive interference (cf. Underwood, 1957) can be demonstrated when participants learn a list of associates (A-B pairs, e.g., dog-house) and afterwards another list of partly overlapping associations (A-C pairs, e.g., dog-car). When participants are later presented with items from list A, they show decreased memory for items from list C compared to a group that learned either only A-C pairs, or B-D (e.g., house-flower) and A-C pairs; a finding that indicates that the old information interfered with learning of the new information. Meanwhile, effects of retroactive interference (cf. Osgood, 1948) can be shown when participants are later tested on their memory for list A-B (i.e., their memory for the old associations is tested). Here, participants show reduced memory for items from list A-B compared to a control group that learned only A-B pairs, or that learned A-B and C-D pairs. Thus, learning of new information compromises the memory of the old information.

Control mechanisms may play a central role in supporting memory in situations of proactive or retroactive interference. One mechanism thought to resolve this interference is selective attention. Selective attention is believed to operate by inhibiting irrelevant information, and biasing resources towards relevant information. Research has provided evidence for the inhibition of irrelevant information in memory tasks (Anderson & Spellman, 1995; Levy & Anderson, 2002), similar to the inhibition of irrelevant stimuli in non-memory tasks (e.g., Tipper, 1985). If an item is repeatedly not retrieved, compared to a competing item that is retrieved, this leads to a decline in the memory for the not-retrieved information, referred to as retrieval-induced forgetting (Anderson, 2003; Anderson, et al., 1994; Bäuml, Zellner, & Vilimek, 2005). Thus, inhibition reduces interference from currently irrelevant information, which improves current memory for relevant information, but may also reduce memory for the inhibited information later on. Forgetting has often been described as a somewhat inevitable failure of memory, but inhibition processes associated with forgetting may also be employed intentionally and may be part of an adaptive process (Mecklinger, Parra, & Waldhauser, 2009). For example, forgetting of irrelevant items is associated with reduced demands on cognitive control processes, evident in decreased RTs in the retrieval of relevant items concurrent with decreasing memory of irrelevant items across several selective retrieval trials (Kuhl, Dudukovic, Kahn, & Wagner, 2007).

In addition to the role of inhibition, it has also been suggested that selective attention operates by increasing the processing of relevant information (target biasing). An example of selective attention during retrieval is to consciously try to remember one specific aspect of information (e.g., someone’s phone number, but not their address). In an experimental condition this could mean to remember a specific kind of information. For example, in one of two different source memory tests participants could be required to remember either the size of an item at encoding, or the encoding task performed on that item (Dobbins & Wagner, 2005). Selective attention during retrieval has also been shown to aid later remembering of that information (Dudukovic, DuBrow, & Wagner, 2009): When participants retrieved previously encoded information under full or divided attention conditions, their memory for these items two days later was better for items seen in the full attention condition and actually decreased for items presented in the divided attention condition, compared to the initial test. This result indicates that even already encoded and previously successfully retrieved items are susceptible to attention effects during retrieval.

As is the case for control mechanisms in other cognitive domains, inhibition and target biasing in memory are not mutually exclusive, and most likely co-occur as mechanisms of selective attention during memory retrieval (cf. Houghton & Tipper, 1996 as well as discussion earlier in this chapter). I will come back to these two accounts when discussing the neural mechanisms of interference resolution in memory retrieval in more detail in later sections.

Summing up, retrieval processes require cognitive control particularly in situations of high interference when associated but irrelevant memories are retrieved. Resolution of conflict in memory is believed to function in a similar way as in other cognitive tasks, via biasing of relevant information and inhibition of irrelevant information.

1.2.4 The Effect of Memory on Attention

The sections above demonstrate the robust effect of control processes on memory. Interactions between memory and cognitive control or attention are, however, not limited to the effect of control on encoding and retrieval. Memory in turn guides our attention and perception (Chun & Turk-Browne, 2007), and long-term memory can also influence executive processes, demonstrating the closely intertwined relationship between the two. For example, when participants have prior knowledge about where a target will appear in a complex visual scene (e.g., based on their knowledge from previous trials) they react to that target significantly faster compared to a target in a new scene, in which their memory did not guide their attention (Summerfield, Lepsien, Gitelman, Mesulam, & Nobre, 2006). Moreover, if an alteration has to be noted in a flicker change detection task, participants react faster when this change involves the same object as in an earlier trial, even if that object is presented at a different location (Becker & Rasmussen, 2008; Chun, 2000). Lastly, memory for a single event can bias attention even several hundred trials afterwards, demonstrating the lasting influence of only one prior exposure: If participants perform one of two tasks on a stimulus and later are presented with the same stimulus, but have to perform a different task than on initial presentation, their RT and error rates are significantly increased compared to a situation in which a new task is performed on a novel stimulus (Waszak, Hommel, & Allport, 2003).

In this thesis, the main emphasis will be on the role of attention and control on memory as well as memory as a measure of control, rather than the influence of memory on control. For this reason, I will not go into further details on studies that have investigated the effect of memory on control processes.

1.3 The Neural Basis of Control and Memory

Evidence of links between cognitive control and memory also stems from neuropsychology and brain imaging. This section reviews findings from patient studies as well as electroencephalographic recordings (EEG) and functional magnetic resonance imaging (fMRI) studies of healthy participants that investigate control processes and memory. It will highlight some striking similarities, but also some key differences, between findings from the two research fields. Specifically, I will focus mainly on overlap and differentiation in areas that have been suggested to be relevant for both control and memory, and not on typical memory systems like the medial temporal lobe.

1.3.1 Control and Memory: Neuropsychological Findings

A role of the frontal cortex in cognitive control has long been suggested. Patients with frontal lesions display a variety of cognitive deficits, such as difficulties in concentration (evident in increased distractibility, Woods & Knight, 1986), difficulties in response inhibition (Floden & Stuss, 2006), difficulties in problem solving (both in the number and appropriateness of solutions generated to a problem, Channon, 2004), and difficulties in the coordination of complex actions or subgoals (e.g., in the allocation of time for each phase or in determining when to terminate a subordinate action, Goel, Grafman, Tajik, Gana, & Danto, 1997). They also display longer RTs and produce more errors in simple tasks, fulfil tasks incompletely with no attempt to structure them before they try to solve them, and are distracted by irrelevant information such as other people's conversations (Alexander, Stuss, Shallice, Picton, & Gillingham, 2005; Duncan, 1986; Shallice & Burgess, 1991).

In addition to frontal areas, parietal regions have often been associated with executive functions, particularly visuo-spatial attention. However, impairments in executive control often tend to be less severe after parietal than frontal lesions (e.g., Daffner et al., 2003). One possible explanation for this finding is that frontal regions are involved in the allocation of resources and biasing of activity in other areas including parietal cortex, whereas parietal areas are active when stimulus-response mappings need to be retrieved and tasks implemented (Brass, Ullsperger, Knoesche, von Cramon, & Phillips, 2005).

Interestingly, a dissociation between frontal and parietal regions has also been reported in memory research. Patients with frontal lesions seem to have difficulties in recalling autobiographical memories, or famous news events, and may display confabulations in these cases, a finding that has been suggested to be due to impairments in using recall strategies (Kopelman, Stanhope, & Kingsley, 1999). They especially show memory impairments for unstructured material or (similarly unstructured) day to day situations (Alexander, Stuss, & Fansabedian, 2003; Gershberg & Shimamura, 1995; Ptak & Schnider, 2004). Deficits in recall in frontal lobe patients have also been associated with a lack of organisation of information at encoding (Hirst & Volpe, 1988), further strengthening the argument that a lack of use of control strategies might be the reason for the memory impairments displayed by patients with frontal lesions. In line with the argument that patients fail to use retrieval strategies, rather than having a memory deficit, these patients show little impairment in recognition memory tests, indicating that the memory trace may be preserved, but not successfully accessed in recall situations. These patients do still display impairments in recognition tests, however, when semantically-related distractors are introduced, in which case they show intrusions of semantically-related items (Baldo, Delis, Kramer, & Shimamura, 2002). Thus, memory deficits in frontal lesion patients seem to be associated with failures of control processes that allow for the organisation of material, and the control of irrelevant information (cf. Blumenfeld & Ranganath, 2007).

In contrast to frontal lesions, lateral parietal lesions are not as consistently associated with memory difficulties (but see Davidson et al., 2008 who found that subtle impairments can be found, especially in the richness of the memory experience), even if they occur in areas that are active in the same memory task in healthy controls (Simons et al., 2008). Similar effects have also been demonstrated using transcranial magnetic stimulation (TMS) (Rossi et al., 2006, but see Vilberg & Rugg, 2008 for a different interpretation of their data). In this study by Rossi et al. (2006), participants completed an encoding task in which they performed indoor/outdoor judgement on pictures, and then were presented with a subset of these pictures as well as distractors during retrieval. Disruption of parietal activity (left or right intraparietal sulcus) caused only weak effects on memory encoding and retrieval.

Thus, memory and cognitive control processes seem to be more impaired in patients with frontal lesions, with only limited or very specific impairments when lateral parietal regions are damaged. These parallels in findings of cognitive control and memory are likely due to partially shared neural processes in both cognitive functions.

1.3.2 EEG Correlates of Control and Memory: Similarities and Differences

Another line of evidence for the common involvement of neural processes and brain regions in memory and control stems from studies of brain activity measured either with EEG or fMRI. EEG measures electrical activity of the brain in the time frame of milliseconds. FMRI does not have such a high temporal resolution, but unlike EEG measures the blood-oxygen-level-dependent (BOLD) signal, a correlate of brain activity, with a spatial resolution of millimetres. Thus, these two measures complement each other in providing detailed information about brain functioning.

1.3.3 EEG Effects Associated with Control and Memory Processes

In the study of cognitive control, several EEG effects are well documented. One way to analyse EEG is in the form of event-related potentials (ERPs). As the name suggests, these are electrophysiological responses elicited by a specific event (e.g., a cue or a stimulus). To calculate ERPs, a segment of the EEG signal (an epoch) is averaged across multiple trials, to cancel out noise and reveal common activity across trials. When studying electrophysiological measures of control processes, two different kinds of control correlates can be differentiated. On the one hand, preparation-related components can be investigated by analysing cue-locked activity. On the other hand, ERP components associated with an increased control demand can be observed when stimulus conditions of different difficulty are compared. Preparation-related ERPs are more easy to interpret because they are less confounded with stimulus-induced interference. Both kinds of control correlates will be reviewed in the following section.

Preparation-Related Effects. An important index of control is the contingent negative variation (CNV). The CNV is a marker of preparation often seen in cued RT-tasks. It is a slow wave that grows in negativity with preparation. The CNV has been shown to increase with more informative cues (van Boxtel & Brunia, 1994), or enhanced preparation demands (e.g., in switch compared to repeat trials in task switching, Tieges et al., 2006). It is frequently reported in studies of cognitive control, but similar negative slow waves are also sometimes reported in studies of short-term and long-term memory (cf. Rösler, Heil, & Glowalla, 1993; Rösler, Heil, & Hennighausen, 1995; Roth et al., 1975), where they likely indicate the preparation to respond to the probe stimulus. Such slow-wave effects have moreover been reported to be associated with subsequent memory performance (Leynes, Allen, & Marsh, 1998; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). It seems that one difference between the standard CNV and the slow wave measured in memory paradigms is that the CNV shows a central topography, whereas the corresponding effect in memory is more frontal (Leynes, et al., 1998). This difference might indicate the involvement of slightly different processes, such as more cognitive preparation in memory, and more motor preparation in other tasks. Overall, the role of the CNV in memory seems to be less well established than in other cognitive tasks.

Another prominent marker of control in cue-locked EEG data is the P3. The P3 is a positive deflection that occurs approximately 300 ms after a salient event such as a cue (or stimulus, see below). Cue-locked effects are often found in task-switching designs (Kieffaber & Hetrick, 2005), which are of particular interest for this thesis. Similar to the CNV, the parietal P3 is often increased in its amplitude when a task cue indicates a switch compared to a repetition of the previous task. A modulation of the P3 is less consistently observed over frontal scalp regions, and either no effect is found or the modulation is not consistently positive or negative, but both have been reported (Gajewski & Falkenstein, 2011; West, Langley, & Bailey, 2011).

Thus, preparation-related ERP components have been documented for cognitive control processes and similar components have sometimes been reported in memory tasks. The observation of similar effects in both fields indicates that preparation in memory and other cognitive tasks may rely on similar processes.

Stimulus-locked effects. P3 components can also be evoked by the stimulus. A P3 to the stimulus is observed in a wide variety of experimental situations, such as the oddball paradigm (in which participants have to respond to an infrequent target), the task-switching paradigm employed in this thesis, or several other experiments that vary frequency, expectancy, or novelty of target stimuli. Due to the range of paradigms the P3 has been measured in, it has been suggested to reflect a number of different processes, such as context updating, or decision making (Friedman, Cycowicz, & Gaeta, 2001; Johnson, 1988; Nieuwenhuis, Aston-Jones, & Cohen, 2005; Polich, 2007; Polich & Kok, 1995). The wide variety of events that elicit P3s make a universal interpretation difficult. Some accounts of P3 activity will be discussed below.

The P3 is typically divided into two main subcomponents, the fronto-cental P3a and the (centro-) parietal P3b (Polich, 2007). The P3a is elicited by stimulus-driven frontal attentional mechanisms. It occurs for novel stimuli (“novelty P3” Friedman, et al., 2001), and is also associated with orientation processes, for example, after infrequent stimuli (Roth, 1973; Simons, Graham, Miles, & Chen, 2001). The P3b, in contrast, is the result of temporo-parietal attention-related activity. This component seems to be more associated with working-memory processes like the updating of the task context (Donchin & Coles, 1988; Lenartowicz, Escobedo-Quiroz, & Cohen, 2010). It has also been said to be associated with the probability of task-relevant events (Gonsalvez & Polich, 2002). The latency of the P3b has been suggested to indicate the time necessary for the evaluation of the stimulus (Donchin & Coles, 1988).

In the memory literature, the distinction between P3a and P3b is not made as frequently. In memory, P3 amplitude has been shown to predict subsequent memory in recognition tests (Johnson, Pfefferbaum, & Kopell, 1985; cf., Wagner, Koutstaal, & Schacter, 1999). The P3 is enhanced for stimuli that are new in the context they are presented in, and these items tend to be better remembered (Fabiani & Donchin, 1995; Fabiani, Karis, & Donchin, 1986, 1990; Karis, Fabiani, & Donchin, 1984). This P3 activity has been interpreted as “novelty P3” or P3a. The P3a might occur in this context as a result of attentional resources being focussed towards a new stimulus, which in turn improves memory for this stimulus later on (Ranganath & Rainer, 2003). However, the relationship between P3 and memory might be more complex. Polich (2007) argues that whereas a link between P3 and memory is supported by a large number of ERP studies, a “comprehensive view has not emerged” (p. 2136). The author suggests that the relationship between P3 and memory might be described as follows: The P3a is elicited by attention demanding processes such as novelty. A subsequent P3b then emerges as the result of memory storage operations. In that sense, P3s elicited in memory paradigms would consists of both P3a and P3b subcomponents.

The latency of the P3 has also been documented to be relevant for memory. Subsequently recognised words elicit P3 components with shorter latencies than unrecognised words during encoding, possibly reflecting more successful allocation of attention during encoding (Johnson, et al., 1985).

Thus, the P3 component is a brain potential that indexes attention-related processes in the context of executive functioning and memory. Different variations of the component seem to be more related to events that automatically capture attention whereas others reflect more strategic uses of attention.

Whereas components such as the P3 can be used to measure the effectiveness of task processing as a function of control, there are also components that are proposed to index directly the degree of control demand. In EEG studies, the N2, a negative ERP component with a fronto-central scalp topography peaking around 200 ms after stimulus onset, is a prominent marker of increased cognitive control demands, or conflict (Nieuwenhuis, Yeung, & Cohen, 2004; Yeung, Botvinick, & Cohen, 2004). It has, for example, been shown when a response has to be withheld in the "go/no-go task", or in incongruent compared to congruent trials in the Eriksen-Flanker task (Heil, Osman, Wiegelmann, Rolke, & Henninghausen, 2000; Kopp, Rist, & Mattler, 1996; Wendt, Heldmann, Munte, & Kluwe, 2007; Yeung, et al., 2004). A similar negative component around 450 ms has been reported in the Stroop task (Hanslmayr et al., 2008; Liotti, Woldorff, Perez, & Mayberg, 2000). An earlier view that the N2 is simply related to response inhibition, has in recent years been adapted to the view that the N2 is related to response conflict, that is, conflict between response inhibition and execution (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003), evident in the finding that an N2 can also be elicited by go stimuli if they are less frequent than no-go stimuli.

In experiments using the "think/no-think" procedure, an adaptation of the go/no-go paradigm, the N2 has also been reported as an important neural marker of the suppression of memories (e.g., Bergström, Velmans, de Fockert, & Richardson-Klavehn, 2007). Similar to no-go trials in which an unwanted response has to be suppressed, in no-think trials participants have to avoid thinking about certain information, for example, they have to avoid recalling a memory. Similar to what is observed in the go/no-go paradigm (Kok, Ramautar, De Ruiter, Band, & Ridderinkhof, 2004), no-think trials elicit a larger N2 than think trials. The magnitude of an N2-like component (slightly earlier than the usual N2) in no-think versus think trials was shown to predict individual differences in performance in a memory test (Bergström, de Fockert, & Richardson-Klavehn, 2009). Thus, the N2 in control paradigms might be tracking similar control demands as the N2 in memory paradigms.

1.3.4 EEG Effects Associated with Memory Encoding

Whereas most EEG components that are related to cognitive control processes can be identified in memory studies as well (as would be expected given that control processes appear to be necessary for successful encoding and retrieval), there are several EEG components which have been specifically related to memory. The next paragraphs will focus on encoding-related EEG effects, as these are of most relevance for the current thesis. Encoding-related EEG effects that predict later memory are referred to as “Dm” (difference based on memory) or “subsequent memory” effects, and there has been a broad range of research studies demonstrating that differences during encoding (Paller, Kutas, & Mayes, 1987; Paller, Mccarthy, & Wood, 1988), and even in the prestimulus encoding interval (Otten, Quayle, Akram, Ditewig, & Rugg, 2006) can predict later memory.

Preparation-Related Effects. Whereas it has been known for some time that activity to a stimulus is predictive of later memory (see below), recent evidence has also suggested that preparatory activity can be associated with subsequent memory. Cue-locked neural activity for later remembered and forgotten items has been shown to differ (Galli, Choy, & Otten, 2012; Otten, et al., 2006; Otten, Quayle, & Puvaneswaran, 2010; Padovani, Koenig, Brandeis, & Perrig, 2011). The topographies of such prestimulus subsequent memory effects have, however, not shown a consistent pattern. Some studies suggest that prestimulus effects are comparable for different material types, such as auditory and visual events (Otten, et al., 2010). Other studies find that prestimulus effects can also vary with task or stimulus material used, for example, evident in differences in the topographies of successful encoding of auditory and visual words, or emotional and semantic material (Galli, et al., 2012; Padovani, et al., 2011).

There is also some discussion with regards to what these prestimulus effects reflect. One proposal is that prestimulus effects reflect overall more “favourable states of mind” (Chun & Turk-Browne, 2007), in that later encoding success might be the result of processes such as overall alertness. Other authors have suggested that these effects most likely reflect active preparation as they have been shown to be enhanced with the prospective of reward (Gruber & Otten, 2010). Further support for the argument that prestimulus memory-effects are not only due to a fluctuations in alertness, but are the result of active preparation processes directed towards the task, comes from the finding that subsequent forgetting in the think/no-think procedure can also be predicted by prestimulus activity (Hanslmayr, Spitzer, & Bauml, 2009). Thus, these prestimulus effects could be the result of controlled processing rather than general variations in arousal or alertness.

Stimulus-locked effects. EEG studies that recorded the encoding phase have documented frontal and central positive slow-wave effects associated with later better remembering (Sanquist, et al., 1980). For example, the encoding of words that are later recalled compared to forgotten is associated with a frontal positivity (Fabiani, et al., 1990; Paller, et al., 1988). This effect is often found in the range of 400 to 800 ms (after onset of the to-be-encoded word) for both recognition and recall, but can also last longer than this (Fernandez et al., 1998; Friedman & Trott, 2000; Neville, Kutas, Chesney, & Schmidt, 1986; Otten & Rugg, 2001a). A similar effect can be found with photographs of unfamiliar faces (Sommer, Komoss, & Schweinberger, 1997; Sommer, Schweinberger, & Matt, 1991) demonstrating some generality of the effect. In addition to this frontal effect, a positive centro-parietal effect in the time range between 300 and 800 ms is also often described (e.g., Sommer, et al., 1991; Voss & Paller, 2009).

To sum up, subsequent memory effects in the stimulus-locked data, and in recent years also in the cue-locked data, are well documented in the memory literature. Whereas these effects are likely in part driven or modulated by control processes, these subsequent memory effects do not have an obvious counterpart in the control literature.

In conclusion, there are consistent similarities between brain potentials related to cognitive control and memory. Often these effects show slight differences (i.e. the N2 in memory is sometimes observed earlier than the N2 in other tasks), but their obvious similarity has led to the conclusion that these processes often share similar roles in the control of non-memory and memory tasks (cf. Wilding & Ranganath, 2012). Thus, several of the EEG results extend the behavioural findings in demonstrating important parallels between the electrophysiological correlates of successful task performance and memory.

1.3.5 FMRI Correlates of Control and Memory: Similarities and Differences

Notable parallels can also be observed in fMRI findings on cognitive control and memory. The subsequent sections will first review evidence for the amplification and inhibition of information in the context of control and LTM fMRI literature. Thereafter, evidence for overlapping brain activations in control and memory research will be reviewed. As a first example, two key regions continuously reported in studies of task switching will be assessed in their importance for memory. Then I will discuss the existence of functional gradients of prefrontal cortex function and how they relate to the cognitive control and memory literature.

Theories of cognitive control have suggested that if conflict from irrelevant information arises, this conflict is resolved via amplification of relevant information, or the inhibition of irrelevant information. This hypothesis has also been assessed with fMRI, as fMRI allows to investigate material-specific differences in activations, due to the high spatial resolution of this method.

Evidence for the enhancement of the cortical representation of relevant information stems, for example, from the finding that areas associated with the processing of relevant information show increased activity in response to high conflict trials in a Stroop paradigm (Egner & Hirsch, 2005). The inhibition of irrelevant material has also been investigated. For example, both the suppression of irrelevant information and the enhancement of relevant information were found in a working-memory task that compared the maintenance of face versus scene pictures to a passive viewing condition (Gazzaley, Cooney, McEvoy, Knight, & D'Esposito, 2005).

FMRI studies on LTM have similarly found evidence for both amplification of relevant information and inhibition of irrelevant information. Stronger activity in task-relevant areas during retrieval, for example, was shown to be associated with correct target retrieval, whereas increased competitor activity was associated with less successful target recall (Kuhl, Rissman, Chun, & Wagner, 2011). Moreover, the results of this study provided evidence for the inhibition of irrelevant information, evident in a decrease of activity in task-irrelevant areas across several retrieval attempts concurrently with the forgetting of this information (Kuhl, et al., 2007).

Thus, it seems that conflict in studies of cognitive control and studies of memories may be resolved in a similar way. Given this potential overlap in mechanisms, a further question refers to whether such operations are supported by the same brain areas. As mentioned earlier, cognitive control processes have been largely associated with frontal and parietal regions. Increased control demands are consistently reported to activate PFC (Koechlin, Ody, & Kouneiher, 2003; Miller, 2000; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). Parietal regions, which have traditionally been linked to visual attention processes, have in recent years also received interest in the broader cognitive control literature (Brass, Ullsperger, et al., 2005; Esterman, Chiu, Tamber-Rosenau, & Yantis, 2009).

In the following, I will, as an example, give a more detailed review of two regions, the inferior frontal junction, and the superior parietal lobe, which are often found to be active in studies using the task-switching paradigm employed in this thesis. I will then give a broader overview of other brain regions. The findings reviewed will be discussed according to anatomical gradients that have been suggested in the literature: An anterior to posterior gradient, a ventral to dorsal gradient, and a medial to lateral gradient.

Key Regions in Task Switching

Task switching activates a network of parietal and frontal regions (cf. Kim, Cilles, Johnson, & Gold, 2011; Wager, Jonides, & Reading, 2004). Even within what should be a relatively homogenous field like task-switching, the paradigms used can vary widely between studies: Tasks can employ different kinds of stimuli (pictures, words, numbers, shapes, and sounds), and the switch can occur between different stimulus features (e.g. shape and colour), between different kinds of stimuli, (e.g., objects and words), or between different response modalities (e.g., shifting between response hands), to name just a few of the differences. It is therefore noteworthy that even though the effects of such differences between tasks and paradigms on brain activity have been assessed (e.g., Kim, Cilles, et al., 2011; Kim, Johnson, Cilles, & Gold, 2011; Wager, et al., 2004), two regions are found to be very consistently activated across studies: the inferior frontal junction (IFJ, Brass, Derrfuss, Forstmann, & von Cramon, 2005; Brass & von Cramon, 2004) and the superior parietal lobe (SPL, Serences, Schwartzbach, Courtney, Golay, & Yantis, 2004; Yantis et al., 2002).

The IFJ lies at the junction of the inferior frontal sulcus and the inferior precentral sulcus (Brass, Derrfuss, et al., 2005). This anatomical location between the PFC and premotor areas means that IFJ is ideally suited to process information from more anterior PFC regions, as well as regions related to action selection processes in premotor cortex (cf. Brass & von Cramon, 2002; Passingham, 1993). Moreover, areas near the IFJ have been associated with language processing (cf. Amunts & von Cramon, 2006), a fact that is particularly interesting given that a central role of verbal self-instruction has often been suggested in task switching (Baddeley, Chincotta, & Adlam, 2001; Miyake, Emerson, Padilla, & Ahn, 2004). The role of the IFJ as a possible hub between other regions is also highlighted by studies that focus on the functional connectivity (i.e., correlations of activity) between brain areas as an index of neural interactions between these regions. Such studies have indicated that functional connectivity between IFJ and other regions varies with the type of task (switching between abstract rules versus switching between response hands) performed by a participant (Stelzel, Basten, & Fiebach, 2011). Task-switching studies suggest a role of IFJ in activating task rules, evident in the finding that IFJ is active in the preparation period when cues allow for the preparation, but only becomes active in response to the stimulus if no advance preparation is possible (Brass & von Cramon, 2002, 2004; Ruge, Braver, & Meiran, 2009; Shi, Zhou, Muller, & Schubert, 2010).

In memory, regions close to IFJ are activated in association with both encoding and retrieval processes (Badre & Wagner, 2007; Blumenfeld, Parks, Yonelinas, & Ranganath, 2011; Blumenfeld & Ranganath, 2007). In a recent meta-analysis of 74 fMRI studies (Kim, 2011), bilateral inferior frontal regions including IFJ were found to be associated with later successful remembering versus forgetting. IFJ activation is also apparent during retrieval (Wimber, Rutschmann, Greenlee, & Bauml, 2009), particularly when participants have to switch between different retrieval tasks (Phillips, Velanova, Wolk, & Wheeler, 2009). A central role of IFJ has been proposed in a wide variety of control-demanding cognitive tasks (in addition to its consistent activation in studies using the task switching paradigm it is also consistently activated in studies using e.g., the Stroop task, or n-back task, Brass, Derrfuss, et al., 2005; Derrfuss, Brass, Neumann, & von Cramon, 2005). Thus, it is not surprising that overlap of activity in this region is seen in studies of task switching and memory, and this overlap corroborates the role of control in memory.

The second area very consistently activated in task switching, the superior parietal lobe (SPL), is part of a set of connections between occipital cortex, premotor cortex, and frontal cortex (Milner & Goodale, 2008). Connections in this pathway have been suggested to bias visual processing in favour of currently relevant objects (cf. “biased competition theory” Desimone & Duncan, 1995). In the attention literature, a distinction between inferior and superior parts of parietal lobe has been proposed (Corbetta & Shulman, 2002), which argues that inferior regions are involved in bottom-up attentional processing, whereas the SPL plays a central role in top-down attention. More specifically, inferior parietal lobe (IPL) has been suggested to be active when attention is caught by salient stimuli (e.g., when salient stimuli outside the focus of processing draw attention to their location, Corbetta, Kincade, & Shulman, 2002). The superior parietal lobe (SPL) has been argued to be involved in top-down attention, like the goal directed processing of information required to achieve a current goal (e.g., cue processing to improve reaction to a stimulus, Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000).

In task switching, SPL (like IFJ) is active in a variety of different task types such as switching between perceptual stimulus attributes, or switching between cognitive sets (Braver, Reynolds, & Donaldson, 2003; Crone, Wendelken, Donohue, & Bunge, 2006; Esterman, et al., 2009; Gurd et al.; Liston, Matalon, Hare, Davidson, & Casey, 2006; Liu, Slotnick, Serences, & Yantis, 2003; Serences, et al., 2004). The broad range of switching studies that find SPL involvement suggests that the SPL plays a broad role in task switching beyond that of only stimulus-oriented attentional control.

The SPL is consistently activated during encoding and retrieval, as indicated in recent meta-analyses (Spaniol et al., 2009; Uncapher & Wagner, 2009). SPL and intra-parietal sulcus (IPS) activity during encoding is thereby consistently reported in conjunction with better subsequent memory (Uncapher, Otten, & Rugg, 2006), whereas activity in more inferior regions including IPL and the temporo-parietal junction (TPJ) is consistently associated with a higher likelihood that items are subsequently forgotten (Otten & Rugg, 2001, cf. Uncapher & Wagner, 2009). Modulation of parietal activity with TMS has furthermore demonstrated that applying stimulation to increase activation in SPL/IPS and decrease activation in IPL leads to better memory performance than if the opposite pattern of stimulation is applied, demonstrating the dissociations of these regions (Jacobson, Goren, Lavidor, & Levy, 2012).

On the basis of overlap of parietal areas associated with memory with areas related to attentional processing, and the findings of the effect of attention on memory encoding (see above), it is often concluded that enhanced memory in conjunction with SPL activity might reflect the involvement of attention and control. Similarly, SPL activation during retrieval is frequently interpreted as attentional processes that act upon memory (Cabeza, Ciaramelli, Olson, & Moscovitch, 2008).

Other interpretations have, however, been suggested. SPL activation during memory processes does not overlap with parietal activity during attention tasks as consistently as initially proposed (Hutchinson, Uncapher, & Wagner, 2009). Moreover, on the basis of the detrimental effect of divided attention on encoding, one might expect parietal activity to be more strongly associated with encoding than retrieval, but this is not the case (Spaniol, et al., 2009). These findings argue against the interpretation that parietal retrieval effects are purely attention based. Alternative suggestions have argued that the role of parietal cortex in memory is better described via its involvement in the subjective experience and confidence in what is remembered (Simons, Peers, Mazuz, Berryhill, & Olson, 2010). Another possibility is that activity in parietal cortex is correlated with the decision on the item in the memory test: according to this idea, evidence of the item’s history is accumulated in parietal cortex and an “old” judgment is made when a certain criterion is surpassed (Wagner, Shannon, Kahn, & Buckner, 2005; see also Vilberg & Rugg, 2009, for a similar proposal).

Taken together the research reviewed above suggests that regions consistently found in studies of cognitive control (and here specifically the task-switching paradigm) are also consistently reported in studies of memory retrieval.

Anatomical Dissociations

Apart from IFJ and SPL, there are of course other brain regions that have been associated with control processes in task-switching designs, and have also been associated with memory. Although it is beyond the scope of this introduction to discuss all of these regions in detail, subsets of these regions have been discussed according to functional gradients of brain function, and different types of gradients have been suggested (Badre, 2008; Badre & D'Esposito, 2007; Botvinick, 2008; Christoff & Gabrieli, 2000; Christoff, Keramatian, Gordon, Smith, & Madler, 2009; Koechlin, et al., 2003; Koechlin & Summerfield, 2007; O'Reilly, 2010; Petrides, 2005). In the following sections, I will discuss anterior to posterior, ventral to dorsal, and medial to lateral gradients of PFC function.

Anterior-Posterior Gradient

In the postulation of an anterior-posterior distinction of PFC function, broadly, the idea is that more anterior regions are responsible for processing more abstract, higher order rules, or the maintenance of general task goals, whereas posterior areas of PFC become active when more concrete tasks are conducted (Badre & D'Esposito, 2007; Koechlin & Summerfield, 2007; Yoshida, Funakoshi, & Ishii, 2010). As would be expected from such a model, more complex or abstract forms of task switching (e.g., switching between a combination of stimulus and response attributes such as the classifications of colours and of numbers, Kim, Johnson, et al., 2011) activate anterior parts of frontal cortex (BA10, e.g., Kim, Johnson, et al., 2011). Moreover, activity in areas of anterior PFC is often sustained, for example, over the course of a task block, rather than transient in response to each trial, consistent with a role for this region in maintaining high-level task goals. In contrast, in tasks that require less abstract operations, for example, response switching tasks, in which participants switch the mappings of stimuli to responses, or perceptual switching tasks, which require participants to switch between stimulus features such as shape or colour, increased activity is observed in more posterior areas such as the pre-supplementary motor area and dorsal anterior cingulate cortex (pre-SMA/dACC, BA6/32) (Kim, Cilles, et al., 2011; Kim, Johnson, et al., 2011; Liston, et al., 2006; Rushworth, Hadland, Paus, & Sipila, 2002).

In memory studies, anterior PFC activation has mostly been observed during retrieval, but not encoding processes (Spaniol et al., 2009, but see Fletcher, Shallice, & Dolan, 1998). During memory retrieval, anterior PFC regions are often associated with source or context memory judgments (King, Hartley, Spiers, Maguire, & Burgess, 2005; Rugg, Fletcher, Chua, & Dolan, 1999; Simons, Owen, Fletcher, & Burgess, 2005), or, more broadly, specific versus broad memory judgments (Ranganath, Johnson, & D'Esposito, 2000). Medial regions of anterior PFC have also been associated with the retrieval of autobiographical memories, or memory of self-generated versus externally generated information (e.g., Cabeza & St Jacques, 2007; Simons, Henson, Gilbert, & Fletcher, 2008). Consistent with a role of anterior PFC in being active in demanding memory and non-memory tasks, source memory compared to a simple/old new judgement is undoubtedly more complex and resembles set switching in that manner.

Accordingly, in studies of task switching and memory, anterior regions have often been associated with performance of more abstract tasks. The next section discusses dissociations observed within more posterior regions, specifically in terms of a functional gradient running in the ventral-dorsal dimension.

Ventral-Dorsal Gradient

An additional dissociation has been suggested between ventral and dorsal regions of frontal cortex (O'Reilly, 2010; Petrides, 2005). According to one view (Petrides, 2005), the dorsal regions of lateral PFC are associated with the monitoring as well as the manipulation of abstract items in working memory. Ventrolateral areas on the other hand have been postulated to be involved in making judgements on stimuli represented in more posterior brain regions, as well as the encoding and retrieval of information. Ventrolateral prefrontal cortex (VLPFC) is proposed to be more related to “first order” executive processes (e.g., selection of or direct comparison between stimuli, maintenance of stimuli, retrieval of goal-relevant information), whereas dorsolateral prefrontal cortex (DLPFC) supports “second order” processes (manipulation as well as processing of relations) (cf. Blumenfeld, Nomura, Gratton, & D'Esposito, 2012; D'Esposito, Postle, Ballard, & Lease, 1999). Consistent with this proposal, it has been observed that the simple maintenance of items in working memory activates VLPFC regions, whereas the updating and manipulation of items in a 2-back task activates both VLPFC and DLPFC (Owen et al., 1999).

Such a differentiation is also consistent with the role proposed for different PFC regions in LTM (cf. Badre & Wagner, 2007; Blumenfeld, et al., 2012; Blumenfeld, et al., 2011). Blumenfeld and colleagues (2011), for example, showed that DLPFC activity is associated with the encoding of relational or between-item information, such that it only showed an increase in activity when participants encoded two nouns as interacting with each other (a process that is very similar to manipulation of information in working memory). VLPFC in contrast was also active when item-specific information (as well as relational) information was encoded, that is, also when participants were instructed to imagine two nouns to be separate from each other and focus on possible differences such as size.

The roles of VLPFC and DLPFC discussed in the control and memory literature are thus very comparable. This similarity suggests that these areas may fulfil similar roles in both areas of cognition.

Medial-Lateral Gradient

Lastly, in an influential review by Miller and Cohen (2001), it has been suggested that one major distinction between regions in PFC is that medial regions like the ACC are related to conflict detection (see also Botvinick, Braver, Carter, Barch, & Cohen, 2001) and signal the occurrence of conflict to lateral regions including the DLPFC. These regions in turn increase their activity in response to enhanced cognitive control demands. Although this broad dissociation still holds, an alternative framework has been suggested that distinguishes between “hot” medial areas (emotionally and motivationally relevant) and “cold” lateral areas (cognitive operations and calculations) (cf. O'Reilly, 2010; Olsson & Ochsner, 2008). According to this framework, medial areas such as ACC detect motivationally salient events, such as high conflict, and signal this information to lateral areas that resolve conflict (Ridderinkhof, van den Wildenberg, et al., 2004).

Activity of the ACC has also been found in memory tasks. As described in the section on interference in memory, control processes are required when multiple conflicting memory representations are active, and ACC might signal exactly this conflict to other regions. Consistent with this account of the role of ACC, ACC activity has been found when items are thought to compete in memory (Bunge, Burrows, & Wagner, 2004; Kompus, Olsson, Larsson, & Nyberg, 2009; Kuhl, et al., 2007), for example, when a cue leads to the retrieval of a target item and a distractor (Jost et al., 2012).

This role of ACC in memory tasks is consistent with the assumption that ACC is involved in performance or conflict monitoring in other cognitive tasks (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004), and that it signals suboptimal performance and initiates countermeasures when appropriate (Botvinick, 2007; Botvinick, et al., 2001; Yeung, et al., 2004). During encoding, ACC activity has not consistently been related to later memory (but see Ludmer, Dudai, & Rubin, 2011).

Moreover, related to the dissociation of “hot” medial and “cold” lateral areas, in the memory literature medial PFC activity is associated with possibly more salient self-referential (autobiographical) memories whereas lateral PFC seems to be associated with search processes and controlled retrieval in standard laboratory as well as autobiographical memory tests (Cabeza & St Jacques, 2007; Spreng, Mar, & Kim, 2009). Perhaps consistent with this distinction, medial anterior prefrontal cortex is more active when recalling internally generated memories, whereas lateral anterior prefrontal cortex does not seem to distinguish whether the to-be-recollected event is internally or externally generated (Christoff & Gabrieli, 2000; Simons, Owen, et al., 2005).

Accordingly, broadly consistent distinctions between the roles of medial and lateral areas can be made for memory and cognitive control processes. This similarity suggests that the medial-lateral gradient is also associated with comparable process in cognitive control and memory.

The literature reviewed above suggests that similarities between cognitive control and memory can be found in several areas of research. First, there are striking similarities in theories and concepts of cognitive control and memory. In the cognitive control literature one line of theories suggests that control is an effortful process and to some degree capacity limited. Another line of work suggests that selective processing determines what will be processed. In the memory literature, it has similarly been suggested that encoding possibilities are limited by the division of attention, whereas other theories have postulated that the selectivity of attention plays a crucial role in what information is encoded. In line with these theoretical accounts, behavioural findings suggest that interference of irrelevant information has a detrimental effect on task performance as well as on later memory. Moreover, neuropsychological research converges on the findings that lesions in frontal areas are associated with more obvious cognitive control and memory deficits than lesions in lateral parietal areas. Neuroimaging results provide additional insight into how control processes are applied in both cognitive control and memory paradigms. The results of the EEG studies reviewed above suggest that preparatory and stimulus-related EEG components can be identified that are associated with beneficial performance in both cognitive control and memory paradigms. Lastly, fMRI evidence suggests that overlapping brain regions are associated with successful task performance as well as memory.

1.3.6 Task Sets in Retrieval: Retrieval Orientation

The previous sections have reviewed general similarities between concepts, behavioural findings, and neuroimaging studies of control and memory. The main emphasis of the research reviewed above was on memory encoding (also the focus of most of this thesis). However, recent work on memory retrieval has focussed on another area of research that shares important parallels with the literature on cognitive control. A striking similarity between task switching and memory research is that both have proposed the existence of specific cognitive “sets” (cf. Sakai, 2008) that a person adopts to solve a particular cognitive task, or retrieve specific memories. Whereas task switching refers to these sets as *task sets*, research on memory retrieval refers to these sets as *retrieval mode* (Tulving, 1983) and *retrieval orientation* (Rugg & Wilding, 2000). Retrieval mode refers to the state or set that a person enters in order to retrieve episodic events (e.g., last year’s visit to Paris) as opposed to general semantic knowledge (e.g., that Paris is the capital of France). Retrieval orientation refers to the specific focus of an episodic retrieval attempt, for example, attempting to recall who you met on that trip to Paris versus recalling the food you ate. As outlined below, concepts of retrieval mode and retrieval orientation (collectively referred to as *retrieval set* in this thesis) show substantial overlap with the concept of task set as studied in task-switching research. Just as a retrieval set must be established when engaging in episodic retrieval, a task set must be established to perform a specific task.

Indeed, in addition to this strong conceptual similarity, there is also some methodological similarity between studies of task sets and retrieval sets. A few studies of retrieval sets have required participants to switch between different retrieval tasks, thus resembling task switching studies also in their experimental design. In these studies participants, for example, switched between different retrieval tasks, such as episodic and semantic tasks (Kompus, et al., 2009; Phillips, et al., 2009), between judging the context an item was presented in versus its recency (Dobbins, Rice, Wagner, & Schacter, 2003; Dobbins & Wagner, 2005), or between simple old/new judgements versus more specific judgements, such as the size of an item at encoding, or in which task context an item was presented (Dobbins & Han, 2006; Ranganath, et al., 2000).

When switches between these tasks are analysed, they have been shown to activate areas comparable to those active in task switching (Phillips, et al., 2009). Phillips et al. (2009, supplementary analyses) had participants switch between an episodic and a semantic task and found that switching activated regions including the SPL and IFJ. Similarly, in other studies in which participants switched randomly between different retrieval sets, activity in regions associated with task-switching was also found, even if this switching was not directly assessed (Dobbins & Han, 2006; Dobbins & Wagner, 2005). These regions included lateral frontal activations including areas in ventral and dorsal lateral prefrontal cortex, IFJ, and anterior prefrontal cortex regions, as well as superior medial parietal regions.

However, there are also substantial differences between the research in the two fields. Overall, the majority of retrieval orientation studies have not included switches between two memory tasks (Herron & Rugg, 2003; Woodruff, Uncapher, & Rugg, 2006) or did not analyse the effect of switching (Dobbins, et al., 2003; Dobbins & Wagner, 2005). The focus of studies on cognitive sets in memory is much more on reflections of differences between tasks, and to a lesser degree on the control processes involved. Conversely, task-switching studies seldom analyse between-task differences, as control processes are assumed to be largely overlapping between tasks (but see Yeung, Nystrom, Aronson, & Cohen, 2006 who analysed such between-task differences to study cognitive control).

Whereas retrieval-orientation studies are less concerned with frontal control processes, set-specific activity is also observed in frontal cortex (Sakai & Passingham, 2006). Here, left-lateralised activity is observed during the recall of items previously categorised semantically and right-lateralised activity is observed during recall of items categorised perceptually (Dobbins & Wagner, 2005), a finding that is also consistent with some of the task-switching data. In a study in which participants were switching between a face and a word task, for example, right lateralised PFC activation was detected for the face task and left lateralised PFC activation for the word task (Yeung, et al., 2006).

Thus, as evident by the findings described above, there is overlap in the concepts, methods and the neural correlates of task-switching and memory retrieval. Studying both in conjunction could provide exciting new findings for research on both cognitive control and memory processes.

1.4 Thesis Outline: Investigating the Control of Task Sets and Long-Term Memory

The goal of the present research is to study the relationship between cognitive control and memory. As detailed above, interest in the interactions between control and memory has grown over recent years (Chun & Johnson, 2011; Chun & Turk-Browne, 2007), partly based on the overlap in activity in neuroimaging studies of attention and memory, in both frontal (Buckner, 2003), and to some degree parietal regions (Cabeza, et al., 2008). Although similarities between the fields have often been noted, few studies have attempted a direct comparison such that control processes and memory processes are evaluated in the same experiment. For this reason, the research presented in this thesis aimed to investigate the interaction between cognitive control and memory directly.

To achieve this goal, I combined a well-studied method from cognitive control research, the task-switching paradigm, with tests of recognition memory. A few studies have already looked at the influence of memory on task switching, or task switching on later memory. These studies have established that memory plays an important role in task switching. For example, the previously-irrelevant task rule has to be activated from LTM when a task is switched, evident in an increase in switch costs with increasing memory-retrieval demands (Mayr & Kliegl, 2000). Moreover, other work has shown that the stimulus history influences task-switching performance. If a different task has been performed with a currently presented stimulus in an earlier trial, this makes performance of the new task more demanding, even if several hundred trials followed in between (Waszak, et al., 2003). Thus, the combination of these two research fields has proven fruitful in the past. Extending this prior work, the research presented in the current thesis introduces new methods and new theoretical questions relating to the effect of switching on memory, including the important aspect of how unattended items are processed (see below).

A central question in the memory literature concerns the nature of the relationship between control and memory. Some theories propose competition between memory processes and the control of task performance due to resource limitation (Liefooghe, et al., 2008; Otten & Rugg, 2001b; Reynolds, Donaldson, Wagner, & Braver, 2004). This view suggests that the concurrent performance of a task limits resources available for the encoding of information and therefore impairs memory encoding. Other theories have argued that control processes might increase the selectivity of processing, and therefore increase memory performance in a similar way to that in which control increases performance in other tasks (Uncapher & Wagner, 2009). Answering whether increased control demands associated with the performance of a task are associated with decreases in overall memory, or with adaptations in the selectivity of processing is therefore an important step in understanding the relationship between cognitive control and memory.

Critically, a similar but independent discussion in the cognitive control literature concerns the nature of control operations. As introduced in the discussion about switch costs, opposing theories suggest reconfiguration and between-task competition. The former view suggests that the reconfiguration of task sets requires time as well as limited resources, resulting in switch costs (e.g., Rogers & Monsell, 1995). On the other hand, it has been argued that interference from the previous task causes this performance decline (e.g., Allport, Styles, & Hsieh, 1994). This view suggests that rather than a resource limit, the selection of the relevant information is of critical importance for successful task performance.

Given the parallels of these discussions in the control and memory literature, a first aim of this thesis was to investigate how enhanced control demands associated with switching affect later memory. Several authors have suggested that increasing control demands during a task-switching encoding phase leads to decreased performance in a later memory test due to resource limitations. Otten and Rugg (2001b), for example, argued that declines in encoding in a paradigm in which participants switched between two tasks could be due to the fact that fewer resources were available for encoding, as resources were necessary for the control of the task set. Similarly, Reynolds and colleagues (2004) argued that increased response selection demands divert resources away from encoding processes. In a study on working memory, Liefooghe and colleagues (2008) likewise argued that task switching and working memory encoding share the same resources, and that therefore task switching places demands on working memory, evident in impairments in working memory maintenance.

Importantly, an alternative view has been suggested. Work that stresses the similarities between effective control and successful memory argues that encoding can be enhanced if resources are directed towards the processing of relevant information. This view implies that interference from the irrelevant material can be overcome with selective processing, in agreement with what would be expected from interference accounts. Consistent with this idea, the employment of control processes has been shown to improve later memory (Uncapher & Wagner, 2009).

Thus, one of the key questions in both task-switching/cognitive control research and in memory research concerns the question of whether cognitive control and memory are best described as competing for processing resources within a capacity-limited system, or whether the selectivity of processing determines performance. The current thesis aims to address this question in the following ways.

Chapter 2 describes the development of the main paradigm used in this thesis. A method was employed to study both selective attention and selective encoding in the same participants. The paradigm introduced consists of an incidental task-switching encoding phase in which two items (an object and a word) are presented in each trial. One of these items is relevant for the task (attended) the other one is irrelevant (unattended). This task-switching phase is followed by a surprise recognition memory test on the items presented during task switching. In this thesis, I extend previous research that has investigated the effect of attention on memory by introducing a critical methodological detail. In contrast to most previous studies of memory encoding, I presented participants with compound stimuli, consisting of an object-picture and a word. This design made it possible to investigate two key ideas: First, the chapter assesses the effect that switching attention between two tasks has on memory for both stimuli presented. This way it is possible to measure the selectivity of encoding. Second, memory was used as a measure of previous control processes. By relating later memory effects to previous performance in the task-switching paradigm, it is possible to explore how focussing of attention influences current performance. The results of this experiment indicated that the increased control demand associated with switching reduced the *selectivity* of processing and memory, evident in a smaller difference (i.e., less selective) in memory ratings to attended and unattended stimuli in switch compared to repeat trials.

Chapter 3 assesses whether the effects described in Chapter 2 could be systematically altered by modulating the use of top-down control. Demonstrating that the use of top-down control in some trials also affects later memory for information presented in these trials would provide crucial evidence that, in fact, similar processes are involved in the control of task performance and encoding. The critical prediction here was that any improvement in task-switching performance due to the increased selectivity of processing achieved via top-down control, should be mirrored in an increased selectivity of encoding. Chapter 3 therefore extended previous findings by introducing top-down modulations of control. Findings consistent with the described hypothesis would provide direct evidence of the link between selective attention and selective encoding.

The experiments in Chapters 2 and 3 used designs in which the task rules for the object and the word stimuli, as well as the to be attended material (object and word) changed simultaneously in switch trials, leaving it somewhat unclear whether switching the task rules, switching attention between the stimuli, or both, was driving the reported effects. To demonstrate that a modulation of the selectivity of processing (evident in later less selective memory for attended and unattended items in switch versus repeat trials) can be observed when only attention is switched between the stimuli, the design was simplified in the experiments reported in Chapter 4. In these experiments the same classification rules were used for the object and the word task. This was also done to make the interpretation of the subsequent EEG experiment (Experiment 7) more straightforward: Experiment 7 assessed the neural correlates of switching attention during encoding. The EEG experiment reported in Chapter 4 explores the neural correlates of the following key processes of interest. First, it was assessed whether frontal subsequent memory effects documented in the EEG literature are the result of selective encoding of relevant information or reflect more general encoding success of both attended and unattended information. This way it was possible to test whether the importance of selectivity of processing and encoding of relevant information postulated in previous chapters would be reflected in the EEG correlates. Moreover, I assessed whether the neural correlates of subsequent memory were modulated by switching, and whether control processes related to switching the task were similar to those associated with selective encoding.

Lastly, Chapter 5 introduces an extension of the method developed in Chapters 2-4 with which control in task performance and control in memory can be compared directly. Whereas the experiments presented in the preceding three chapters investigated switching during memory encoding, Chapter 5 focuses on switching during memory retrieval. In this chapter, “task sets” in the task-switching phase are compared to retrieval orientations in memory. This experiment aims to provide some direct evidence of the similarity between both concepts, by assessing the effects of switching tasks and switching between memory in the same participants.

Together the experiments reported in this thesis aim to improve the understanding of interactions between control and memory, by applying methods, knowledge and ideas from one field to the other. This integrative approach intends to provide new paradigms and analysis methods to study control and memory in a more complete framework.

Chapter 2:

Task Switching and Long-Term Memory Encoding

The goal of this chapter was to establish a robust paradigm with which to investigate the relationship between cognitive control and memory. To explore this relationship, it was necessary to develop a method that allows for the assessment of cognitive control and memory within one experiment in the same participants. For this reason a task-switching paradigm was combined with a recognition memory test. This way it was possible to explore the effect of control-demanding switching on later memory. The first experiment presented in this chapter describes an initial version of the paradigm tested. Based on the results of this experiment, the design was adapted and tested in Experiment 2. This adapted design will serve as the basis for the all the experiments subsequently reported in this thesis.

Interactions between cognitive control and memory have received substantial research interest over past years (e.g., Chun & Johnson, 2011; Gazzaley, 2010; Mecklinger, 2010; Uncapher, Hutchinson, & Wagner, 2011), but researchers are just beginning to understand the mechanisms by which cognitive control and attention influence memory processes and vice versa. Experiments that have focussed on the effect of cognitive control on memory have shown that memory tends to be impaired when participants perform multiple tasks concurrently (Craik, et al., 1996; Naveh-Benjamin, et al., 1998) or when they are distracted by irrelevant information (Wais, Rubens, Boccanfuso, & Gazzaley, 2010). These findings suggest that control is important for memory. In turn it has been demonstrated that memory can guide attention (Becker & Rasmussen, 2008; Summerfield, et al., 2006). These and other examples outlined in the introduction demonstrate the closely intertwined relationship between memory and cognitive control.

A well-established finding is that control is particularly effective when it is consistently directed to a particular type of information (e.g. the same location, Chica et al., 2011); we are less able to filter out distracting information when we switch between different types of information (cf. Dreisbach & Wenke, 2011). Task switching is a powerful tool in studying cognitive control and attention. Switching between two tasks typically results in a performance cost – increases in RTs and error rates – that has been referred to as the *switch cost*. As outlined in the introduction, different theories on the nature of this cost prevail. One proposal is that reconfiguration of task sets requires time and resources, resulting in these switch costs (e.g., Rogers & Monsell, 1995). On the other hand, it has been argued that interference from the previously irrelevant task causes this performance decline (e.g., Allport, et al., 1994). The finding that advance preparation diminishes the switch cost (Meiran, 1996; Monsell & Mizon, 2006) is taken as evidence for the reconfiguration of task sets. Evidence for the interference view stems from findings that bivalent stimuli (stimuli on which both, rather than only one of the tasks can be performed) cause increased switch costs (Rogers & Monsell, 1995), as well as from the finding that interference is increased when the alternative task has frequently been performed on a stimulus (Waszak, et al., 2003).

Importantly, both views find parallels in an independent discussion in memory. Earlier experiments have examined how attention-demanding processes during encoding affect later memory and this research has revealed that dividing attention impairs encoding. Some authors have suggested that this finding indicates that memory and control compete for limited processing resources. For example, Craik, et al. (1996) argue that “the division of attention between two tasks itself requires attentional resources that are therefore not available for memory” (p. 172), and speculate that “as resources are withdrawn the participant must employ shallower types of encoding” (p. 174), and that “subsequent memory performance is therefore lower than it ought to be if the participant had used the available time to carryout deeper, semantic processing” (p. 174).

Perhaps consistent with this view, it has been found that switching limits the amount of information that is encoded. For example, in an experiment by Reynolds, Donaldson, Wagner, and Braver (2004) information presented in switch trials was encoded less successfully than information presented in repeat trials. The authors argued that “there should be higher demand placed on response selection processes, specifically on the task-switch trials” and that these increased response selection demands “might also provide a measure of the extent to which processing resources are diverted away from the required elaborative encoding required to create a robust memory trace.” (p. 1481). Finding similar effects, Otten and Rugg (2001b) suggest that their results might “reflect competition between processes supporting encoding and processes required for the control of the “task set,” such that on trials where demands for such control were relatively heavy, fewer resources were available for encoding.”. These accounts parallel the reconfiguration view in task switching, in which it is postulated that resource-demanding reconfiguration processes are the cause of switch costs.

Critically, these studies have focussed only on attended information, which allows for an alternative interpretation of these results. Specifically, it could be that switching the task affects encoding by influencing which information attention is allocated to. That is, switching could influence the selectivity of attention at encoding: Participants may overall encode the same amount of information, but may just be less selective for task-relevant information during switching. This account is similar to the interference view in task-switching, in which it is argued that the tendency to process the previously relevant task is the cause of the switch cost. In fact, previous research has provided support for the claim that attention can influence the selectivity of encoding. Source memory judgments are more accurate when they are made on a stimulus dimension that was relevant during encoding than when the stimulus dimension was irrelevant, suggesting that encoding can be selective (cf. Uncapher & Rugg, 2009).

Critically, the hypothesis that switching limits the selectivity of processing can only be assessed when the effect of memory on unattended information is explored as well. If task switching affects memory by reducing the selectivity of encoding, this should be evident in a decrease in memory for attended information in switch relative to repeat trials, consistent with the findings of previous studies described above. Importantly, however, switching should also increase the amount of unattended information that is encoded, because residual levels of attention should still be allocated to the now irrelevant information that was relevant in the previous trial. Thus, as the task-switching studies reviewed above only included attended material, it is not possible to determine whether switching resulted in an overall impairment in memory (as reconfiguration theories might predict) or a specific reduction in the selectivity of memory encoding (as interference theories would predict).

A first key interest in this thesis was therefore to contrast these two opposing views that see control as a limited resource versus a mechanism to increase selectivity of processing. To assess selective processing of information, I extended the approach of previous experiments (e.g., Otten & Rugg, 2001b) to include unattended information. Although the effect of attention on memory is well established, the processing of unattended stimuli has been less systematically researched. This is because most studies present only relevant/attended material in each trial even when participants are asked to switch between different material types (e.g., Otten & Rugg, 2001b; Reynolds, et al., 2004). By including unattended information, I aimed to investigate selective attention and selective encoding to further the understanding on how unattended information is processed and to give clearer insight in the relationship between processing of attended and unattended information.

2.1 Experiment 1

The first experiment of this thesis investigated the effect of task switching on later memory success in order to study interactions between cognitive control and memory. The goal was to develop a paradigm in which effects of switching on memory could be studied for both attended and unattended material, thus extending previous paradigms that only focussed on attended information. For this reason, a paradigm was employed in which participants first completed a sequence of task-switching blocks with trial-unique stimuli (i.e., stimuli were only presented once in the task-switching phase); then they were tested for their memory of those stimuli. Critically, this analysis focussed on how shifting attention between two types of stimuli simultaneously presented on the screen influences memory encoding. This method created a situation in which one stimulus was attended to while the other stimulus was unattended. Using this approach it was possible to have participants switch between information that was currently relevant and attended and information that was irrelevant and unattended. Of interest was the participants’ memory performance as a function of task-switching condition (switch vs. repeat), the encoding success of attended versus unattended stimuli, the interaction between both variables, and the relationship between performance at encoding and retrieval.

For the task-switching phase, it was expected to find the well-documented switch cost, evident in an increase in RTs and error rates in switch compared to repeat trials. The main focus of this study was, however, the results of the memory test. The critical prediction here was that the participants' recognition memory for attended and unattended information should be influenced by whether or not they switched the task during the encoding of that information. Crucially, I wanted to distinguish between two possible outcomes: whether overall memory would be reduced in switch trials (as would be expected from reconfiguration models in task switching and resource-limitation models in memory), or whether overall memory would be the same in switch and repeat trials, with switching only influencing the selectivity of encoding. If this was the case, memory should be more selective in repeat trials than in switch trials, evident as a larger difference in memory ratings for attended and unattended information in repeat compared to switch trials. This result would indicate that encoding capacity is not constrained by resource limitations due to the concurrent performance of a task switch, and that the previously observed effect of switching on encoding is due to a reduced selectivity of processing (consistent with interference models of task switching and models that emphasize the selectivity of encoding).

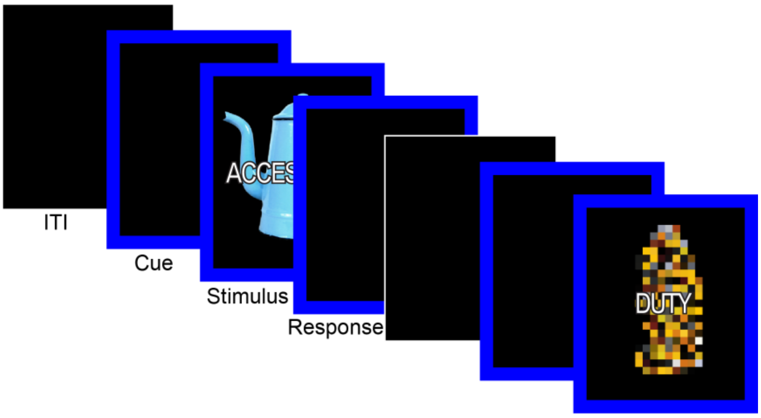
2.1.1 Methods

Participants. The sample consisted of 4 male and 12 female participants with a mean age of 22.1 years (standard deviation [*SD*] = 4.59 years). All of them were fluent English speakers. They received payment or course credits for their involvement and gave informed consent.

Material. Stimuli included in this experiment were words, object pictures, random character strings and scrambled object pictures. Stimuli were presented on a black background with the words/strings superimposed on the pictures in white font colour. The pictures taken were photo-realistic objects drawn from the Hemera Photo-Objects Collections (Hemera Photo Objects, Hull, Quebec, Canada). To create the scrambled object pictures, an original object picture was divided into squares. The squares were scrambled and half of the picture's squares were exchanged with another picture's squares. Colour in the squares was averaged. The words were a subset taken from the stimulus set reported by Poldrack et al. (1999), which consisted of a mix of abstract and concrete nouns that were 1-, 2-, or 3-syllables long. The length of the words varied between 3 and 10 letters, with an average length of 6.02 (*SD* = 1.44). The original list was reported by Poldrack to have a mean word frequency (according to Francis & Kucera, 1982) of 63.4 per million for abstract words and 47.0 per million for concrete words. The random character strings were constructed by replacing the letters in the experimental words with various non-letter and non-number symbols (e.g., !,£,%,§,=,# etc.). Words and objects were assigned randomly to the experimental conditions, separately for each participant. Thus, the pairings of objects and words within a trial was random, and pairings were rarely if ever repeated across participants, making it highly unlikely that any semantic associations between these pairs could be driving any experimental effects observed.

Tasks. Participants switched between two tasks. In the object task participants had to report whether the object was natural or man-made. The word task required participants to indicate whether it had exactly two syllables or not. At the beginning of each trial, participants were presented with a coloured frame cue for 800 ms indicating which task they should perform. A blue frame signified that they had to attend to the word and a red frame indicated that they had to attend to the object. After 800 ms, a compound stimulus was added to the cue and was displayed to the participants for 300 ms before it disappeared again. Figure 2.1 shows the exact timing of a trial. Either a word and an object, a word and a scrambled object, or a random character string and an object were presented as stimuli.

(A) Repeat trial



(B) Switch trial

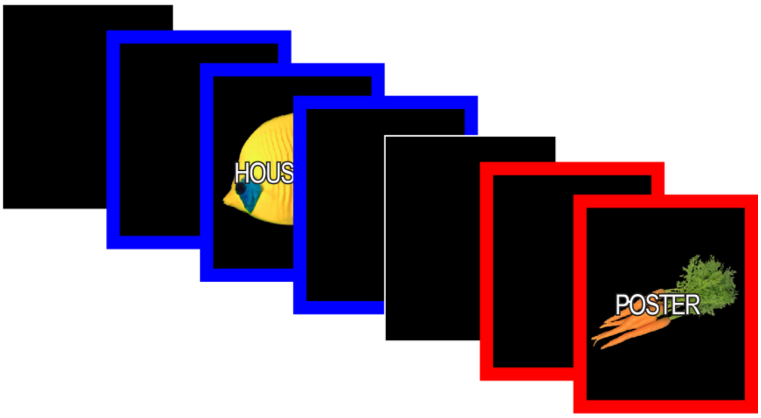


Figure 2.1: The upper panel (A) shows an example of a repeat, and the lower panel (B) shows an example of a switch trial. At the beginning of a trial, an intertrial interval (ITI, black screen, 500 ms) was presented. This was followed by a cue, and then the presentation of the stimulus (picture and overlaid word). The stimulus was presented for 300 ms before it disappeared. As soon as the participant responded, the next ITI started. The last stimulus on the repeat trial shows a scrambled object picture.

Participants responded by selecting one of four keys on a standard computer keyboard (the “x” and “n” keys were used for the object and the “z” and “m” keys for the word task, the index fingers were used for the object, and the middle fingers for the word task). There was no time limit on the responses, but participants were instructed to respond as quickly as possible while being accurate. The screen cleared for an inter-trial interval

(ITI) of 500 ms after the participant's response, followed by the cue for the subsequent trial.

Depending on the material participants attended to and the material presented to them, one of four experimental conditions resulted. In the univalent object condition, participants saw an object and a superimposed random character string, and had to attend to the object. In the bivalent object condition, participants also had to attend to the object, but this object was accompanied by a superimposed word. Stimuli in the univalent word condition comprised a scrambled picture and a word, and the participants had to attend to the word. In the bivalent word condition, an intact picture was shown with the to-be-attended word.

The entire stimulus (including the frame) subtended approximately 18.9° of visual angle on the screen vertically and horizontally. The letters/characters subtended approximately 0.76° of visual angle vertically.

Before the main experimental blocks, participants were first trained with a 16-trial block of the object task, then with a 16-trial block of the word task, followed by two task-switching blocks of 20 trials in which all 4 conditions (bivalent object, bivalent word, univalent object, and univalent word condition) were intermixed. Stimuli used in these practice blocks were not used in the main experiment.

After this training, participants completed 5 blocks of task switching with 40 trials each. The sequence in which the trial conditions were presented was randomized across blocks for each participant, resulting in approximately equal numbers of switch and repeat trials. Each condition (bivalent object, bivalent word, univalent object, and univalent word condition) was presented equally often. At the end of each block, participants received feedback on their performance in terms of reaction times (RTs) and error rates. If their error rate was higher than 10%, they were instructed to be more accurate. If their error rate approached 0%, they were instructed to try to respond faster.

Trials were classified as repeat trials if the same material was attended to in the previous as well as current trial (see Figure 2.1A), and as switch trials if the alternate material was attended to in the previous trial (see Figure 2.1B). The switch cost was defined as the difference in mean RT and percentage of errors between switch and repeat trials.

After completion of the task-switching blocks, a surprise forced-choice recognition memory test followed. Participants were presented with two stimuli on each trial (see Figure 2.2 for examples). These were either two words or two objects, presented next to each other on the screen. One of the stimuli had been seen before in the task-switching phase of the experiment, the other one was a new stimulus. Participants had to indicate which of the two stimuli was the old one. They responded with one of four keys. Two keys on the right indicated that the stimulus on the right was the old one, two keys on the left indicated that the stimulus on the left was the old one. Depending on their confidence participants pressed the outmost keys to indicate a confident and the other key to indicate an unconfident judgment.

The memory test consisted of 300 trials total with a break after 150 trials. Answers to the memory test were self-paced (i.e., there was no time limit to the response). After the participant made a choice the screen cleared for a 500 ms ITI before the next trial started. The pictures and words were presented in the same size as during the task-switching phase, but were now presented next to each other.

For the analysis of the task-switching data, RT outliers (3 *SD* above the mean) and trials following an error were excluded. For the RT-data analysis, error trials were also excluded. Trials answered incorrectly during task-switching were excluded in the analysis of the memory data.

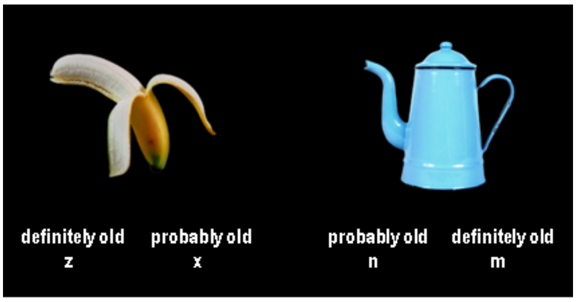


Figure 2.2. *Example of stimulus presentation in the memory test in Experiment 1. In each trial, a new and an old picture or word were shown. Participants were instructed to choose the old stimulus, and indicated whether it was probably or definitely the old one by pressing one of two keys. Each trial was followed by a 500 ms ITI. There was no time limit for the response.*

2.1.2 Results

Task Switching

In a first step, I wanted to assess whether switching versus repeating the task led to the usually observed switch cost and how this cost was affected by the type of trial (univalent or bivalent). For this purpose, analyses of RT data were conducted on all trials, excluding error trials and trials following errors, as well as excluding RT outliers (defined as RTs with 3*SD* above or below the mean). For the analysis of the error-rate data only trials following errors were excluded.

An ANOVA with factors switch (switch vs. repeat), material (object vs. word), and mode (univalent vs. bivalent stimuli) revealed the following effects (see Figure 2.3 and Figure 2.4). A main effect of switch, $F(1, 15) = 34.81$, $p < .01$, indicated that responses to switch trials were slower (1089 ms) than those to repeat trials (918 ms), but a similar trend was not significant in the error data (7.9% vs. 6.1%), $F(1, 15) = 2.19$, $p = .159$. A main effect of material, $F(1, 15) = 25.71$, $p < .01$, indicated slower responses to word than object trials (1100 ms vs. 906 ms), and higher error rates for words than objects (11.6% vs. 2.4%), *F*(1, 15) = 23.00, $p < .01$. A main effect of mode showed that RTs to bivalent trials were slower (1041 ms) than to univalent trials (965 ms), *F*(1, 15) = 17.00, $p < .05$. Furthermore, there was a significant interaction between switch and mode in the RTs, *F*(1, 15) = 4.94, $p < .05$, which indicated a larger switch cost for bivalent than univalent stimuli. Follow-up *t*-tests revealed a significant difference between RTs in bivalent compared to univalent switch trials, *t*(15) = 4.61, $p < .01$, and a marginally significant difference between bivalent and univalent repeat trials, *t*(15) = -1.85, $p = .084$. Lastly, the interaction between material and mode in the error data reached significance, *F*(1, 15) = 5.85, $p < .05$, and indicated that mode affected word trials more than object trials. There were significantly more errors in bivalent word than univalent word trials, *t*(15) = 2.28, $p < .05$, but no significant difference between bivalent and univalent object trials, $t < 1$.

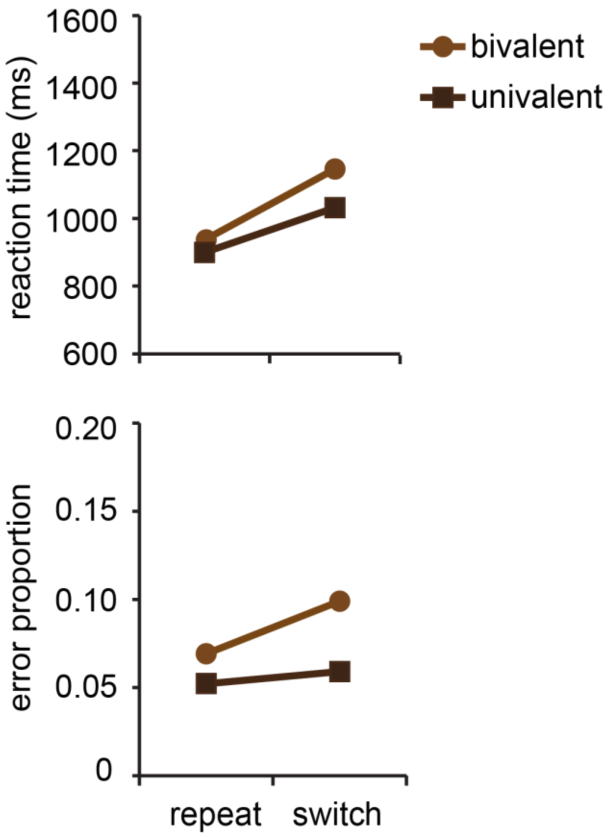


Figure 2.3: Reaction times and error rates for bivalent and univalent switch and repeat trials in Experiment 1.

Note: Throughout this thesis figures will not display error bars. The figures displayed in this thesis are frequently used to visualise both interactions and main effects. As the standard errors of the mean will differ for different effects, there is no straightforward way in choosing error bars. Moreover, standard errors of the means are not necessarily meaningful in within-subject designs as they do not carry any information about the statistical significance as standard errors of the mean include between-subject variance which can mask significant effects (Franz & Loftus, 2012; cf. Loftus & Masson, 1994). Statistical significance will therefore be discussed in the relevant text sections instead.

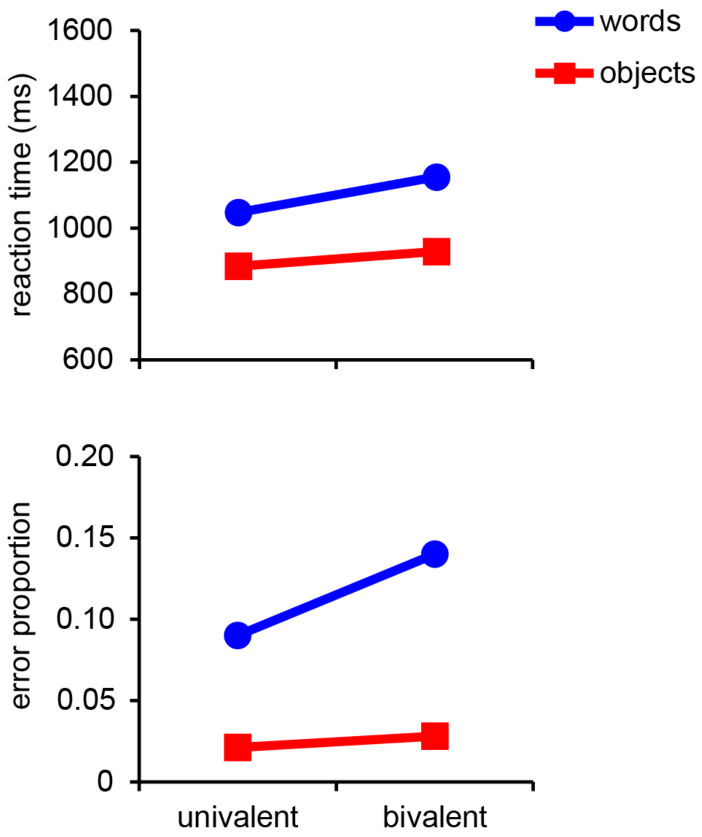


Figure 2.4: Reaction times and error rates for bivalent and univalent word and object trials in Experiment 1.

Memory Data

The Effect of Switching Attention on Memory

The analysis of the memory data addressed the main question of the experiment: How does task switching influence encoding success? A preliminary analysis using the different confidence ratings suggested that confidence did not modulate the memory ratings in a meaningful way. For this reason, old items in the memory test were classified as *remembered* when the old item was given a “definitely old” or “probably old” judgment, and as *forgotten* when the new item was given a “definitely old” or “probably old” judgment (i.e., collapsing across confidence ratings). Memory success in the different experimental conditions was then defined as the percentage of old items that received a remembered versus a forgotten judgment.

An ANOVA was performed to test the effect of attention (attended vs. unattended) and switching on recognition memory success for objects and words presented during task switching. The main effect of attention reached significance, $F(1, 15) = 98.26$, $p < .01$, indicating that attended items were remembered significantly better than unattended items (77.5% vs. 58.9%). Moreover, a main effect of material, $F(1, 15) = 24.68$, $p < .01$, indicated that objects were remembered better than words (73.4% vs. 63.0%). This difference might be due to the fact that the word task, even though overall more difficult during task switching, was a shallower encoding task than the object task.

A significant interaction between switch and material, $F(1, 15) = 5.69$, $p < .05$, moreover indicated a larger difference between objects and words in repeat than switch trials (see Figure 2.5). Nevertheless, differences between objects and words were significant in both repeat, $t(15) = -5.37$, $p < .01$, and switch trials, $t(15) = -2.18$, $p < .05$. Moreover, there was a trend for an interaction between material and attention (see Figure

2.6), which indicated a tendency for attended and unattended words to be more similar to each other than attended and unattended objects, *F*(1, 15) = 4.08, *p* = .062.

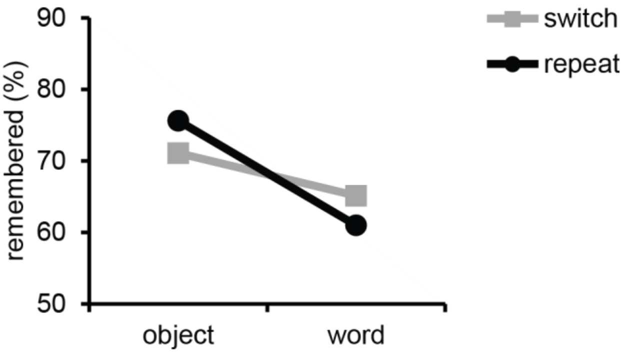


Figure 2.5: Percentage of remembered items (items receiving a 'definitely old', or 'probably old' judgment in the forced choice recognition test) in the object and word condition separately for items presented in switch and repeat trials in Experiment 1.

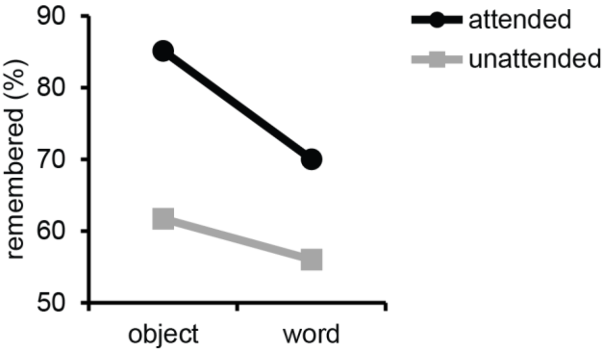


Figure 2.6: Percentage of remembered items (items receiving a 'definitely old', or 'probably old' judgment in the forced choice recognition test) the object and word condition separately for attended and unattended items in Experiment 1.

Importantly, the main effect of switch was not significant, providing no evidence that switching impairs overall encoding success, *F* < 1. Thus, information presented in repeat trials was not remembered significantly better than information presented in switch trials (68.3% vs. 68.1%), contrary to the prediction of resource-limitation models.

Interestingly, there was a trend for an interaction between switch and attention, *F*(1, 15) = 3.63, *p* = .076, with a smaller difference in the memory rating for attended and unattended items previously presented in switch compared to repeat trials (see Figure 2.7). Whereas attended items seemed to be remembered worse when they appeared on switch trials as compared to repeat trials, unattended items showed the opposite pattern. This effect was interesting as it indicated that encoding success is not reduced in switch trials, but is simply less selective. Given the central importance of this data for theories on the relationship between control and attention, follow-up *t*-tests were conducted to explore this effect further, even though it was only marginally significant. There was a numerical decrease in the percentage of items remembered between repeat and switch trials in the attended condition, and this decrease was marginally reliable, $t(15) = 1.91$, $p = .075$. The numerical increase in the percentage of items remembered in the unattended condition was, however, not significant, $t(15) = -1.24$, $p = .234$.

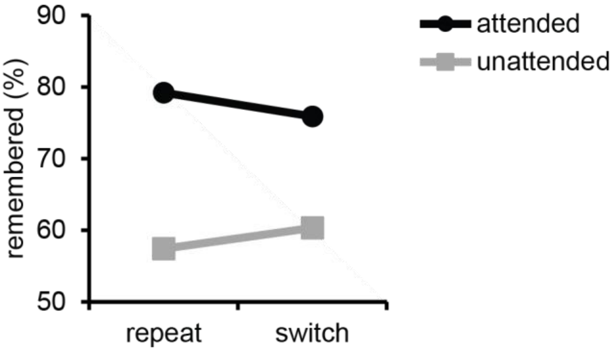


Figure 2.7: Percentage of remembered items (items receiving a 'definitely old', or 'probably old' judgment in the forced choice recognition test) for attended and unattended stimuli, separately for repeat and switch trials in Experiment 1.

2.1.3 Discussion

This first experiment was conducted to establish a paradigm that allows the study of interactions between cognitive control and long-term memory. The data displayed the basic effect of task switching (switch cost), and this effect was increased for bivalent stimuli (cf. Rogers & Monsell, 1995). Thus, the usual effects of switching were replicated in the current study.

Given that basic effects of task switching were observed, the key question in this experiment concerned the nature of the relationship between control and encoding. The results replicated the well-documented effect of attention on memory, with attended items being remembered better than unattended items (Rock & Gutman, 1981; Yi, et al., 2006). At the same time, very similar rates of items presented in switch or repeat trials during task switching were remembered in the later memory test, and thus there was no evidence that increased control demands in switch trials put a strain on resources available for encoding. Crucially, a trend for an intriguing interaction between attention and switching was seen in the data. This effect could indicate that rather than limiting the amount of information that can be encoded in a switch trial, the effectiveness with which control is directed towards the relevant information might be reduced. However, this effect was still unreliable in the current study. I will return to a more detailed discussion of this finding in the general discussion at the end of the chapter.

In sum, the current experiment provided some interesting starting points for further investigation, but also room for improvements: The interaction between attention and switching, which was central to the question of how cognitive control and memory interact, was inconsistent across participants. Moreover, participants displayed much weaker performance in the word than the object trial condition: Behavioural performance during task switching was worse for word compared to object stimuli. Thus, it seems that the word task was more difficult than the object task. Words were also remembered less successfully than objects. This might have been due to the fact that the syllable task for words was a more shallow encoding task (Craik & Lockhart, 1972) than the natural/man-made judgment for objects.

The goal of the next experiment was to address these weaknesses of the current design and to increase the reliability of the design with respect to key contrasts. Specifically, I addressed the following problems. The shallow syllable task for words was changed to a task with greater processing depth in the following studies—an abstract/concrete judgement. This change was anticipated to increase memory for words, and therefore to reduce possible noise stemming from performance deficits in the word task. Moreover, the coloured object stimuli were transformed into greyscale pictures to make them less dominant in comparison to the word stimuli. Previewing the coming chapters, these changes were effective, and word and object tasks were more comparable to each other. As the variable of material type (objects or words) did not interact with any of the key variables in a systematic way in subsequent experiments, I will not report any further effects of material type in the current or in subsequent chapters.

Another alteration entailed that the forced-choice memory test was changed to a rating test. In the new memory test, participants were presented with one stimulus on each trial—which could be either old or new—and rated it on a scale from 1 (certainly new) to 6 (certainly old). The forced-choice test had the disadvantage that participants were able to use two retrieval strategies – they could try to identify the old item or the new item to make a decision. By introducing a rating scale it was intended to receive a more accurate measurement on how confident participants were about their memories. This adapted memory test also meant that it was possible to reduce the number of new items in the memory test (as a ratio of 1:1 between new and old stimuli was no longer required) and include more trials in the task-switching phase.

The goal for subsequent experiments was to follow-up on descriptive, but non-significant effects observed in the current experiment. Particularly, it was assessed whether the effect of switching attention on the selectivity of memory encoding, a trend for which was seen in the marginal interaction between attention and switch, would be reliable in subsequent experiments. Importantly, the current data did not indicate that switching attention reduces memory overall, but that it limits the selectivity with which information is encoded. Demonstrating a reliable effect of switching attention on memory in subsequent experiments, while not finding evidence that switching affects memory overall, would provide strong evidence that switching decreases the selectivity of encoding, but does not limit encoding capacity.

2.2 Experiment 2

The second experiment was set up to investigate the questions outlined above with an improved design, as well as to replicate and substantiate the effects of attention and switching on task performance and memory. The general set up of the paradigm remained the same with a task-switching phase followed by a memory test. The main changes to the previous study included a change of the syllable task for words to an abstract/concrete judgement and a change of the forced-choice memory test to a rating test.

2.2.1 Methods

Participants. Nineteen participants took part in this study. One participant had to be excluded due to poor overall performance in the memory test: Whereas all other participants gave higher memory ratings to old (mean memory rating across all participants = 4.00, *SD* = 1.28) than new items (mean memory rating across all participants 2.95, *SD* = 1.56), this participant actually gave lower ratings to old (mean memory rating 3.31, *SD* = 1.00) than new items (mean memory rating 3.87, *SD* = 1.24), even though it was repeatedly checked by the experimenter that this person was using the rating scale the correct way. The final sample consisted of 8 male and 10 female participants with a mean age of 19.2 years (*SD* = 1.30 years). All of them were native English speakers. They received course credits for their involvement and gave informed consent.

Material. Stimuli included in this experiment were the same words, object pictures, random character strings and scrambled object pictures as in Experiment 1. To reduce the salience of the object pictures, so that this task was of comparable difficulty to the word classification task, object pictures were transformed into greyscale pictures for this study. Stimuli were presented on a black background with the words (or character strings) superimposed on the pictures in green font colour.

Procedure. Before the main experiment started, participants were first trained with a block of the object task (including only univalent and bivalent object trials; a total of 30 trials), a block of the word task (including only univalent and bivalent word trials; a total of 30 trials), and two blocks of all four conditions intermixed (each block had 18 trials), in this order. The stimuli used in these practice blocks were not used in the later experiment. If participants performed poorly in the last two practice blocks (i.e., both blocks > 15% errors), they were required to completed the practice again (this happened in approximately 50% of participants).

After this training, participants completed 5 blocks of task switching with 48 trials each. The experiment included 120 trials of each the object and the word task (a total of 240 trials). Of these trials, 40 were univalent word trials (word superimposed a scrambled object picture), 40 were univalent object trials (object picture with superimposed random character string) as well as 80 bivalent word and 80 bivalent objects trials (each with a word superimposed on an object). The sequence in which these conditions were presented was randomized. At the end of each block, participants received feedback about their performance. If their error rate was higher than 10% they were instructed to be more accurate. If their error rate approached 0% they were instructed to try to respond faster.

After this task-switching part of the study, which again served as an encoding phase, participants completed a surprise memory test. Participants were presented with a single stimulus (either an object or a word) in each trial. The size of each object picture and each word was the same as during the encoding/task-switching phase. Most of the stimuli presented (66.7%) were old stimuli. The rest (33.3%) were new stimuli, neither presented in the training nor the task-switching experiment. Participants had to rate each stimulus on a 1-6 scale depending on whether they thought it was old or new. The number 1 indicated a sure judgement that the item is new; the number 6 indicated a sure response that it is old. Participants were instructed to only use the 6 response when they were able to recall specific detail about having seen this item in the task-switching phase. Ratings between these extreme values were used for less confident answers, with 2 and 5 indicating a higher confidence and 3 and 4 a lower confidence new and old response, respectively. Participants used the number keys on the main keyboard (not the separate number pad), and responded with both hands.

The memory test consisted of a total of 602 trials. The first 10 trials were excluded from subsequent analysis because they were included in a training block to explain the task. After this training, participants conducted 8 blocks of the memory test with 74 trials each. The blocks were divided into object blocks (O, only objects were presented) and word blocks (W, only words were presented) and were delivered in WOOWWOOW or OWWOOWWO order, counterbalanced across participants. The order in which the stimuli were presented within the blocks was randomised. After each block participants received feedback on their performance.

Answers to the memory test were time limited to 2500 ms. If no response was given within this time the word “LATE!” appeared in red letters for 1000 ms. Once the “LATE!” feedback appeared no response was possible any more. Participants were accordingly instructed to respond within the 2500 ms time window. After a response or after the “LATE!” feedback a 500 ms ITI followed, before the next trial started.

The analysis of the task-switching data excluded RT outliers (2 *SD* above the mean). This cut-off resulted in 7.9% of the data being excluded (7.2% in switch and 8.6% in repeat trials). In addition to RT outliers analyses also excluded post-error trials. For the analysis of the memory data, trials answered incorrectly during task-switching were excluded. Visual inspection of the distribution of the RT data indicated that it was positively skewed and the Kolmogorov-Smirnov test revealed a significant departure from normality. This was the case for both repeat ($KS = .15$, $p < .001$) and switch trial data ($KS = .09$, $p < .001$). The distributions are however clearly unimodal and comparable across conditions, and ANOVAs are usually robust to such violations of normality (Nimon, 2012). For this reason ANOVAs have been employed to analyse the data.

2.2.2 Results

In the analysis of this study, I aimed to assess whether effects found in the first experiment could be replicated and extended. First of all, I will present the analysis of the basic effect of task switching on performance, and crucially the effect of switching on later memory. I will furthermore introduce a measure of trial-by-trial variations in subsequent memory as a predictor of earlier task-switching performance. This analysis aimed to reveal the interdependence of control during task switching and later memory. The following section presents a very detailed analysis of the data obtained with this paradigm, since this paradigm provides the foundation for all subsequent work in the thesis.

Task Switching

To analyse basic effects of task performance, a repeated-measures ANOVA with the factors switch (switch vs. repeat), and mode (bivalent stimuli vs. univalent stimuli) was conducted on the RT and error rate data from the task-switching blocks. These analyses revealed significant main effects of mode and switch in both RTs and error rates. The main effect of switch for the RTs, *F*(1, 17) = 60.90, *p* < .01, and error rates, *F*(1, 17) = 12.71, *p* < .05, indicated that responses given in switch trials were significantly slower (1469 ms vs. 1043 ms) and resulted in more errors (9.9% vs. 6.5%) than responses given in repeat trials, revealing a robust switch effect. Furthermore, responses were slower in bivalent trials (1316 ms) than in univalent trials (1196 ms), *F*(1, 17) = 31.41, *p* < .01, and resulted in more errors (9.5% vs. 6.8%), *F*(1, 17) = 4.69, *p* < .05, which indicates interference from the irrelevant material in the bivalent stimulus. Unlike the previous study, however, no interaction between switch and mode was found in the RTs, *F*(1, 17) = 1.42, *p* = .250, or error rates *F*(1, 17) = 2.46, *p* = .135.

A second ANOVA focused only on the data from bivalent trials, to investigate whether response congruence affected task-switching performance. A trial was defined as congruent when the response to the attended material required the same hand as the response to the ignored material would. A trial was defined as incongruent if different hands would have to be used to respond to the attended versus ignored material. Specifically, it was assessed whether RTs were faster, and trials were answered correctly more often, when congruent stimulus pairs were presented than when incongruent stimulus pairs were presented, and whether congruency affected the switch cost. Two repeated-measures ANOVAs on the RTs and error rates with the factors switch, and congruency were conducted. The ANOVAs did not reveal significant main effects of congruency or interaction effects, *F*s < 1.64, *p*s > .218. The lack of a congruency effect was possibly due to the fact that the same hand, but different fingers were used for the responses.

As an interim summary, the task-switching data showed clear effects of switching in both RT and error rate data. Furthermore, differences between bivalent and univalent trials were found, though the interaction between switch and mode was not significant in the current study. Overall, this data suggests that the systematic manipulation of attention in the task-switching part of the study was successful. Of crucial interest was how the variables that affected task performance influenced later memory. This question is the focus of the next analyses. Since congruence effects were not significant, and I did not have specific predictions about the effect of congruency on memory, this variable was not included in further analysis. As mode did no interact with switching in the current study, and showed no tendency to affect memory in the earlier experiment, the analyses reported in the following will focus on bivalent trials, which are of more central interest for the main hypothesis.

Memory

The next analysis investigated whether the variables shown to affect task-switching also affected the memory scores, and in how far task-switching and memory-test performance are related to each other. The key question of this analysis was how switching affected memory for attended versus unattended information.

Basic Performance in the Memory Test

The distribution of memory ratings for different trial conditions is presented in Figure 2.8. These analyses excluded items appearing on trials with incorrect responses during task switching, as it was not clear in these trials whether participants were performing the correct task. Memory ratings were significantly higher for attended items ($M = 4.54$, $SE = 0.11$) than for unattended items ($M = 3.33$, $SE = 0.05$), $t(17) = 15.84$, $p < .01$, but unattended items were still rated significantly higher than new items ($M = 2.90$, $SE = 0.08$), $t(17) = 5.75$, $p < .01$, in contrast to some reports that unattended items do not show better memory than new items (Rock & Gutman, 1981), or that unattended items are not recognised above chance level (Yi & Chun, 2005). Attended univalent and attended bivalent items did not differ in their memory ratings (*M* = 4.55, *SE* = 0.06 vs. *M* = 4.54, *SE* = 0.04), *t* < 1.

If attended and unattended items compete for processing (as would be expected from interference accounts of task switching) the ratings to the attended and unattended items in bivalent trials should display a negative correlation. The ratings for the attended and unattended item of each trial were correlated for each participant. The correlations across participants ranged from *r* = .067 to *r* = – .212 with a mean of *r* = –.04 across participants. A t-test was employed to assess whether the subjects' 18 correlation scores were significantly different from zero. The results of this test indicated that this was the case, *t*(17) = 2.46, *p* < .05. This result suggests that there was indeed competition between attended and unattended items.

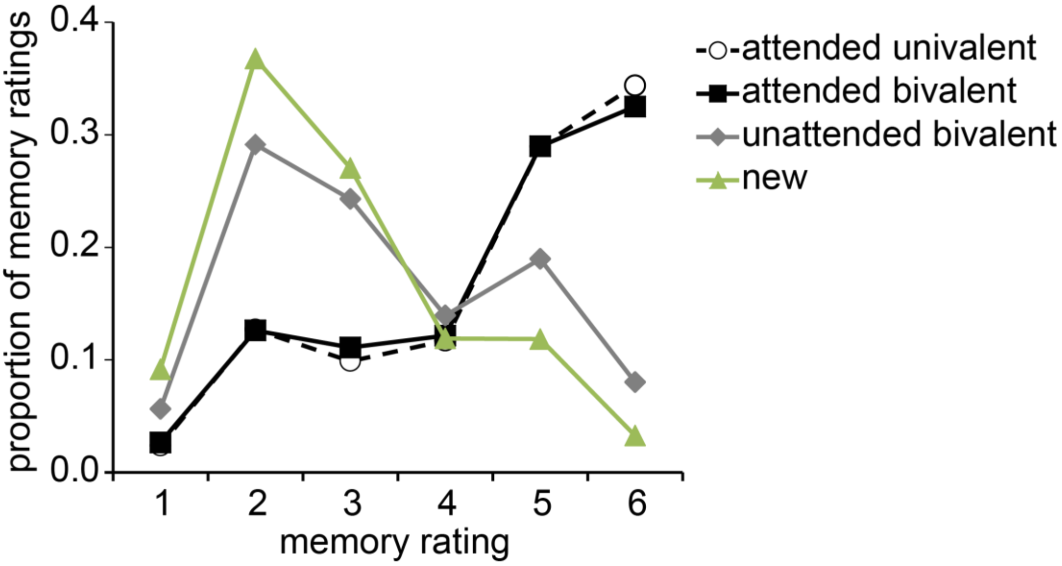


Figure 2.8: Distribution of memory ratings for attended items presented during univalend (black dotted line) and bivalent (black solid line) trials, as well as unattended items presented during bivalent trials (grey line), and new items (green line) in Experiment 2.

Effects of Switching and Attention on Later Memory

The first ANOVA on the memory test data focussed on the crucial test of the relationship between cognitive control and encoding. Based on the trend found in the previous experiment, as well as expected from interference accounts of task switching, it was predicted that switching should result in a decrease in selectivity of attention rather than a general processing deficit in switch trials. Therefore, it was predicted that memory for attended and unattended items should be more similar (less selective) in switch versus repeat trials. The alternative hypothesis, that switching limits processing resources would, in contrast, predict an overall decrease in memory for items presented in switch trials.

To test the effect of attention and switching during encoding on later memory, an ANOVA with variables switch and attention was conducted. The results indicated a main effect of attention, $F(1, 17) = 298.50$, $p < .01$, as well as a switch by attention interaction, $F(1, 17) = 11.46$, $p < .01$. Thus, this interaction, which was marginally significant in the first study, was reliable here (Figure 2.9). Follow-up *t*-tests indicated that there was a significant decrease in memory for attended information in switch compared to repeat trials, $t(17)= -2.75$, $p < .05$, and a significant increase in memory for unattended information in switch compared to repeat trials, $t(17) = 2.90$, $p < .05$. Importantly, and also consistent with what was found in the first experiment, the main effect of switching was not reliable, $F < 1$, and overall memory in switch and repeat trials was almost identical (mean memory ratings of 3.93 vs. 3.92).

These results are in agreement with the argument that the possible mechanism underlying the switch effect is a less successful focusing of attention on the relevant task/material in the switch condition, which results in an increase of the memory score for the unattended item and a decrease for the memory score of the attended item. It does not, however, agree with the hypothesis that processing resources are limited and that switching impairs encoding as it requires such limited resources.

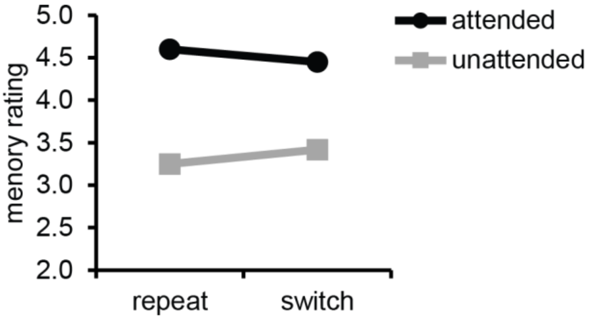


Figure 2.9: Memory ratings for attended and unattended items presented in repeat and switch trials in the task-switching phase in Experiment 2.

Memory Selectivity

The switch by attention interaction indicates that task switching reduces the effectiveness of attentional focussing, resulting in reduced memory for task-relevant information but enhanced memory for task-irrelevant information. Thus, switching results in reduced *memory selectivity*. An interesting feature of this measure is that it can be computed for each bivalent trial by calculating the difference in the rating score for attended and unattended items. Thus, we can calculate a trial-by-trial measure of the effectiveness of attentional focussing in the task-switching phase.

If memory selectivity is in fact a measure of attentional focussing, performance should vary with memory selectivity: Trials receiving a high memory selectivity score, that is, trials with a high memory rating for the attended item and a low rating for the unattended item, should be associated with better performance, because the score on this measure indicates effective focussing on relevant information during task switching. Therefore, it was predicted that high memory selectivity should be associated with fast RTs and low error rates in the task-switching phase. Low selectivity trials, on the other hand, that is, trials with a lower memory rating for the attended than for the unattended item, should conversely be associated with increased RTs and frequent errors. Accordingly, the memory selectivity score was calculated for each bivalent task-switching trial. The resulting score ranged from +5 (if the attended item was rated 6 “sure old”, and the unattended item rated 1 “sure new”) to -5 (if the opposite rating was given). Once these scores were calculated, trials were divided into three difference bins according to this score, separately for each participant and for switch and repeat trials. In a last step, the mean RT and error rate for each of these three bins was calculated. Thus, the dependent measures in these analyses were the RTs and error rates during the earlier task-switching phase. The data was entered into two ANOVAs separately for RTs and error rates, with variables memory selectivity (high, medium and low) as well as switch. The upper panel of Figure 2.10 displays the distribution of memory selectivity scores, the middle panel the results of the ANOVA on the task-switching RTs, and the lower panel the results of the task-switching error rates. The upper panel of Table 1 presents descriptive statistics for memory selectivity scores. The distribution of the memory selectivity data different significantly from a normal distribution (*KS* = .11, *p* < .001). As can be seen from the top panel of Figure 2.10, memory selectivity scores exhibit a positive skew for both switch and repeat trials. Nevertheless, inspection of the plot indicates that although the data are not normally distributed, the distributions are unimodel and show departures from normality (skewness) in a similar fashion across condition, a situation to which ANOVAs are generally robust.

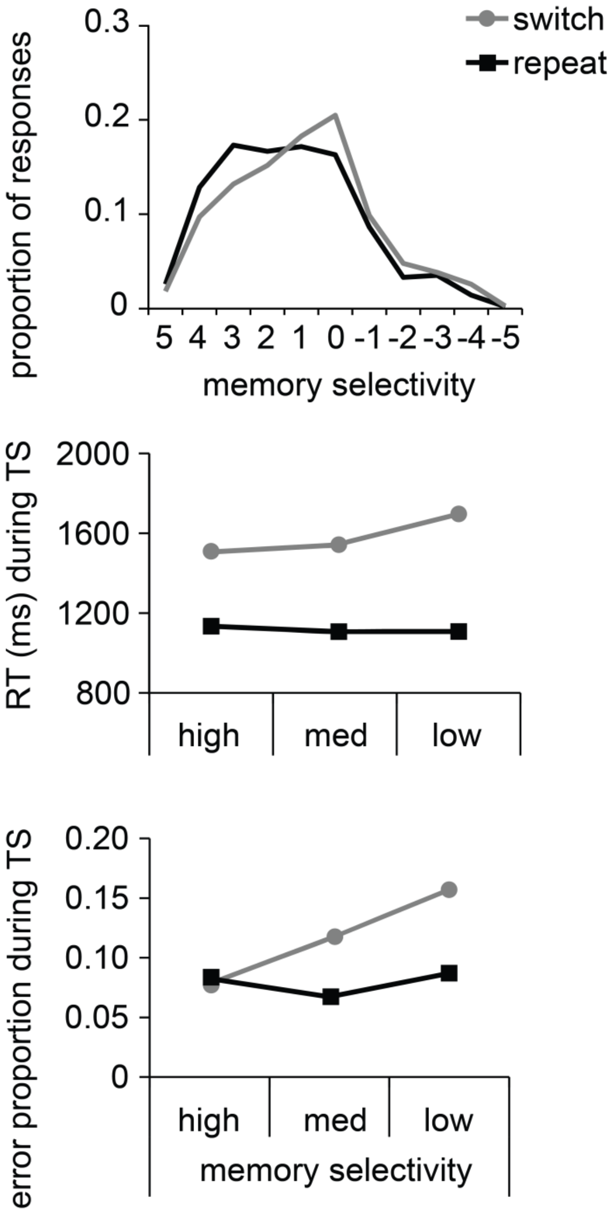


Figure 2.10: Distribution, RTs, and error rates during task switching (TS) in switch and repeat trials as a function of later memory selectivity in Experiment 2.

The ANOVAs for RT and error rates confirmed main effects of switch in both RTs, *F*(1, 17) = 62.37, *p* < .01, and error rates, *F*(1, 17) = 9.70, *p* < .01, that were already described above (switch costs). Importantly, and as predicted, the main effect of memory selectivity was significant in both RTs, *F*(2, 34) = 3.41, *p* < .05, and error rates, *F*(2, 34) = 5.67, *p* < .01. These results indicate that task-switching performance could be reliably “predicted” based on later memory. Decreasing memory selectivity was associated with increasing RTs and error rates. However, and somewhat unexpectedly, memory selectivity interacted with switching in RTs, $F(2, 34) = 7.77$, $p < .01$, and error rates, $F(2, 34) = 3.43$, $p < .05$. memory selectivity seemed to predict RTs and error rates only in switch trials even though switch and repeat trials exhibited similar levels of variability in memory selectivity scores (average *SD*s of 0.71 and 0.72, respectively, $t < 1$). Follow-up analyses revealed that there was a reliable main effect of memory selectivity in switch trials for both RTs, $F(2, 34) = 7.14$, $p < .05$, linear trend: $F(1, 17) = 9.51$, $p < .01$ and error rates, $F(2, 34) = 7.36$, $p < .01$, linear trend: $F(1, 17) = 20.00$, $p < .01$, but not for repeat trials, where no obvious relationship between performance and memory selectivity was observed, *F*s < 1. This contrast suggests that successful task performance (i.e., correct and fast responses) was highly reliant on effective cognitive control in switch trials, whereas repeat trials were qualitatively more robust to variations in levels of cognitive control and interference.

		high	medium	low
memory selectivity	repeat	3.52 (0.53)	1.57 (0.47)	-0.85 (1.12)
	switch	3.18 (0.61)	1.16 (0.41)	-1.08 (1.14)
		high	medium	low
salience difference	repeat	0.62 (0.31)	0.00 (0.14)	-0.60 (0.31)
	switch	0.68 (0.33)	0.01 (0.15)	-0.64 (0.32)

Table 1: Means and standard deviations (in parentheses) of memory selectivity and salience difference scores in the respective bin divisions, separately for repeat and switch trials in Experiment 2.

Stimulus Salience

Following the investigation of effectiveness of cognitive control on task performance, the next goal was to investigate a possible source of variability in effective control and interference across trials. One possibility, which will be investigated in more detail in the next chapter, is that such variations in task performance could arise because top-down control is applied inconsistently across trials, leading to some trials being prepared better than others (De Jong, 2000). In addition to such top-down influences, variability in performance might also be driven by bottom-up factors, like stimulus characteristics. One of these characteristics might be that individual stimuli differ in their salience or strength of association with the required task (Arrington, Weaver, & Pauker, 2010; Gollan & Ferreira, 2009). Studies have, for example, found that stimuli can prime certain tasks, evident in a preference for this task if participants are given the choice (Arrington, et al., 2010), or that certain stimuli can prime bilingual participants to switch languages, even though such switching is also associated with a cost (Gollan & Ferreira, 2009).

If stimuli differ in their salience, we would expect certain stimuli to be generally more easily processed when they are task relevant, and lead to increased interference when task irrelevant. Given that all participants were presented with the same stimuli, but these stimuli were presented in different conditions, it was possible to calculate an index of such salience, as outlined below. It was accordingly predicted that more salient stimuli should result in better performance when they appear as task-relevant target stimuli, and should lead to poorer performance when they appear as task-irrelevant distractors.

To test this prediction, *salience scores* for all stimuli for each participant were calculated. These salience scores were computed separately for each participant by calculating the average memory rating that a particular stimulus received from all remaining participants. This way, the salience score would index the average rating a stimulus receives, irrespective of which task condition it was presented in. Moreover, by using this method the salience score were not biased by the rating that each participant gave to a stimulus her/himself, as this rating was excluded for each participant. Salience scores were calculated by first normalizing the memory ratings for each participant separately for words and objects, attended and unattended items, and switch and repeat trials. This normalisation ensured that ratings were comparable for stimuli presented in different conditions. In a next step, all trials were divided into three bins according to the relative salience of the attended and unattended item (i.e., higher, approximately equal, or lower salience score for the attended compared to the unattended item). Descriptive statistics for salience scores in the different bins are given in the lower rows of Table 1, and the distribution of these scores is displayed in Figure 2.11. The stimulus salience data did not show a significant departure from normality (*KS* = .02, *p* = .83).

Finally, mean RTs and error rates for each of these bins were calculated. Thus, this analysis paralleled the analysis of memory selectivity, now substituting other participants' memory ratings as the key predictor of each participant's task-switching performance.

An ANOVA with factors salience difference (higher, approximately equal, or lower salience score for the attended compared to the unattended item) and switch on the task-switching RTs revealed a significant main effect of Salience, *F*(2, 34) = 3.31, *p* < .05, mirroring the main effect of Selectivity in the previous analyses (see Figure 2.11). The interaction between relative salience and switching was marginally significant, *F*(2, 34) = 3.02, *p* = .062. Even though this effect was only marginally reliable, follow–up analyses were calculated for better comparisons with the memory-selectivity data. Similar to what was found in the memory-selectivity analysis, stimulus salience influenced performance on switch trials only. For these trials, a robust increase in RT was observed when task-relevant information was relatively less salient than task-irrelevant stimuli compared to the case when task-relevant information was relatively more salient than task-irrelevant information, *F*(2, 34) = 3.91, *p* < .05, linear trend: *F*(1, 17) = 4.64, *p* < .05. Again no reliable differences were found for repeat trials, *F*(2, 34) = 1.93, *p* = .16, indicating that behaviour is only sensitive to such bottom-up factors in situations of high between-task conflict. The effects of salience were only found in the RT data with no corresponding effect on error rates.

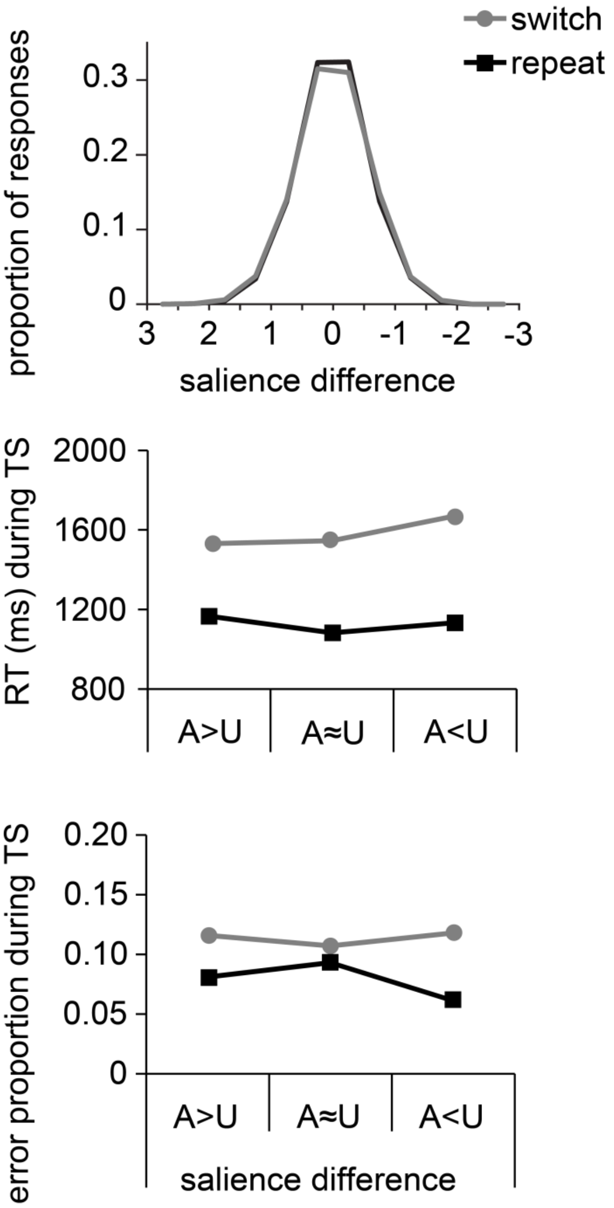


Figure 2.11: Distribution, RTs, and error rates of switch and repeat trials with higher (A>U), approximately equal (A≈U), or lower salience (A>U) of the attended compared to the unattended item in Experiment 2.

Given the striking similarity in the pattern of results of the memory selectivity and salience difference analyses, an important question concerns the relationship between these measures. For this reason it was investigated whether memory selectivity and salience tracked the same processes, in that memory selectivity was driven by the salience of the stimuli. In a first step the memory-selectivity scores and the salience-difference scores of each bivalent trial were correlated for each participant. Correlation analysis confirmed that memory-selectivity and salience-difference scores were positively correlated, as one might expect, but only weakly, mean $r = .118$, $t(17) = 10.55$, $p < .01$. Thus, it seems that memory selectivity and salience difference are measuring different concepts, but salience might still influence the memory selectivity measure. To test whether memory selectivity effects were reliable even without the effect of stimulus salience, the effect of salience was partialled out from the memory-selectivity data. The ANOVA on the resulting scores again revealed a significant main effect of memory selectivity, $F(2, 34) = 3.85$, $p < .05$, as well as an interaction between memory selectivity and switching, $F(2, 34) = 7.43$, $p < .05$. Thus, the results indicate that the effects of memory selectivity cannot be explained by the effects of salience alone.

Effects of Task-Switching Performance on Later Memory

As the experiments described in subsequent chapters are based on the paradigm presented here, I conducted further analyses to investigate the relationship between cognitive control and memory in more detail. The results presented below investigate how performance in the task-switching phase of the experiment is related to subsequent memory.

Task-Switching Reaction Time and Later Memory

The memory-selectivity analysis indicated that later memory could be used to predict earlier task-switching performance. If effective task switching and memory encoding rely on the same processes, it should similarly be possible to predict later memory based on prior task-switching performance. Specifically, the analysis presented here was conducted to test the hypothesis that different RTs during task switching are associated with different memory ratings. That is, the logic of the memory-selectivity analysis was reversed, so that differences in prior task-switching performance were used to predict later memory. In fact, this analysis provides a different perspective on the data, but is highly related to the memory-selectivity analysis described above.

Bivalent trials from the task-switching phase were divided into three bins according to their RT. Then the average memory ratings for attended and unattended items were calculated for each RT bin. These RT bins were determined separately for each participant and separately for switch and repeat as well as object and word trials. Trials that were answered incorrectly during task switching were excluded from these analyses, and outliers of RT during task-switching were excluded separately for each participant and for each combination of material, switch, and attention. Only data from the bivalent conditions were used because only these trials included attended and unattended items.

An ANOVA with factors attention, switch, and RT bin (reaction time during task switching, fast, medium and slow) was conducted. Based on the interference view of task switching, it was assumed that larger RTs during task switching reflect enhanced conflict between the tasks. This conflict should thus be reflected in more similar memory ratings for the word and picture presented on a given trial. Therefore, it was predicted that longer RTs during task switching should be associated with more similar ratings of the attended and the unattended items.

Interestingly, this analysis revealed a three-way interaction between attention, switch, and RT bin, $F(2, 34) = 5.29$, $p <.01$. Separate ANOVAs for switch and repeat trials showed a significant RT bin by attention interaction for switch trials, $F(2, 34) = 8.29$, $p < .01$, but not for repeat trials, $F < 1$. Figure 2.12 shows the memory ratings for attended and unattended items depending on their RT bin, separately for repeat and switch trials. As can be seen in Figure 2.12, the difference between attended and unattended items remains similar (or even increases slightly) with increasing RT in repeat trials, while it decreases in switch trials. Follow-up ANOVAs on the attended and unattended items in switch trials revealed that there was a significant increase in memory ratings for unattended items with increasing RT during task switching, *F*(2, 34) = 6.83, *p* < .01, with a significant linear trend, *F*(1, 17) = 11.38, *p* < .01. The decrease in memory rating with increasing RT-bin for the attended items in switch trials was not significant, *F*(1, 17) = 1.55, *p* = .226.

Accordingly, enhanced conflict in switch trials but not in repeat trials (as indicated by increased RTs) is associated with more similar memory ratings for attended and unattended items. This finding is in agreement with the idea that switch effects stem from a failure to attend to the relevant material, and/or a tendency to attend to the irrelevant one: A tendency to attend to currently irrelevant material explains an increase in the rating of the unattended material with increasing RT. Furthermore, a failure to attend to the relevant item would result in a decrease in the memory score for the attended item with increasing RT, which is only seen on a descriptive level here.

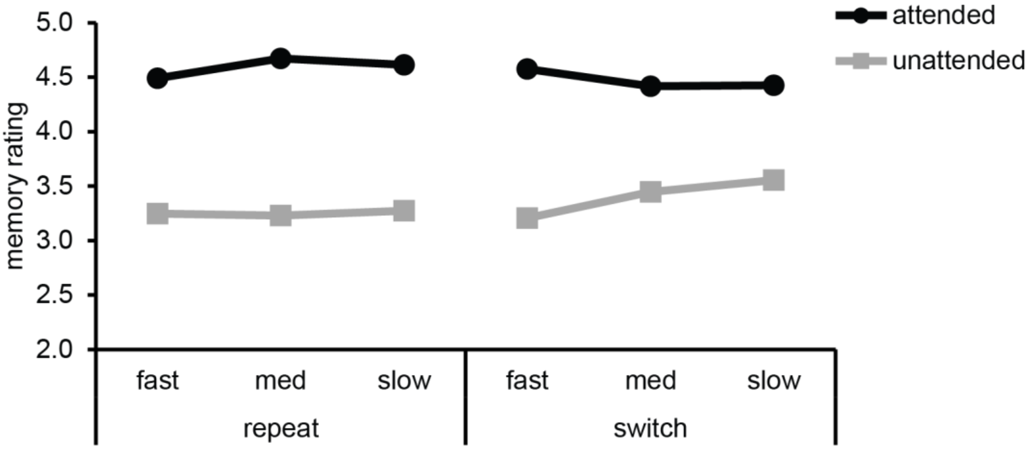


Figure 2.12: Mean memory ratings in switch and repeat trials, depending on RT bin (fast, medium [med], slow), separately for attended and unattended items in Experiment 2.

Task-Switching Accuracy and Later Memory

The previous analysis demonstrated that increased task-switching RTs are associated with a decrease in memory selectivity in switch trials, indicating that processing during task-switching influenced later memory. Another measure of task-switching performance is accuracy. All the analyses of the memory data reported above excluded trials with erroneous responses. Error analyses can, however, provide useful information about how tasks are solved by differentiating between different kinds of errors. For example, it has been shown that task errors (i.e., errors caused by applying the wrong task rules) are more likely in switch trials, consistent with the idea of between-task interference (Meiran & Daichman, 2005). Moreover, it has been shown that committing such task errors may actually improve performance (reduces switch costs) in the next trial, when the task is switched (Steinhauser & Hubner, 2006), suggesting that the incorrect task is strengthened by task execution in this case. Analysing how accuracy during task-switching is associated with later memory should therefore provide us with additional information about the nature of control processes during task switching.

It was predicted that the impact of switching on later memory should be enhanced in trials that led to an error during task switching because errors in the task-switching phase could have resulted from a failure to focus attention to the relevant material. Accordingly, an ANOVA with variables attention, switch, and accuracy (i.e., accuracy during task-switching) was conducted. One participant had to be excluded from this ANOVA because s/he conducted no errors in the repeat condition.

The results of this ANOVA are shown in Figure 2.13 and revealed a significant main effect of attention, $F(1, 16) = 102.03$, $p < .01$ (attended material was remembered better than unattended material). There was no significant main effect of accuracy, $F < 1$, indicating that items presented in trials that led to an error did not generally lead to decreased or increased memory for the information presented in this trial. The attention and switch interaction that was reported above was also found in this analysis, $F(1, 16) = 18.86$, $p < .01$, as well as an interaction between attention and accuracy, $F(1, 16) = 5.82$, $p < .05$. These interactions were further qualified by a reliable three-way interaction between attention, accuracy, and switch, $F(1, 16) = 7.34$, $p < .05$. Visual inspection of the plots suggested that memory for attended and unattended items presented in repeat trials was not strongly affected by accuracy. Attended and unattended items presented in switch trials, however, were substantially affected by accuracy: Here memory ratings for attended and unattended items were much more similar to each other for items presented in error trials than items presented in correctly answered trials.

To explore this three-way interaction further, separate ANOVAs for switch and repeat trials were conducted. The repeat-trial ANOVA revealed only a significant main effect of attention, $F(1, 16) = 86.82$, $p < .01$, but no significant effect of accuracy, $F < 1$, nor an interaction between accuracy and attention, $F < 1$. The switch-trial ANOVA, however, indicated an interaction between attention and accuracy, $F(1, 16) = 12.28$, $p < .01$, in addition to the main effect of attention, $F(1, 16) = 26.92$, $p < .01$. There was a significant difference between correct attended and unattended items in switch trials, $t(16) = -11.95$, $p < .01$, but no significant difference between incorrectly answered attended and unattended items, $t < 1$. There was no significant main effect of accuracy in this ANOVA of the switch trials, $F < 1$.

Overall, the pattern of these data indicates that errors in repeat trials might have been due to different processes (e.g., a difficult trial) than errors in switch trials (e.g., interference from the other task). That is, in repeat trials, participants appeared to be attending to the correct item. They may have committed an error because they encountered a word they did not know, or an object they were not sure how to classify, and therefore had to guess. Alternatively, they might have confused the response keys (response error). For switch trials, however, the data suggest that participants may have been attending to the irrelevant item, and committed task errors. This would be consistent with the finding that task errors are more likely in switch than repeat trials (Meiran & Daichman, 2005), which might be driving this effect. It could therefore be argued that the three-way interaction between attention, switch, and accuracy described above is driven by error trials in which participants responded to the wrong material (task errors as compared to response errors or guessing). To test whether this was the case, in a next step task-errors (i.e., all errors in which participants answered with response keys associated with the other task) were excluded from the analyses.

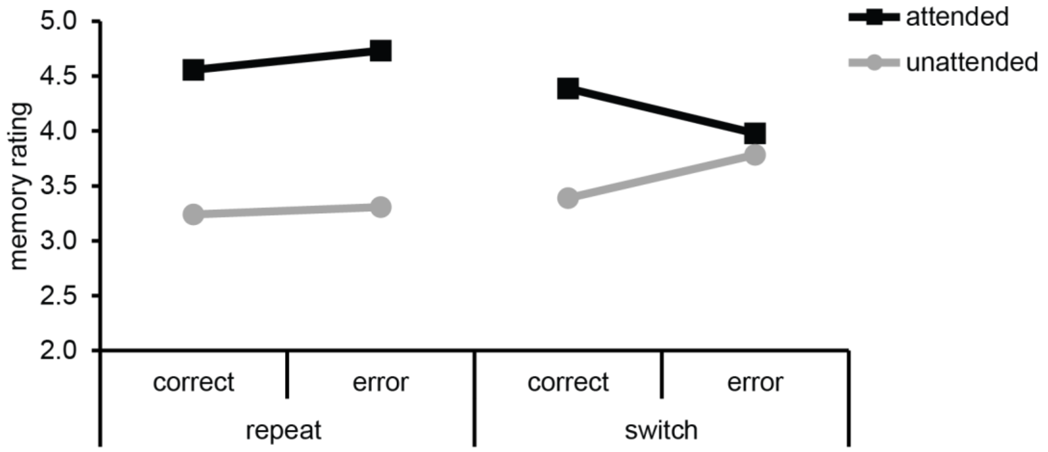


Figure 2.13: Mean memory ratings in switch and repeat trials, depending on accuracy, separately for attended and unattended items in Experiment 2.

2.2.3 Discussion

The goal of the current experiment was to investigate whether numerical effects observed in Experiment 1, such as a modulation of memory for attended and unattended items by switching, would be statistically reliable with an optimised design. Critically, the current results revealed a significant interaction between attention and switching in the memory data. This interaction demonstrated that the selectivity of encoding was influenced by switching, but that switching did not have a significant effect on memory overall. Accordingly, these data are not in agreement with resource-limitation accounts. These accounts would have predicted an overall decrease of memory in switch trials, as switch trials are associated with increased control demands, which should have limited control resources available for encoding.

In line with these results, the memory selectivity analysis revealed that later less selective memory was associated with an increase in RTs and error rates, particularly in switch trials. Related to this, increased RTs and error rates during task-switching predicted a lack of selectivity in later encoding, also specifically in switch trials. These data suggest that the relationship between cognitive control and memory is better characterised by accounts that emphasise interference between the tasks. Moreover, the accuracy data provide some additional insight into the nature of control processes during switch trials. Errors in switch trials seemed to be more influenced by conflict from the alternative task, with no difference in later memory between attended and unattended items in switch error trials. Errors in repeat trials, in contrast, appear have been more frequently caused by difficult items or response confusions. This conclusion is based on the finding that attended items in repeat trials that led to an error were at least as well remembered as attended items in repeat trials that were responded to correctly. This indicates that participants attended to the correct item. In switch trials, however, the increase of memory ratings to unattended items in error trials compared to correct trials, as well as the decrease in memory ratings for attended items suggests that participants may have been partly attending to the currently irrelevant item. Nevertheless, the accuracy data also suggests that task errors unlikely account for this effect completely, as a similar trend was observed when task errors were excluded. This indicates that even when participants performed the correct task, interference from the irrelevant task might have caused conflict. It has to be noted that the experimental results reported here might have been influenced by the inclusion of univalent and bivalent trials. The fact that the amount of interpretable information presented to participants varied, even when the task stayed the same, might have caused additional interference to participants or at least could have made the data noisier. However, to preview, similar results were obtained in experiments reported in later chapters which did not include univalent trials, suggesting that the univalent/bivalent manipulation was not driving or altering substantially the described effects.

2.3 General Discussion

Taken together, the two experiments described in this chapter document the development of a paradigm for investigating interactions between memory and cognitive control. This paradigm forms the basis for all subsequent experiments in this thesis. The results of the two experiments demonstrate characteristic switch costs in RTs and error rates in the task-switching phase. Crucially, the memory data indicated that later memory for attended and unattended information was modulated by switching. This finding indicated that in a situation in which attention is shifted, attention is less selective, leading to increased processing of the irrelevant information. This was a key result in the investigation of the relationship between memory and cognitive control.

Importantly, this interaction between attention and switching adjudicates between two opposing interpretations of previous observations of reduced memory during task switching (Otten & Rugg, 2001b; Reynolds, et al., 2004). Because previous studies focused almost exclusively on memory for attended information, they were ambiguous about the relationship between memory and cognitive control. They suggested that the observed decrease in memory for attended information after a switch was a result of a limitation in resources (Otten & Rugg, 2001b), or of resource sharing mechanisms (cf. Liefooghe, et al., 2008). Importantly, however, these interpretations do not explain the current results. If resources were limited, memory for unattended information should similarly have been decreased, but the opposite was the case: Memory for unattended material was better, not worse, when the task was switched. The increase in memory for unattended information on switch trials suggests that the increased need and employment of cognitive control in switch trials does not limit the control resources available for encoding, but that cognitive control is directed less selectively towards relevant information.

Thus, the current results help to clarify the nature of the often suggested interdependence between memory and cognitive control: Encoding of relevant information is dependent on the selectivity of processing. For theories of memory encoding, these results suggest that selective attention and selective encoding could share mechanisms rather than compete with each other, at least as long as the information encoded is relevant for the control demanding task (cf. Uncapher & Rugg, 2009).

The memory selectivity analysis furthermore demonstrated that memory ratings can be used as an index of earlier task performance. The data support the claim that the observed reduction in memory selectivity in switch trials is likely due to between-task competition (cf. Allport, et al., 1994), as RTs increase with decreasing selectiveness of processing of the relevant item. Thus, the results are interesting for the field of task switching, where there has been a debate regarding the nature of the switch cost. The current findings support the interpretation that switch costs arise because the previously relevant information interferes with the processing of the currently relevant task (cf. Yeung, et al., 2006). Accordingly, although a role of reconfiguration processes cannot be ruled out here, the current data rather suggest that switch costs are driven by between-task interference. A similar effect on the RTs that was limited to switch trials was also observed in the analysis of stimulus salience, suggesting that bottom-up attentional capture affects performance in a similar way to memory selectivity.

It was somewhat surprising that both memory selectivity and stimulus salience had an effect only on switch trials. A possible explanation for this finding is that in repeat trials task sets were established strongly enough to “shield” performance from interfering information (Dreisbach & Haider, 2008), whereas this was not the case in switch trials, which required more flexibility (cf. Dreisbach & Wenke, 2011). This result could indicate that in the current design, repeat trials were less dependent on the successful allocation of cognitive control. This interpretation would, however, be somewhat at odds with findings that between-task interference has been shown to have substantial effects on task performance even in the absence of task switches, for example in the Stroop task. A potential explanation might be the methodology used in the current study: Participants responded with two non-overlapping sets of response keys in the current study and conducted completely different tasks on the stimuli. Thus, it might have been particularly easy to shield performance in repeat trials, by focussing on a subset of stimulus-response mappings. A larger effect on repeat trials might be observed when more overlap in tasks and stimulus-response mappings is used. Chapter 4 will assess this question with a simplified design in which the same classification rule and stimulus-response mappings are used for both the object and the word task.

Several analyses extended the results described above. To demonstrate the relationship between control during encoding on later memory, I investigated how performance differences during task-switching affected later memory, effectively reversing the idea of the memory-selectivity analysis. Dividing the trials into bins based on their RT during task switching, and assessing later memory for items in these bins, indicated that earlier RT predicted later selectivity of encoding. Similar to the memory selectivity and salience analyses, however, this relationship was only observed for items presented in switch trials. Here, less effective control (slower RTs) predicted less selective memory later on. To investigate a possible source of this effect, I furthermore investigated how errors during task switching were related to later memory. This analysis revealed that errors were associated with very similar memory ratings for attended and unattended items, but only for switch trials and not for repeat trials. Together, these results indicate that interference from the irrelevant task puts an increased demand on control processes which leads to a less effective focussing of control on relevant items, and increased processing of irrelevant information. Moreover, these results indicate that errors in switch and repeat trials may be driven by different factors. Errors in repeat trials might have resulted from more difficult trials (such as words that were less clearly abstract or concrete, or pictures that the participant did not recognize) or a confusion of the response keys. In contrast, errors in switch trials seem to be caused much more by interference from the irrelevant task.

One of the most interesting aspects of the current design is that it provides a trial-by-trial measure of the processing of the relevant compared to irrelevant information. This method in a way mimics approaches used in neuroimaging to contrast activity in task-relevant and irrelevant regions (e.g., Gilbert & Shallice, 2002; Wylie, Javitt, & Foxe, 2006; Yeung, et al., 2006). This research has provided evidence that irrelevant information is processed increasingly in switch trials (e.g., of task-irrelevant words in the left temporal cortex after switching to a face classification task). An advantage of the data provided here is that brain activity is ambiguous to the degree that greater activity can be the result of improved processing as well as increased processing demands. The advantage of the memory selectivity measure is that that it provides a more transparent measure: memory selectivity tracks the efficiency of processing, in switch trials at least, thereby providing a simpler to collect and less ambiguous measure of effective processing than some neuroimaging research.

A limitation of the current design is that it is not clear whether the increased processing of the irrelevant material stems from the fact that it has been attended before, or whether a lack of focussing results in spare processing capacity that is automatically allocated to any other information (cf. Lavie, 2005). That is, it is possible that participants encoded the unattended information better in switch trials, not because they attended to it in the previous trial, but because the high demand of switching caused them to direct less cognitive control to the relevant information, so that spare cognitive resources were directed to any other available information. In the experimental setting, with little other than the unattended information available, this unattended information would have been processed. For memory research this would translate to the question whether unattended material is only encoded when it was recently relevant, or whether memory is encoded at a constant rate, meaning that irrelevant material is always encoded if spare capacity is available to do so (cf. Rissman, Gazzaley, & D'Esposito, 2009).

For this reason, a question for future research concerns whether cognitive control selects only information previously or presently relevant (in that control is not fully withdrawn from previously relevant information), or whether it is directed to any available information, but this process is less selective in highly demanding situations. This question can be addressed if the current design is slightly modified. If three instead of two material types were used, the question could be answered whether material is encoded because it was previously relevant or whether material that was not relevant in the previous trial would be encoded as well. Recent research using eye-tracking provides some evidence supporting the interpretation that processing of previously relevant information is enhanced in switch trials (Longman, Lavric, & Monsell, 2012). Participants in this study had to complete tasks on items presented at one of three different locations, and the relevant location was either switched or repeated between trials. Participants showed a stronger tendency to fixate locations that were relevant in the previous trial when the location was switched, rather than locations that were irrelevant in the previous (and current) trial. This finding provides some evidence that irrelevant material is processed because it was important in the previous trial, rather than because spare capacity is automatically and non-discriminatorily allocated to this material.

Thus, the current data display the benefit of combining cognitive control and memory research to answer questions relating to both fields. The two experiments reported in this chapter together demonstrated that cognitive control serves to resolve competition between tasks, and that fluctuations in the success of this process affect performance in task switching as well as later memory. Memory encoding does not appear to compete with control for limited resources, but rather can be more or less selective depending on how effectively control is directed towards relevant information during encoding. To conclude, the design described in the current chapter provides a stable paradigm to study effects of selective processing during task performance and on later memory.

Chapter 3:

The Influence of Top-Down Control on Task Switching and Memory

The results reported in Chapter 2 demonstrate that selective processing is a key factor in successful task performance and later memory. Specifically, two factors that contributed to variability in performance were identified: memory selectivity and stimulus salience. Analysis of the influence of stimulus salience demonstrated that bottom-up effects affect performance. Moreover, analysis of the influence of memory selectivity indicated that selective processing plays a crucial role in task performance. The selectivity of processing might at least partly be driven by top-down processes. I next wanted to investigate whether systematic manipulation of top-down control would affect task performance and memory in a similar way.

Previous research has indicated that attention affects LTM encoding, as would be expected (Rissman, et al., 2009; Uncapher, et al., 2011). The aim of the current chapter is to investigate whether a direct manipulation of top-down control during task switching affects both performance during task switching and memory. If the main benefit of attention is to increase the selectivity of processing, increasing top-down processing should enhance the selectivity of memory as well. Showing that this is the case is an important step in demonstrating that the same mechanisms that are known to be related to task performance and working memory (e.g., Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Gazzaley & Nobre, 2012; Rutman, Clapp, Chadick, & Gazzaley, 2010; Zanto, Rubens, Thangavel, & Gazzaley, 2011), also have an effect on LTM encoding, a relationship that has been discussed in recent literature (cf. Bollinger, Rubens, Zanto, & Gazzaley, 2010; Khader, Jost, Ranganath, & Rosler, 2010; Meeuwissen, Takashima, Fernandez, & Jensen, 2011).

Top-down control is known to fluctuate over time (Macdonald, Mathan, & Yeung, 2011), a fact that is attributed to processes such as mind wandering (Smallwood, Beach, Schooler, & Handy, 2008). In Experiment 2, the effects of such fluctuations of control were analysed. In the experiments of the present chapter, the strength of top-down control was manipulated directly. I predicted that manipulations of top-down control would affect performance and memory in a similar way, by increasing the selectivity of processing. An alternative prediction could suggest that top-down control should bias the balance of resources towards current performance at the cost of memory or vice versa, an idea suggested by early resource-sharing accounts (Broadbent, 1958; Norman & Bobrow, 1975). A similar idea is also implied in some task–switching models which argue that limited resources are required to prepare the relevant task (Rogers & Monsell, 1995; Rubinstein, et al., 2001). Thus, the experiments in the current chapter aimed to provide further evidence on the relationship between control and memory as discussed in Chapter 2.

Top-down influences on task switching have been demonstrated in various ways. Effective top-down control requires time, will, and motivation. For this reason, the experiments in this chapter used three experimental manipulations to induce increased top-down processing: variation of the time to prepare the task (cue-stimulus interval, or CSI), contrasting standard cued (or “instructed”) switching with a voluntary switch condition in which participants themselves choose which task to perform, and lastly, a manipulation of motivation via reward incentives. I will give a brief overview of the background to each of these manipulations here. A more detailed review of the relevant literature will precede each experiment.

One of the most common and well-documented top-down effects in task-switching research is that of manipulating preparation time. It has been shown that switch costs decrease with increased preparation time (e.g., Meiran, 1996; Monsell, 2003). This effect has been taken as indication of the successful engagement of cognitive control. As CSI manipulation has been thoroughly studied in the task-switching literature, this manipulation was used as a first method to try to systematically increase top-down control here. The effects of manipulations of preparation time were investigated in Experiment 3.

The second method with which I aimed to influence top-down control was by introducing a voluntary switching condition. In this paradigm, participants are given the choice over what task to perform on each trial (within some broad constraints). The voluntary task-switching paradigm has been suggested to be a more direct test of top-down control than traditional task switching, as the task choice has been argued to require top-down processes (Arrington & Logan, 2004, 2005). Voluntary task switching furthermore introduces another interesting aspect into the design: If participants choose which task to perform themselves, this might also increase their intrinsic motivation to perform better (cf. Holroyd & Yeung, 2012). Motivational factors have been used in the study of optimising behaviour and have long been related to increases in cognitive control (Holroyd & Yeung, 2012; Maddox & Markman, 2010). Experiment 4 assesses such motivational factors by comparing the effects of voluntary and instructed task switching on task performance and memory.

Whereas voluntary task switching addresses intrinsic motivation, another motivational factor that has been widely researched is reward. Reward here refers to an external motivational source and similarly has also been related performance improvements (Padmala & Pessoa, 2011; Zedelius, Veling, Bijleveld, & Aarts, 2012). For example, decreased RTs and error rates were observed in response to incongruent stimuli in a reward compared to a no-reward condition (Locke & Braver, 2008). Reward has also been associated with performance enhancement such as a reduction in switch costs in task switching (Kleinsorge & Rinkenauer, 2012). Of interest for the research presented here was the impact of reward on task switching and later memory. The effect of reward was assessed in Experiment 5.

For these three manipulations of top-down control, I make some general predictions. As switching tasks seems to limit the selectivity with which we process information, I predicted that top-down control can be used to counteract this effect. Enhanced top-down control should result in better focussing on the task-relevant information and reduced processing of task-irrelevant information, which should be evident in the task-switching data as faster RTs and reduced error rates, as well as a reduction of switch costs. In memory, the effects of this selective processing should be evident in more selective encoding (cf. Uncapher & Rugg, 2009).

The same experimental approach as in Experiment 2 was employed in these studies. Participants first conducted a task-switching phase in which they switched between the same object and word tasks as in Experiment 2. They then completed a recognition memory test on words and objects presented during task switching, as well as new words and objects. During the task-switching phase top-down control was manipulated either between blocks (Experiment 3) or in short trial sequences within the block (Experiment 4 and 5).

3.1 Experiment 3: The Influence of Preparation Time

The effect of task preparation is one of the most robust top-down effects reported in the task-switching literature. Usually, an overall reduction in RTs and error rates is observed, alongside a reduction in the switch cost. This effect of preparation in the cued task-switching design has been argued to be due to two processes: active preparation and the passive decay of the previous task set (e.g., Koch & Allport, 2006). Evidence for active preparation stems from the finding that RTs tend to decrease when the time between a task cue and the stimulus increases, even if the overall interval between the trials is held constant (Meiran, 1996; Monsell & Mizon, 2006). Passive decay of the interfering task influences performance in switch trials when the time between the trials increases (more specifically, the time between the response in the previous trial and the stimulus of the current trial, also referred to as response-stimulus interval, RSI). In this context, it is found that participants perform better in switch trials when the time between the preceding trial and the current trial is increased, and that this effect occurs even when the time between the cue and the stimulus (cue-stimulus interval, CSI) is not varied (Meiran, Chorev, & Sapir, 2000). For this reason, designs have been developed that control for passive decay when investigating task preparation. This is done by keeping the RSI constant while varying the CSI, so that passive decay can be assumed to be comparable between different preparation times.

To manipulate available preparation time for the task, the delay between the cue and the onset of the stimulus (CSI) is varied. The longer the CSI, the more the participant can prepare for the task, and thus should perform better. Specifically, I compared a short and a long preparation time condition. Whereas CSI was constant at 800 ms in the previous experiment, Experiment 3 compared a condition in which the CSI was short (5 ms), giving participants almost no time to prepare the task indicated by the cue, with a condition in which the CSI was long (1000 ms), giving them more time to prepare (Allport, et al., 1994; Meiran, 1996).

On the basis of previous research, I predicted that longer preparation times would decrease task-switching RTs and error rates, as well as switch costs (e.g., Altmann, 2004; Koch, 2001; Nieuwenhuis & Monsell, 2002). Furthermore, these performance improvements during task switching should be associated with better later memory for attended and reduced memory for unattended information in trials with long preparation time, because this longer preparation time should improve focussing on the relevant material.

The design of the task-switching phase was determined based on several pilot studies in which surprisingly weak effects of CSI on switch costs were found. As this is a surprising finding given numerous replications of the reduction of switch costs with increasing CSI in the literature (e.g., Meiran, 1996, 2000; Monsell, 2003; Sohn & Anderson, 2001), I tested the effect of several methodological changes in pilot experiments. In the course of these pilots, different preparation interval lengths and different cue types (different colours or words instead of coloured frames) were used, and CSI was varied either trial- or blockwise. The pilot data for the experiment described here showed a strong numerical trend for a decrease in switch costs with increasing preparation time. I accordingly used the design of this pilot experiment for the final Experiment 3.

3.1.1 Methods

Participants. There were 16 paid participants, five male and 11 female, aged between 18 and 27 years (*mean* = 20.6, *SD* = 2.4). All of them were native English speakers and gave informed consent.

Procedure. In the current experiment, I used more easily interpretable cues than in the previous study to enhance preparation effects. Specifically, the colour of the cue frame matched the colour of the stimuli. The greyscale objects were cued with a grey frame, and the now brown words with a brown frame (see Figure 3.1). The colour of the words was changed from green to brown because pilot studies indicated that participants found the bright green cue frame distracting. Moreover, CSI length varied blockwise rather than trial-by-trial. Previous research has indicated that varying CSI blockwise rather than on a trial-by-trial level might increase participants' effort to prepare in the long CSI condition, as no uncertainty exists about whether or not preparation could be completed (cf. Rogers & Monsell, 1995). CSI lengths were varied between 5 ms (short/no preparation) and 1000 ms (long), to contrast no preparation with preparation effects. The response-cue interval was varied to be 1500 ms long (in the short CSI condition) or 505 ms long (in the long CSI condition), resulting in a constant overall RSI of 1505 ms.

Figure 3.1: Example stimuli in the Experiment 3. The greyscale objects were cued with a grey frame, the brown words with a brown frame.

As in previous experiments, participants first conducted a practice block of both the object and the word task alone (single-task blocks), each including 30 trials. Then they practised switching between both tasks for two blocks of 30 trials (mixed-block condition). Compared to Experiment 2, the number of practice trials was increased to 30 trials in each block, to ensure that participants were sufficiently trained to perform task switching when no prior preparation was possible. Moreover, both single-task blocks and the first of the mixed-practice blocks had short CSIs. The second mixed-practice block had long CSIs, so participants could get accustomed to both conditions. After this practice, participants completed eight task-switching blocks of 30 trials each in the main experiment. The order of CSI length in the blocks was counterbalanced between participants and was either SLLSSLLS or LSSLLSSL (with S indicating a short and L indicating a long CSI).

There were explicit instructions about preparation time in this experiment. Participants were told that "The frame will appear before the picture and the word are shown" and were instructed to "use this additional time to prepare for the task, so that you can respond quickly and accurately." Participants were informed orally that there would be blocks in which the preparation time would be short and blocks in which the preparation time would be long. To increase trial numbers for later memory analysis, and because the univalent condition (i.e., trials in which a word and a scrambled object picture, or a random character string and an object were shown) did not lead to interesting effects in previous experiments, univalent trials were not included. Thus, participants were only presented with bivalent trials, containing both an object and a word, as these trials allowed for a comparison of ratings for the attended and the unattended item in the later memory test.

Task switching was again followed by a recognition-memory test. In the memory test the ratio of new to old items was decreased to 1:4. By reducing the number of new items, it was possible to increase the number of items included in the task-switching phase and consequently also the number of old items in the later memory test for subsequent analysis. The memory test was otherwise the same as in Experiment 2, and included 8 blocks of either object or word stimuli in which participants rated on a scale from 1 to 6 on each trial whether they thought that the object or word presented was new or old.

For the analysis of the task-switching data, RT outliers (3 *SD* above the mean) were excluded. This cut-off of 3 *SD* resulted in 2.6% and 3.8% of the trials being rejected in the short and long CSI conditions, respectively, (3.1% of switch trials and 3.6% of repeat trials). Additionally, post-error trials were excluded. Trials answered incorrectly during task-switching were excluded in the analysis of the memory data.

3.1.2 Results

Task Switching

To assess the effect of preparation time on task performance and switch costs, an ANOVA with variables switch and CSI (short versus long) was conducted (see Figure 3.2). The ANOVA revealed main effects of switch in the RTs, $F(1, 15) = 53.91$, $p < .01$, and error rates, $F(1, 15) = 5.21$, $p < .05$, with longer RTs and higher error rates in switch than in repeat trials (1287 ms vs. 1068 ms, and 6.9% vs. 4.8%, respectively). Furthermore, the main effect of CSI reached significance in the RTs, $F(1, 15) = 91.11$, $p < .01$, with slower RTs in the short than in the long CSI condition (1333 ms vs. 1022 ms), and in the error rates, $F(1, 15) = 8.57$, $p < .01$, with more errors in the short than in the long CSI condition (7.0% vs. 4.6%). There was, however, no reliable interaction between switch and CSI (*Fs* < 1 for both RTs and error rates). Numerically, there was a larger cost of switching in the short than the long CSI condition in RTs (241 ms vs. 196 ms) and the error rates (2.5% vs. 1.8%), but this effect was inconsistent across participants.

Thus, even though the CSI by switch interaction effects were descriptively found in the pilot data to this study, they again failed to reach significance in the full study. As mentioned above, the lack of this effect is surprising given the wide replication in task-switching studies (cf. Kiesel, et al., 2010; Vandierendonck, et al., 2010), but it followed a pattern of insignificant results in several pilot studies. Possible reasons for the lack of this effect will be considered in the discussion. Nevertheless, a robust main effect of CSI on overall task performance was observed. This effect is of interest, as it enables the investigation of possible effects of CSI on later memory.

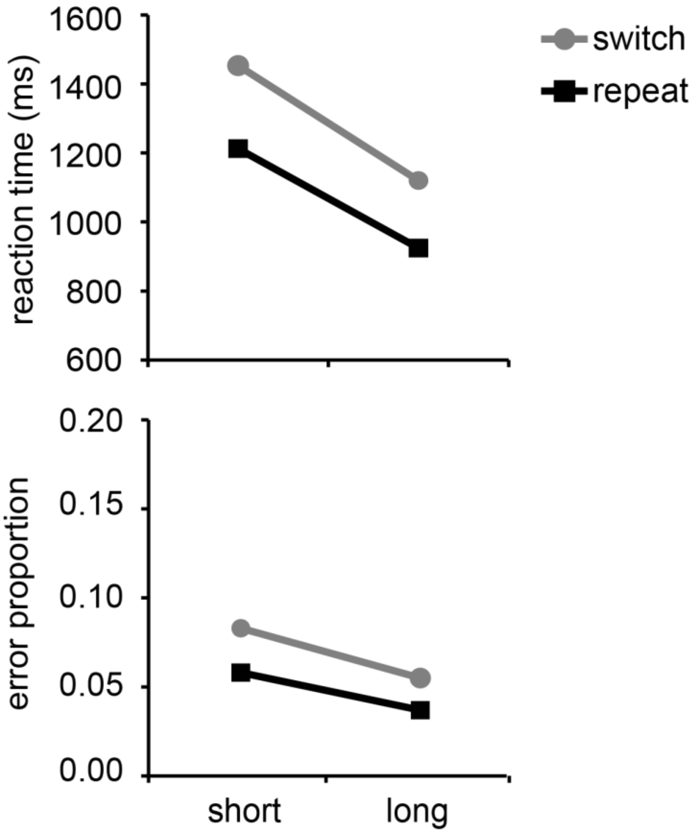


Figure 3.2: Task-switching performance in Experiment 3, showing RTs and error rates for switch and repeat trials, separately for short CSI and long CSI blocks.

Memory

To assess whether the same variables that affect performance during task switching also affect memory, I investigated whether variations in CSI also influenced performance in the memory test. Specifically, I wanted to assess whether the main effect of CSI during task switching, described above, was associated with corresponding changes in later memory. An ANOVA with variables switch, CSI, and attention revealed a main effect of switch, *F*(1, 15) = 7.89, *p* < .05, with better memory for items presented in repeat than switch trials during the task-switching phase (mean memory ratings of 3.84 vs. 3.76), as well as a main effect of attention, *F*(1, 15) = 143.30, *p* < .01, with better memory for attended than unattended items (mean memory ratings 4.49 vs. 3.11). The main effect of CSI did not reach significance, $F(1, 15) = 1.06$, $p = .320$ (mean memory ratings of 3.78 for the short CSI condition and 3.82 for the long CSI condition).

The main effects were qualified by several interactions. Reliable interactions were observed between switch and attention, $F(1, 15) = 55.72$, $p < .01$, switch and CSI, $F(1, 15) = 9.95$, $p < .01$, and between CSI and attention, $F(1, 15) = 10.36$, $p < .01$ (see Figure 3.3). The interaction between attention and switch replicated the results of Experiment 2, indicating that the difference in memory ratings for attended and unattended items was reduced on switch trials. Pairwise comparisons revealed a significant decrease in ratings between attended repeat and switch trials, $t(15) = -5.74$, $p < .01$, and a significant increase in ratings between unattended repeat and switch trials, $t(15) = 2.51$, $p < .05$.

The interaction between switch and CSI indicated a larger difference in memory for items appearing in short versus long CSI blocks when the task repeated compared to switched. Repeat trials seemed to benefit from the long CSI condition, $t(15) = -2.62$, $p < .05$, but a similar effect was not observed in switch trials, $t(15) = 1.09$, $p = .293$. Lastly, the interaction between CSI and attention indicated a larger difference between attended and unattended items in long compared to short CSI trials. There was no significant effect of CSI on memory for unattended information, $t(15) = 1.60$, $p = .130$, but there was a significant improvement in the memory scores for attended items from the short to the long CSI condition, $t(15) = -2.90$, $p < .05$. Thus, the long CSI condition seemed to improve allocation of attention to the relevant stimulus. This effect was consistent with the effect of CSI in the task-switching data, where a longer preparation interval was associated with better performance in both switch and repeat trials.

The three-way interaction between switch, attention, and CSI did not reach significance, $F(1, 15) = 2.96$, $p = .106$. Numerically, the familiar pattern of the switch by attention interaction was seen in the short CSI condition, with a smaller effect of attention in switch than repeat trials. In the long CSI condition, memory ratings to attended items were overall increased in both switch and repeat trials, leading to an overall increased difference between attended and unattended items. Moreover, the unattended items did not display the previously observed increase in memory ratings between repeat and switch trials, but showed a tendency for a decrease in memory ratings. The lack of a significant three-way interaction was not surprising given a similar lack of an interaction between CSI and switch in the task-switching data, and therefore was consistent with the prediction that enhanced top-down control should affect performance in task switching and memory in a similar way.

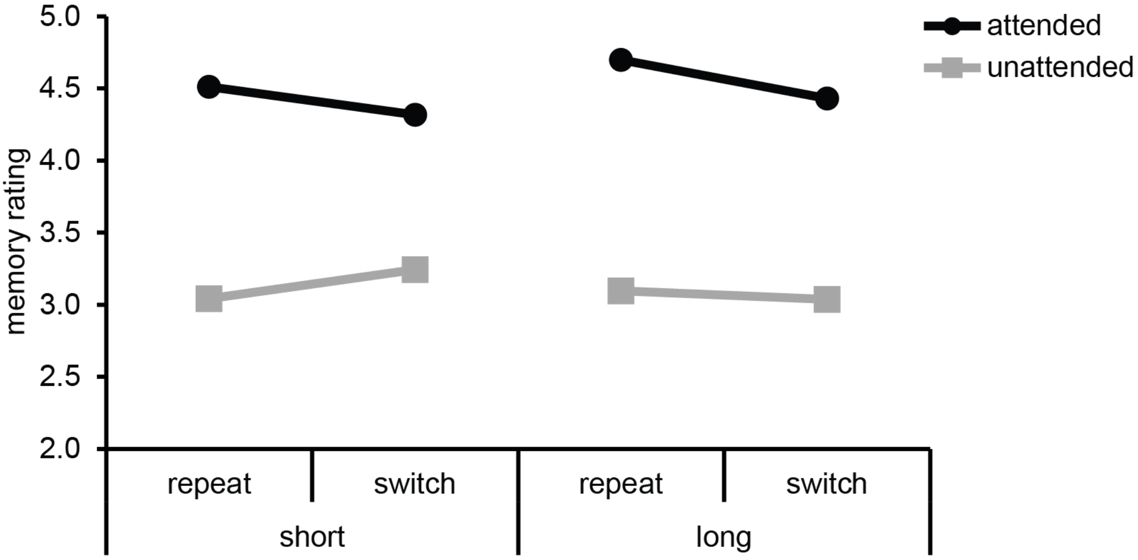


Figure 3.3: Memory ratings for attended and unattended items presented in the short or long CSI condition separately for switch and repeat trials in Experiment 3.

3.1.3 Discussion

The goal of the current experiment was to demonstrate that a manipulation of preparation time affects task-switching performance and later memory. The results indicated that the long CSI condition led to an improvement in performance in the task-switching phase, evident in a main effect of CSI. Importantly, the results of the memory test suggested that the top-down manipulation of control during task-switching also affected later memory: Consistent with the hypothesis that performance in the memory test should be affected by variations of preparation time in a similar way to the task-switching data, a greater difference between memory for attended and unattended items was observed in the long CSI condition.

More surprisingly, the present results did not replicate the well-established reduction in switch costs that is typically observed as preparation time is increased (Meiran, 1996; Monsell & Mizon, 2006). It was predicted that a reduction in switch costs in the task-switching phase should be accompanied by a corresponding effect in the memory data, evident in an effect of longer preparation time on the decreased selectivity of memory in switch compared to repeat trials. As CSI and switch did not interact in the task-switching data, the lack of a three-way interaction in the memory data might not be surprising: If CSI triggered similar preparation processes in switch and repeat trials during task switching, we would not expect that differences between these trial types occur during later memory.

Overall, these results indicate that variations on top-down control during task performance not only influence the selectivity of information processing, but also the selectivity of later memory, suggesting that a mutual benefit in task performance and later memory can be observed with increases in top-down control. The finding of an effect of longer preparation time specifically on memory for attended information rather than a general effect of preparation time on memory bears some similarity with the findings of Experiment 2, where an interaction between attention and switching was found: In both cases the selectivity of memory was affected rather than overall memory. This finding extends previous results in the memory literature. Whereas it has been argued that the preparation phase may play a central role for memory encoding (e.g., subsequent memory effects during this period were described in EEG studies, Otten, et al., 2006), it has been argued that these effects might reflect a “favourable state of mind” (Chun & Turk-Browne, 2007), rather than being related to actual preparation processes. The current results however suggest that the top-down modulation of control by active task preparation influences later memory in terms of an increase in selective encoding, rather than an overall effect on memory. The results also substantiate the conclusion that increased recruitment of control during task switching does not limit the resources available for encoding: The fact that selectivity was increased (evident in the fact that attended items in the long CSI condition showed better memory than in the short CSI condition) in a situation in which more top-down control was employed supports the hypothesis that the selectivity of processing is a key factor in task performance and memory.

Several findings were also observed that are of relevance for the task-switching literature. The lack of the predicted reduction in switch costs with preparation in the task-switching data was surprising, not least because several pilot studies were run to optimise this effect. Whereas this finding is in strong contrast to the vast majority of studies that find a reduction of switch costs with increasing RT, several factors might have contributed to the lack of a reliable effect here. For example, it has been suggested that in complex tasks preparation can be equally beneficial for switch and repeat trials (Dreisbach, Haider, & Kluwe, 2002), and similarly that there is no difference between switch and repeat trials when complex or abstract task cues are used (Monsell & Mizon, 2006). Moreover, it has been suggested that preparation can only counteract switch costs to a limited amount if conflict arises with stimulus presentation (Hakun & Ravizza, 2012), and lastly, sometimes limited preparation effects are found when stimulus-response mappings of the different tasks do not overlap, (e.g., Meiran, Levine, Meiran, & Henik, 2000; Poljac & Bekkering, 2009), or when tasks switch frequently (Dreisbach, et al., 2002; Koch, 2005). Thus, a combination of the factors above might explain the lack of a reduction of switch costs with increased preparation time in the current experiment. Attempts to adapt the design based on parameters discussed in the literature, to increase this effect of preparation time on the switch cost, were not successful.

Given that several pilot studies were run with different manipulation of the design that aimed to increase the effect of preparation time on the switch cost, the lack of this effect seems to be a fairly stable finding here. This could indicate that under certain conditions, task preparation might be comparably advantageous for switch and repeat trials, or simply that the interaction effect loses its stability under specific task conditions. Overall, however, the majority of task-switching studies find reductions of switch costs with longer preparation time, even if the factors above apply, making the lack of a reduction of switch costs still a surprising finding here. Nevertheless, the current research was mainly concerned with the relationship between control processes during task switching, and the effect of this control on later memory. The reduction of switch costs with increasing CSI was not of central importance for this topic. The key finding of the current experiment was that, regardless of the lack of an effect of CSI on switching, increased preparation time affected performance in task switching and memory in the corresponding way.

Overall, these results extend the findings of Experiment 2 and indicate an overlap between processes that control task performance and those responsible for encoding success (cf. Chun & Johnson, 2011). The results suggest that better task performance in the long CSI condition is not likely due to some unspecific, general influences such as arousal, predictability of the stimulus (cf., Sanders, 1972), or processing of the task cue (Logan & Bundesen, 2003; Schneider & Logan, 2005), as a general increase in memory would have been expected in this case. The current results rather indicate an increased selectivity of processing in the long CSI condition. This effect does not seem to be different for switch and repeat trials. This is a noteworthy finding because in Experiment 2 memory selectivity seemed to affect the switch trials only (an effect replicated for the experiments presented in the current chapter, see below). One possible interpretation of this divergence of findings is that when overall selectivity increases in the long CSI condition, this generally increases performance. However, this increased selectivity appears to be somewhat independent from the fact that the task sets are still less stable (more flexible) in switch trials (cf. Dreisbach & Wenke, 2011).

A surprising finding in the current experiment was that memory was overall worse in switch than in repeat trials, an effect that was not observed in the previous experiments (and, to preview later sections of this thesis, none of the later experiments either). This effect of switching was modulated by preparation time. There was a significant increase in the ratings for items from repeat trials between the short and long CSI condition. Thus, repeat trials seemed to benefit from a long preparation time. This finding somewhat contradicts the claim of reconfiguration accounts of task switching that longer CSIs are particularly beneficial for switch trials due to task-preparation processes (Rubinstein, et al., 2001). The large memory effect for repeat trials could instead indicate that participants establish a more stable repeat trial set (Dreisbach & Haider, 2008; Dreisbach & Wenke, 2011) in situation in which they have a lot of time to prepare – potentially because the preparation time could allow them to switch to the other set if necessary (cf. Monsell, 2003).

To conclude, manipulating preparation time had effects on task performance that also affected memory. Contrary to the predictions, CSI and switching did not interact in the task-switching data. In line with the lack of a modulation of switch costs by increased preparation time during task switching, the memory data showed an effect of preparation time on attended items that did not significantly differ between switch and repeat trials. Task performance as well as memory for attended information was improved in the long CSI condition, suggesting that the selectivity of processing was in fact increased here. Importantly, consistent with the predictions, task switching and memory encoding were thus affected by changes in top-down control in the same manner, suggesting that similar processes are involved in successful task performance and memory encoding. Increased top-down control in an incidental encoding paradigm thus improved performance in the task, as well as later memory.

3.2 Experiment 4: The Influence of Voluntary and Instructed Task Choice

Experiment 3 provided some initial support for the hypothesis that top-down control affects task switching and memory in a similar way, by increasing the selectivity of processing. Experiment 4 implemented a different manipulation to increase the strength of top-down control, with the aim of replicating the earlier findings and generalising the conclusions drawn. Moreover, the current experiment addressed a current debate in the task-switching literature: the question of the nature of control processes in the voluntary task-switching design.

In the current experiment, participants again completed a task-switching phase followed by a memory test. To manipulate top-down control, I introduced a voluntary task-switching condition. The task-switching phase in the current experiment consisted of trial sequences in which participants chose the task themselves (voluntary task switching), and trial sequences in which the task required was indicated by a cue (instructed task switching, as in previous experiments). The topic of voluntary task switching has stimulated a considerable amount of research in recent years (e.g., Arrington & Yates, 2009; Liefooghe, et al., 2010; Orr, Carp, & Weissman, 2012; Orr & Weissman, 2011; Yeung, 2010), as it arguably targets top-down control-related processes more directly (Arrington & Logan, 2005): Arrington and Logan (2005) propose that the fact that participants are required to choose the task themselves in the voluntary task-switching design ensures that an act of top-down control is involved in the task-switching procedure which, according to the authors, is not the case in instructed task switching. Moreover, if participants choose the task themselves, they might be more committed to perform well, which should increase top-down control, as intrinsic motivation has been shown to increase performance (e.g., Robinson et al., 2012). According to this view, voluntary task switching should be more efficient than instructed task switching.

There are, however, interesting reasons to predict other results. First, choosing a task is in itself a demanding process because there is ambiguity about which task to choose (Arrington & Logan, 2005). In addition to (or as a result of) this ambiguity, participants might not have formed a strong decision, and thus a strong task set, for the task to perform. This could impair their performance on the task. In comparison, an instructed task might not involve the participants' own decision, but clearly indicates which task to perform (Arrington & Logan, 2005). Thus, the very characteristics of the voluntary task-switching paradigm that have been argued to make it a better measure of top-down control, might actually result in impaired control and increased conflict in this condition compared to instructed switching. For this reason it is ambiguous whether a performance benefit or decline should be postulated for the voluntary task-switching compared to the instructed condition. Therefore, the current experiment also aimed to address the question of control processes in voluntary compared to instructed switching paradigms.

Importantly, in the design that was used in the current experiment, I assessed the RTs to a cue that instructed participants to choose a task in a voluntary switching condition, or to indicate the relevant task in the instructed condition (see details below, cf. Orr, et al., 2012; Poljac & Yeung, 2012a). This method provided me with a measure in addition to the task-switching RTs and error rates. If there are differences in speed of responding to the instructed cue (indicating which task they ought to perform) and the voluntary cue (indicating which task they choose to perform) it is possible to use this information to draw conclusions about the involvement of control processes.

Thus, the rationale of the voluntary task-switching paradigm suggests that voluntary task switching depends more on top-down control than instructed switching. This leads to the prediction that performance in voluntary task-switching trials should be improved compared to performance in instructed task-switching trials. However, as noted, an interesting alternative prediction is possible: voluntary task switching could be more demanding, as task sets might be less clearly established than in the instructed condition, leading to impaired performance compared to instructed trials. On the basis of the standard rationale of the voluntary task-switching design (Arrington & Logan, 2004, 2005), I predicted to find performance improvements in the voluntary compared to the instructed task-switching condition in the task switching and memory data. Specifically, I expected voluntary task switching to be associated with better performance in the task-switching phase and correspondingly higher selectivity of later memory.

3.2.1 Methods

Participants. Participants in this study were six male and ten female undergraduate students from the University of Oxford. Their age ranged from 20 to 22 years with a mean of 20.5 and a *SD* of 0.9. All participants were native English speakers, right-handed, and had normal or corrected-to-normal vision. They gave informed consent to take part in the study.

Procedure. This experiment compared voluntary with instructed task-switching trials. Overall, the procedure was similar to that used in previous experiments, with a task-switching encoding phase followed by a surprise memory test. There were 5 experimental task-switching blocks overall. Each 40-trial block of the task-switching phase was divided into 4 sequences of 10 trials of either instructed or voluntary task switching. The cue type (instructed vs. voluntary) was varied between sequences. In the voluntary task-switching sequences, participants were instructed to try to choose the task randomly ("as if they were tossing a coin" to decide) and to try to perform roughly equal numbers of trials of each task as well as of task switches and repetitions. At the end of each block, they received feedback about how often they switched and how often they performed the object and word task. An example of the trial timing is given in Figure 3.4.

In the voluntary task-switching procedure, participants had to choose the task by button press while the cue was on the screen (i.e., prior to stimulus presentation). This procedure was chosen for the following reason: Task-switching designs that have used a different approach, and had participants choose the task upon stimulus presentation have shown that task choice is influence by stimulus characteristics, such as stimulus repetitions, priming effects and associations between stimuli and tasks (Arrington, 2008; Arrington, et al., 2010; Demanet, et al., 2010; Mayr & Bell, 2006). By using the current method, and ensuring that participants did not see the stimulus before they made their choice, their decision could not have been influenced by stimulus characteristics.

A similar cue-response procedure was used in the instructed task-switching sequences. Here participants pressed a key to indicate the instructed task. In the voluntary-switching sequences, a purple cue indicated that participants should choose which task to perform; in the instructed task-switching sequences a red cue indicated the object task and the blue cue the word task (see Figure 3.4). When the cue appeared, participants indicated their task choice (in the voluntary condition) or which task was instructed (in the instructed condition). After this response to the cue, the screen cleared briefly (250 ms) before the stimulus, surrounded by the cue frame, appeared and participants responded to the stimulus.

In this study, the mapping of the keys to responses differed from the other studies. Participants used the “z” key to indicate that they chose the word task, and the “m” key to indicate that they chose the object task. After the response to the cue, the stimulus appeared. Participants then used the “x” (“abstract”) and “c” (“concrete”) keys to respond to words, and the “b” (“man-made”) and “n” (“natural”) keys to respond to objects. Task choice was indicated with the ring fingers, and the responses to the tasks were given with index and middle fingers. The different mapping of the keys in this study compared to previous experiments was employed to ensure that the same hand was used for the task choice as well as the task, to make it easier for the participants to remember the relevant mappings.

In this experiment, participants completed two single-task practice blocks (32 trials each), as well as two mixed-task practice blocks (20 trials each), before completing a voluntary task-switching practice block (20 trials). This was done to familiarise participants with the task, and how to balance the choice of switching/repeating and object/and word task. The memory test was the same as in Experiment 3.

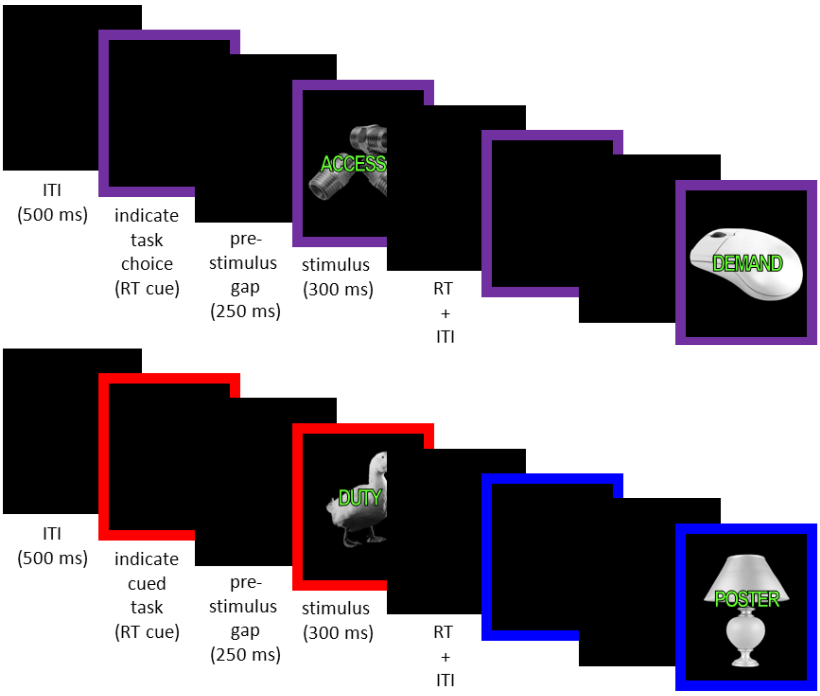


Figure 3.4: Example trials in voluntary (upper panel) and instructed (lower panel) task-switching sequences in Experiment 4.

3.2.2 Results

Task Switching

Task Choice and Choice Speed

An important feature of the current design was that it was not only possible to assess performance in response to the stimulus, but also in response to the cue that participants were presented with. The first analysis focused on this response to the task cue: in voluntary task switching, the analysis focused on the distribution of participants' task choices, and for both voluntary task switching and instructed task switching, the speed of responding to the cues was analysed. The first analysis assessed whether participants followed the task instructions to perform both tasks, as well as task switches and repetitions equally often. No significant difference was evident in the frequency with which participants chose the object and word tasks (50.8% vs. 49.2%, *SD* = 5.23, *t*(15) =

1.56, $p = .14$), nor in how often they switched or repeated tasks (49.5% vs. 50.5%, SD = 10.39, $t < 1$). Collectively, these results suggest that participants broadly followed instructions to perform both tasks as well as switch and repeat tasks equally often.

Next, it was analysed whether there were systematic differences in the time taken to decide on a task/indicate the instructed task. If differences in the RTs to the cue are observed between voluntary and instructed conditions, this could indicate that participants used different strategies to respond to the cue, were more or less thoughtful in their response, or found the decision to the cue more or less difficult. In conjunction with the data from the subsequent response to the stimulus, these RT data can provide valuable information about the amount of top-down control involved in voluntary compared to instructed task switching. For this purpose, I compared RTs to the cue when participants had to indicate which task they were supposed to, or chose to do.

An ANOVA with factors switching and cueing type (voluntary vs. instructed) revealed main effects for both switching, $F(1, 15) = 33.07$, $p < .01$, and cueing type, $F(1, 15) = 87.65$, $p < .01$, as well as an interaction between cueing type and switching, $F(1, 15) = 6.89$, $p < .05$. Participants were faster to indicate task choice in voluntary compared to instructed trials (393 ms vs. 565 ms), as well as being faster to indicate task choice in repeat than in switch trials (431 ms vs. 518 ms) (see Figure 3.5). All pairwise comparisons were significant, $t(15) > 2.96$, $p < .05$. The difference between switch and repeat trials was larger in the instructed than the voluntary condition, $t(15) = 2.63$, $p < .05$. Thus, participants overall made faster responses to voluntary than instructed trials, and their response time did not seem to differ as much between switch and repeat trials in the voluntary condition. This finding could indicate increased motivation and increased top-down control in voluntary task-switching trials, in that the cost of a choice to switch tasks is reduced. However, this finding could also indicate that participants did not commit to their choice and made a “hasty” decision. Given these two alternative interpretations, it was important to assess how these differences relate to task performance in response to the stimulus.

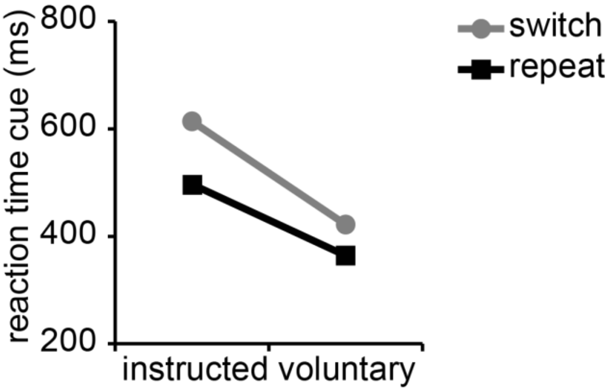


Figure 3.5: RTs to the cue in instructed and voluntary conditions, separately for switch and repeat trials in Experiment 4.

Task Performance

To examine performance in response to the stimulus, RTs and error rates were entered into a ANOVAs with variables switch and cueing type (see Figure 3.6). A main effect of switch in the RT data, $F(1, 15) = 52.59$, $p < .01$, indicated slower responses in switch trials than repeat trials (1244 ms vs. 1047 ms). The effect of switching was only marginally significant in the error rates, $F(1, 15) = 4.14$, $p = .06$ (8.4% in switch vs. 7.2% in repeat trials). Furthermore, the analysis revealed a main effect cueing type in the RT data, $F(1, 15) = 6.93$, $p < .05$, which was not significant in the error rate data, $F < 1$. In contrast to the RT to the cue, responses to the stimulus in the voluntary condition were slower than those in the instructed condition (1066 ms vs. 978 ms). No interaction between cueing type and switch was found in the RTs, $F < 1$, or error rates, $F < 1$.

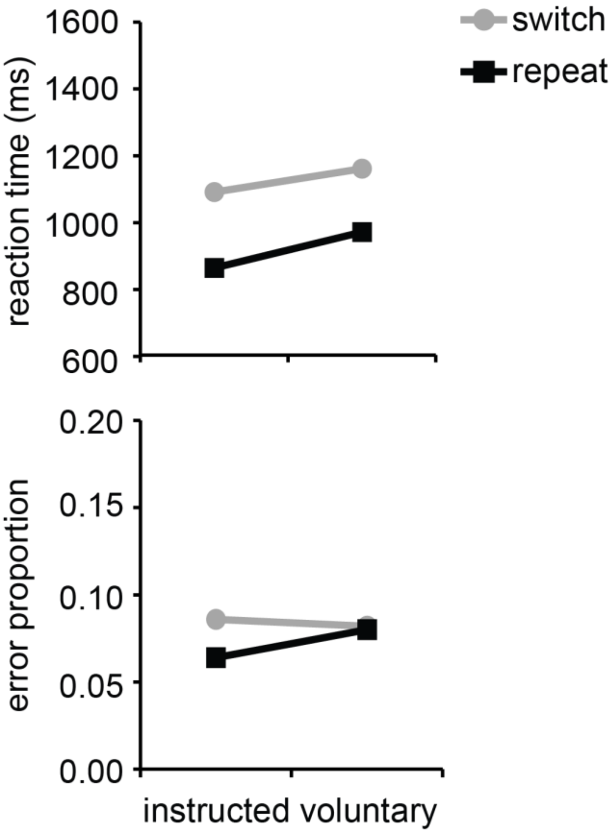


Figure 3.6: RTs and error rates to the stimulus in instructed and voluntary conditions, separately for switch and repeat trials in Experiment 4.

The discussion considers these performance differences between voluntary and instructed task switching in more detail. For now, the key point to note is that the combination of faster RTs to the cue and worse performance in response to the actual stimulus during voluntary task switching suggests that participants might have made a premature decision in the cue phase in these trials. This finding indicates that the response to the cue possibly has not been as well prepared in voluntary as in instructed trials, thus indicating that voluntary trials may actually be associated with less top-down control.

Memory

As indicated above, there was a significant difference in performance between voluntary and instructed trials in the task-switching phase. The key question regarding performance in the memory test was whether a corresponding effect of cueing type (voluntary versus instructed) could also be found in the memory data. On the basis of the data from the task-switching phase, I predicted that instructed trials, which were associated with better task-switching performance, should result in corresponding effects in the memory test (i.e., more selective memory).

An ANOVA on the memory data including switch, cueing type, and attention as variables revealed the following effects (see Figure 3.7). The main effect of attention reached significance, $F(1, 15) = 188.79$, $p < .01$, with attended items being remembered better than unattended items (mean memory ratings of 4.74 vs. 3.20), as did the interaction between attention and switch, $F(1, 15) = 14.92$, $p < .01$, which indicated the usual pattern of reduced selectivity of memory in switch compared to repeat trials. Follow up *t*-tests indicated that there was a significant increase in memory ratings for unattended items between repeat and switch trials, $t(15) = 2.64$, $p < .05$, whereas a numerically opposite trend between attended items in repeat versus switch trials was only marginally significant, $t(15) = -1.85$, $p = .084$.

Moreover, the interaction between cueing type and attention reached significance, $F(1, 15) = 12.74$, $p < .01$. The memory difference between attended and unattended items was greater for items presented during instructed than voluntary-switching trials. That is, memory was more selective for items presented during instructed switching. Pairwise comparisons revealed that attended items in instructed trials were remembered significantly better than attended items in voluntary trials, $t(15) = 2.31$, $p < .05$. Descriptively, there was a trend in the opposite direction for unattended items, however, it did not reach significance, $t(15) = -1.70$, $p = .110$. Thus, the cueing type modulated how well relevant items were attended and later remembered. Consistent with the task-switching data, instructed attended items were remembered better than voluntary attended items. No reliable main effect of the cueing type was found, $F < 1$ (mean memory rating instructed 3.98, mean memory rating voluntary 3.96), indicating that whether the task was chosen voluntarily or whether the task was instructed did not significantly affect how much information was encoded overall. Moreover, no significant main effect of switching was observed, $F < 1$, similarly indicating that there was no evidence for an effect of switching on overall memory.

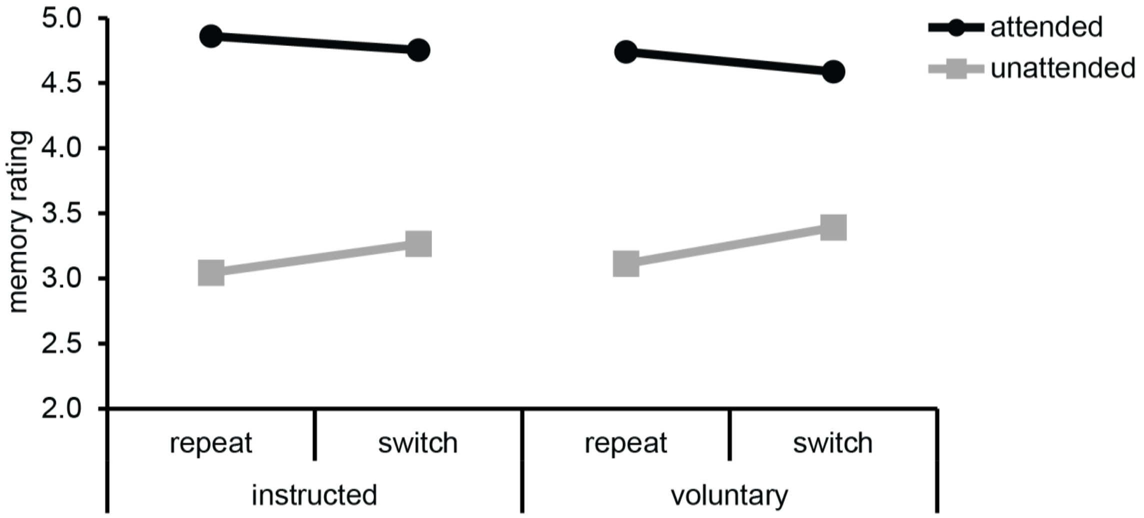


Figure 3.7: Memory test performance in Experiment 4 showing memory ratings for attended and unattended items that were presented in repeat or switch trials, separately for the instructed and voluntary condition.

3.2.3 Discussion

There were two main objectives of this study. The first was to demonstrate that performance differences in the two cueing-type conditions (instructed vs. voluntary) in the task-switching phase should also be reflected in corresponding performance differences in memory. Evidence consistent with this prediction would replicate and generalise the findings of Experiment 3, and thereby provide further support for the hypothesis that similar processes are involved in successful task performance and encoding. A second key point of this study was to investigate the nature of control processes in voluntary task switching compared to instructed task switching, to address the debate on whether voluntary task switching is associated with less or more effective top-down control than instructed task switching (cf. Arrington & Logan, 2005; Yeung, 2010).

Consistent with the predictions made with regards to the first research question, performance differences between voluntary and instructed trials in the task-switching phase were mirrored in the memory data: The task-switching data indicated that responses to stimuli in voluntary task-switching trials were slower than instructed trials, suggesting less successful application of cognitive control. Correspondingly, in the memory data, instructed trials led to better memory for attended items than voluntary trials, with a numerical trend in the opposite direction for the unattended items.

The correspondence of effects of the type of switching task (voluntary or instructed) on task-switching performance (better performance in instructed trials) and performance in the memory test (better memory for attended items specifically in instructed trials) suggests that similar mechanisms influence performance in both task switching and memory. Importantly, the type of switching (voluntary or instructed) influenced the selectivity of processing, rather than overall performance, consistent with a similar effect of CSI in Experiment 3. Moreover, as memory did not reliably differ between voluntary and instructed trials overall, it cannot be assumed that performance in the memory test was affected by the type of switching in general. Instead, this observation is more consistent with the claim that the selectivity of processing is of central importance for the performance differences observed. The finding that differences in top-down control affect the selectivity of processing rather than overall performance is also consistent with the findings of Experiment 3. Also similar to Experiment 3, cueing type did not affect memory for attended and unattended items differentially in switch and repeat trials. This finding was not unexpected given the lack of an effect of cueing type on the switch costs in the task-switching data. Accordingly, it seems that cueing type, influences performance in the same way for switch and repeat trials, by increasing the selectivity of processing.

Overall, the data indicate that voluntary task switching is associated with less effective control than instructed switching, contrary to its original purpose (Arrington & Logan, 2005). Participants responded more quickly to the cue but more slowly to the following stimulus, possibly indicating that they did not complete the choice process or were not committed to the choice. Together the combined analysis of the Cue-RT data and the responses to the stimuli indicated that voluntary trials might have been associated with less effective top-down control than instructed switching (in contrast to what was predicted by, Arrington & Logan, 2005). Crucially, this interpretation that voluntary trials in general employ *less* effective top-down processes than instructed trials is in agreement the finding that attended items presented in instructed trials were associated with better memory than those presented in the voluntary condition, as this result suggested the effectiveness of control is worse in voluntary trials and increased in instructed trials. The decreased RTs and decreased difference between switch and repeat trials in response to the cue, combined with worse task performance in the subsequent trial suggests that participants did not prepare the choice effectively and did not differentiate between switch and repeat trials as much as in instructed trials, indicative of a rather “hasty” decision. This analysis suggests, that participants had not fully decided which task to perform when they responded, and were thus slower to respond to the stimulus.

The findings reported in this chapter have several implications for theories of cognitive control. It has been suggested that the voluntary task-switching paradigm may be a more direct test of top-down control than instructed task switching, based on the proposal that the task choice requires top-down processes (Arrington & Logan, 2004, 2005). The degree to which voluntary task switching is a “pure” measure of top-down control processes has however recently been questioned (Yeung, 2010), as studies have shown that bottom-up effects influence choice behaviour in the voluntary task-switching paradigm. In this context, stimulus availability, stimulus repetitions, priming effects and associations between stimuli and tasks (Arrington, 2008; Arrington, et al., 2010; Demanet, et al., 2010; Mayr & Bell, 2006) have been found to influence task choice in voluntary task switching. Other bottom-up processes such as task congruency (Orr & Weissman, 2011), between-task interference (Yeung, 2010), and task history (Lien & Ruthruff, 2008) also influence choice behaviour in the voluntary task-switching paradigm, indicating that bottom-up processes play a role in voluntary task switching. The research presented here is in agreement with these prior findings (e.g., Orr & Weissman, 2011; Yeung, 2010), as it suggests that it cannot simply be assumed that voluntary task switching is a "pure" measure of, or is associated with increased, top-down control.

The better performance in instructed than voluntary trials could be due to the fact that participants were told to try to switch and repeat the tasks equally often and to choose object and word task approximately equally often. The additional requirement to keep track of prior responses could have distracted them from focussing on the actual task. Furthermore, conflict in the voluntary task-switching condition might be enhanced in any case: In voluntary task switching the cue does not carry any information about the task to perform, meaning that which task set to choose is ambiguous (cf. Arrington & Logan, 2005). In line with this argument, a recent EEG study has shown that participants seem to correct their task choice when they are switching in the voluntary task-switching paradigm, rather than immediately choosing a different task. This effect was evident in the finding that EEG correlates of motor preparation for the respond hand that was relevant in the preceding trial was observed before correlates of preparation of the response hand relevant in the current trial (Vandamme, Szmalec, Liefooghe, & Vandierendonck, 2010). This finding indicates competition in voluntary switch trials, a factor that could also explain performance differences in the current experiment. In contrast, in the instructed task-switching paradigm, the cue clearly indicates which task to choose which could lead to less ambiguity and a more strongly established task set. Accordingly, a methodological implication of the data presented here is that if voluntary task switching and instructed task switching are to be compared systematically, paradigms need to ensure that task choice is conducted in a sufficiently controlled manner, so that participants fully decide on a task before they answer to the cue.

In sum, the data from the task-switching phase suggest that voluntary trials exhibited less top-down control than instructed trials. Thus, voluntary task switching, which was introduced as a manipulation of enhanced top-down control, might in fact lead to less effective control processing, because it is possible to make a task choice without committing to a decision – the very process that was assumed by Arrington and Logan (2004, 2005) to involve top-down control. Crucially, the memory results of the present experiment suggest that encoding success—and, specifically, selectivity of encoding—depends on the effective allocation of control during the encoding phase. This process seems to be more successful in the instructed conditions. Importantly, and replicating as well as generalising the results of Experiment 3, enhanced use of top-down control during task performance does not appear to induce competition between task control and memory encoding (evident in the finding that memory was comparable in both switching conditions) but increases the selectivity of processing.

3.3 Experiment 5: The Influence of Reward

This experiment investigated the influence of reward on task-switching performance and subsequent memory. The effect of reward on task performance and memory is well documented (e.g., Chiew & Braver, 2011). For example, the prospect of reward has been shown to significantly reduce RTs and error rates in flanker task (Hubner & Schlosser, 2010), and high compared to low reward incentives during encoding increases performance in a later memory test (Halsband, Ferdinand, Bridger, & Mecklinger, 2012). Moreover, reward has also been demonstrated to reduce the switch cost in the task-switching paradigm (Kleinsorge & Rinkenauer, 2012).

Reward has been shown to lead to more stable mode of cognitive control in the task-switching paradigm, evident in better performance when faced with distraction, at least when the achievement of reward is perceived to be effortful (e.g., Mueller et al., 2007). Furthermore, reward history seems to influence how reward affects performance. In a study by Shen and Chun (2011), monetary reward incentives led participants to prepare flexibly for different tasks in a task-switching paradigm evident in a reduction of switch costs, but only when reward increased from the previous to the current trial. If reward remained on a constant level, participants seemed to perform better when staying on the same task. Thus, whether reward leads to increased flexibility or more stable deployment of control processes seems to depend on a range of different factors such as perceived effort as well as the history of previous reward.

One mechanism by which reward might influence performance is by encouraging effective advance preparation (cf. Kleinsorge & Rinkenauer, 2012). In task-switching studies, reward incentives contingent upon performance (no errors in a specified numbers of trials) have been shown to reduce switch costs, and trials in which reward could be obtained displayed larger CNVs, a measure of preparation processes (Capa, Bouquet, Dreher, & Dufour, 2012). Moreover, increased top-down control associated with reward has been shown to bias the processing of relevant versus irrelevant information in visual cortex (Padmala & Pessoa, 2011).

In the current experiment, I contrasted a reward condition with a standard task-switching condition. On the basis of the literature reviewed in the preceding paragraphs, the following effects were predicted. During task-switching, reward should increase the effort to focus attention on relevant material and thus lead to better task-switching performance. This increased attentional focussing should again be reflected in the memory scores, where I expected to find more selective memory for items presented in reward trials, based on similar observations in Experiments 3 and 4. Confirmation of these predictions would provide further support for the importance of selective processing in task performance and memory, and would indicate that performance enhancements associated with reward are due to an increased selectivity of processing.

3.3.1 Methods

Participants. Participants in this study were three male and 13 female undergraduate students of the University of Oxford. Their age ranged from 18 to 26 years (*mean* = 21.8, *SD* = 2.8). Participants were paid for their participation. Furthermore, participants were able to gain monetary reward (between £0 and £6) during the experiment. All participants were native English speakers, and had normal or corrected-to-normal vision. They gave informed consent to take part in the study. One participant was excluded due to failure to comply to task instructions to always respond as quickly as possible (with RTs in switch no-reward trials more than 600 ms slower than in repeat no-reward trials, and almost 800 ms slower than in switch reward trials).

Procedure. Participants completed a practice block of only the word and only the object task with 32 trials each, as well as two mixed-task blocks with both object and word trials, before being informed about the reward condition. Participants were then instructed that different trial sequences could either be reward or no-reward sequences in the main experiment. Good performance (accuracy and speed) in certain trials but not others would result in monetary reward. At the beginning of each 10-trial sequence they were instructed whether good performance in this trial sequence would be rewarded or not. In each reward sequence they were able to gain 50p. Reward sequences were marked with yellow stars in the corners of the cue frames. Figure 3.8 shows an example of two trials of a reward sequence.

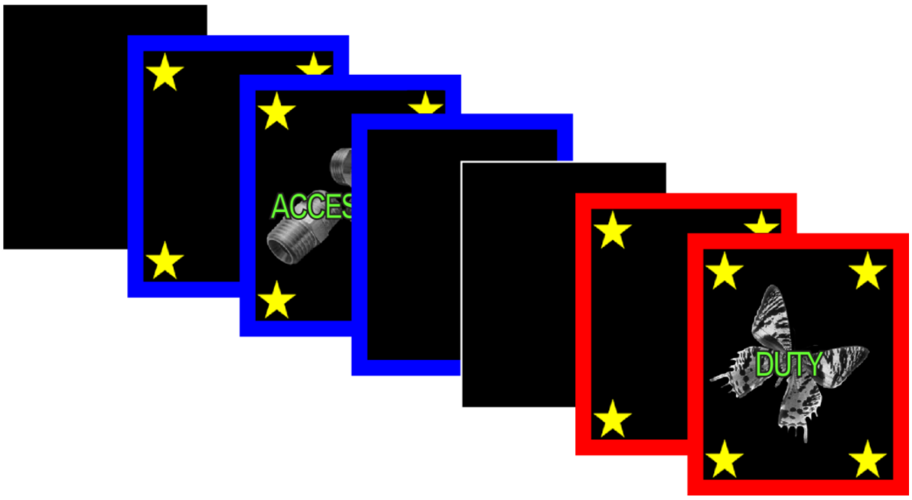


Figure 3.8: Example of a word and an object reward trial in Experiment 5. Yellow stars in the corner of the cue and stimulus frames indicate that the sequence is a reward sequence.

There were 5 blocks of 40 trials in the task-switching phase. Each block comprised four sequences of ten trials, two of which were reward sequences and two of which were no-reward sequences. The order of the sequences within each block was randomized. Within each sequence there were equal numbers of switch and repeat trials. At the end of each reward sequence, feedback was given on the RT, error rate, and whether or not participants received reward in this sequence. Specifically the feedback was “Well done! So far you have gained £ (amount they have gained)” if they received reward, and “Sorry, no reward! - Too many errors!”, “Sorry, no reward! - Too slow!”, or "Sorry, no reward! - Too many errors and too slow!" if they did not meet the criteria for reward. Participants received the “Well done!” feedback if their error rate was below or equal to 10% errors and their RT was 10% faster than in the previous reward sequence. For the first reward sequence, the RT of the last training block minus 10% was used as a cut-off. Note that at this stage participants did not know about the reward condition and how it was calculated, so they could not use strategies to maximize reward such as intentionally trying to be slow in this block. If the sequence they completed was not a reward sequence, the feedback included their RT and error rate together with the sentence "This was not a reward sequence.". The same response keys as in the Experiment 3 were used. The memory test was the same as in Experiments 3 and 4.

3.3.2 Results

Task Switching

On average participants gained £1.90 (minimum: £0, maximum: £3.5, *SD* = 0.8). First, the effect of reward on task-switching performance was assessed to determine whether the reward condition showed the expected performance improvements (see Figure 3.9). An ANOVA with variables switch and reward revealed a significant main effect of switch in the RT data, *F*(1, 14) = 130.25 *p* < .01, with lower RTs for repeat than switch trials (791 ms vs. 978 ms), and in the error data, *F*(1, 14) = 6.00, *p* < .05, with lower error rates for repeat than switch trials (7.6% vs. 10.1%). There was a main effect of reward only in the RT data, *F*(1, 14) = 13.58 *p* < .01, with faster responses in reward sequences than in no-reward trials (844 ms vs. 925 ms). Furthermore, the switch by reward interaction reached significance in the RT data, *F*(1, 14) = 6.88, *p* < .05, and was marginally significant in the error rate data, *F*(1, 14) = 3.34, *p* = .089. There was a smaller switch cost in the RTs in the reward than the no-reward condition, with a similar trend for errors. Follow-up *t*-tests indicated that there were significant differences between repeat trials in the reward and no-reward condition, *t*(14) = 2.45, *p* < .05, switch trials in the reward and no-reward conditions, *t*(14) = 3.57, *p* < .01, repeat and switch trials in the no-reward condition, *t*(14) = -10.13, *p* < .01, and repeat and switch trials in the reward condition, *t*(14) = -6.58, *p* < .01. Thus, in contrast to the CSI and voluntary task-switching experiments, the reward condition affected the switch cost in addition to overall performance during task switching.

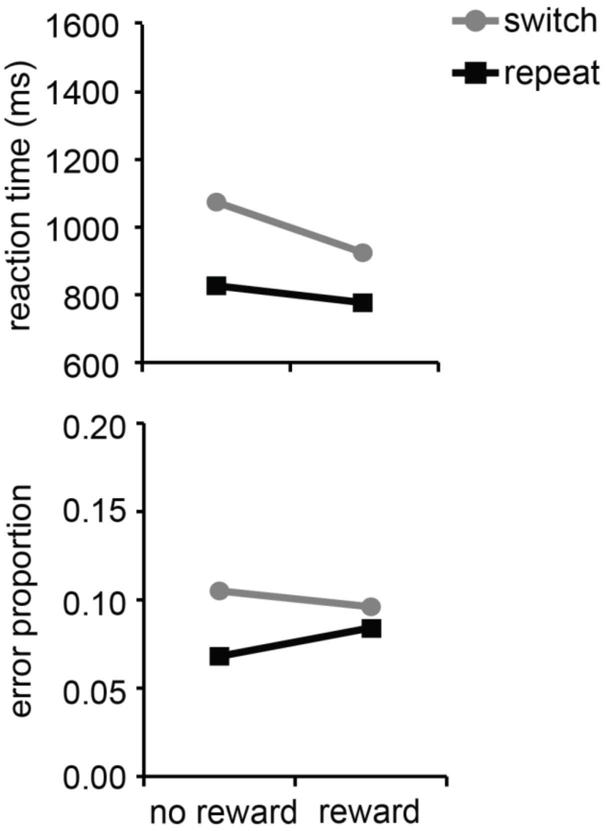


Figure 3.9. RTs and error rates for switch and repeat trials in the reward and no-reward condition in Experiment 5 (n = 15).

Memory

To assess the effect of top-down control on later memory, an ANOVA with attention, switch, and reward as variables was conducted. As in Experiments 3 and 4, the critical question here was whether memory would be affected by switching in the same way as task-switching performance. Therefore, here we might expect the effect of reward on later memory to be modulated by whether or not the item was presented in a switch or repeat trial during task switching, as the effect of reward was modulated by switching in the task-switching phase.

The main effect of reward was not significant, $F < 1$ (mean memory rating no-reward trials 3.83, versus reward trials 3.78). There was a significant effect of attention, $F(1, 14) = 139.81$, $p < .01$, with attended items resulting in better memory than unattended items (mean memory ratings 4.44 vs. 3.17), and a significant interaction between switch and attention $F(1, 14) = 8.67$, $p < .05$, with more similar ratings to attended and unattended items in switch compared to repeat trials, replicating the findings of earlier studies. The interaction between switch, attention, and reward descriptively showed the predicted pattern of a stronger interaction between switch and attention in no-reward than reward trials, (Figure 3.10), but did not reach significance ($p = .130$).

Inspection of the separate participants' data indicated that one participant had a switch-reward interaction effect in the opposite direction (i.e., this participant showed larger switch costs in reward trials) that was more than 2 *SD* away from the mean of all participants. Re-analysis of the data excluding this participant did not substantially change the task-switching data results: The main effect of switch remained significant in the RTs, $F(1, 13) = 126.96$, $p < .01$, and was marginally significant in the error data, $F(1, 13) = 4.34$, $p = .058$. Moreover, the main effect of reward was again only significant in the RT data, $F(1, 13) = 14.78$, $p < .01$. The switch by reward interaction remained significant in the RT data, $F(1, 13) = 10.46$, $p < .01$, whereas a non-significant trend was observed in the error rate data, $F(1, 13) = 3.05$, $p = .104$.

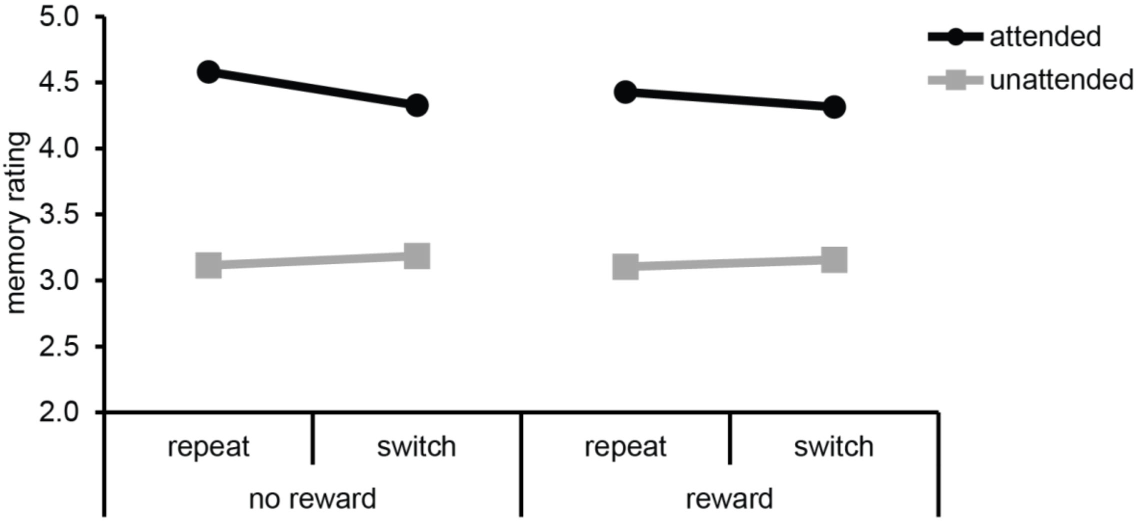


Figure 3.10: Memory rating for the different combinations of attention, switch, and reward in Experiment 5 (n = 15).

After excluding this outlying participant, the ANOVA on the memory data revealed a main effect of attention, *F*(1, 13) = 121.23, *p* < .01, and an interaction between switch and attention *F*(1, 13) = 6.86, *p* < .05. The main effect of reward was not reliable, *F* < 1, but critically there was a reliable interaction between switch, attention and reward, *F*(1, 13) = 5.94, *p* < .05. Separate follow-up ANOVAs for reward and no-reward trials revealed that there was a significant interaction between switch and attention in the no-reward data, *F*(1, 13) = 13.61, *p* < .01, but not in the reward data, *F* < 1. For the no-reward condition, the usual decrease in selectivity of memory in switch compared to repeat trials was observed. Such a reduction in memory selectivity was not reliably observed in the reward data. Follow-up *t*-tests on the no-reward trials indicated that there was a significant increase for the memory ratings of unattended items in switch trials compared to repeat trials, *t*(13) = -2.19 , *p* < .05, as well as a significant decrease of memory ratings for attended items, *t*(13) = 3.32 , *p* < .01. In the reward condition, the differences between attended switch and repeat trials (4.44 vs. 4.37) and unattended switch and repeat trials (3.16 vs. 3.17) were numerically small and not statistically reliable.

These results are in accordance with the prediction that top-down control processes during the task-switching phase can influence the effective use of top-down control, reflected in greater selectivity in switch trials in later memory in the reward condition. These results must however be interpreted with caution, because the critical three-way interaction between reward, switch, and attention only reached significance once an outlying participant was excluded.

3.3.3 Discussion

The reward manipulation was successful in this experiment in leading to decreased costs of task switching. Critically, the successful manipulation of the switch cost was also reflected in the memory data, where reward counteracted the decrease of selectivity in switch trials (an effect that was significant after exclusion of an outlying participant). This interaction indicated that reward incentives improved the effective use of control in switch trials, and decreased the switch-related reduction in selectivity found in other experiments. This finding is consistent with the notion that reward incentives enhance the recruitment of cognitive control processes and bias the processing of relevant stimuli (e.g., Padmala & Pessoa, 2011), thus leading to more selective processing. Importantly, in contrast to other experiments in the current chapter, switching interacted with the effects of reward on performance in reward and no-reward trials in the task-switching and memory data. This suggests that patterns of effects of increased control on later memory depend on processing during the task-switching phase: When switch and repeat trials are affected differentially by increases in control during task switching, memory for items encountered on these trials is also affected to different degrees. If switch performance is not differentially affected during task switching (as seen in Experiments 3 and 4) there is also no differential effect of enhanced top-down control on later memory for items presented on switch and repeat trials.

For theories of memory, the results of the current experiment provide further evidence that memory does not compete for resources with task control, extending the results of Experiments 3 and 4. The current findings demonstrate that focussed task performance increases selectivity of memory even under highly demanding situations, such as the one of the reward condition in the current experiment. This is an important extension to Experiment 3 and 4, which were not as demanding, and where an increased use of top-down control was encouraged but not as necessary for successful task performance. This result is in contrast to studies that have shown detrimental effects on encoding when participants performed a difficult compared to an easy secondary task (Kensinger, Clarke, & Corkin, 2003; see also Uncapher & Rugg, 2005). The difference between previous studies (Kensinger, et al., 2003; see also Uncapher & Rugg, 2005) and the current paradigm is that, in the current experiment, the difficult task was performed on the same material that was later used in the memory test, whereas in the studies mentioned above attention was divided between different tasks, and the material presented in the difficult task was not relevant for the memory test. Importantly, the current findings are also not compatible with resource-limitation accounts, which would have predicted limited encoding success in this situation (cf. Otten & Rugg, 2001b). Lastly, if reward had increased overall arousal, this should have led to better memory in the reward condition overall, not to increased selectivity, as observed in the current experiment. In sum, the data again indicate that the selectivity of processing is a key element in successful task performance and memory, even if control demands are high.

For theories of cognitive control, the results are consistent with previous findings that highlight that reward influences the successful recruitment of cognitive control

(Hubner & Schlosser, 2010; Kleinsorge & Rinkenauer, 2012; Mueller, et al., 2007). Specifically, the reward manipulation increased the selectivity of attentional processing. This effect was especially pronounced in switch trials. Previous research has suggested that consistent levels of reward increase the stability of cognitive control (versus the flexibility) (Mueller, et al., 2007), and therefore specifically improves performance in repeat trials (Shen & Chun, 2011). Improvements in the current experiment were, however, seen in switch trials, evident in the reduction of the switch cost, which suggests that the effect of reward on cognitive control might be more complex: One possible interpretation is that the key influence of reward on control is not increased stability, but increased selectivity of processing, in contrast to more broad, non-selective, but flexible processing.

It has to be noted that the results presented in this study were statistically unreliable unless an outlying participant was excluded. Future research will have to replicate these findings to demonstrate their robustness. With this caveat in mind, overall the findings of the current experiment extend the findings of previous experiments in this thesis, not only by replicating overlap of the effects of increased top-down control on task and memory performance seen in Experiments 3 and 4, but also by demonstrating that that this relationship holds even in situations of high control demand.

3.4 Memory Selectivity

Experiment 2 introduced the idea that memory selectivity—the difference between memory ratings for attended and unattended items—can be used as a measure of how well attention was focussed during task switching. One important step in demonstrating that this measure is robust is to replicate its ability to predict task-switching performance, as well as the somewhat surprising interaction with switching (i.e., the lack of an effect of memory selectivity in repeat trials). I therefore ran corresponding analyses of memory selectivity on the data from each of the three experiments reported in this chapter.

As in Experiment 2, memory selectivity was calculated separately for switch and repeat, object and word stimuli, and attended and unattended items, excluding RT outliers, as well as error trials. In addition, the scores were also calculated separately for each of the levels of manipulation of top-down control. As the manipulations of top-down control were included as additional variables in the analyses of memory selectivity, the data was only divided into two bins here, to ensure sufficient cell sizes. To test whether the results of the memory selectivity analysis in Experiment 2, specifically the interaction between switch and memory selectivity, could be replicated robustly, I conducted ANOVAs on the RTs and error rates during task switching including switch, memory selectivity and the relevant top-down manipulation as variables for each of the experiments. Importantly, the main focus of this analysis was whether the interaction between memory selectivity and switching would replicate, as this was an unexpected, but interesting effect in Experiment 2. I did not expect a modulation of the memory selectivity effect by the relevant top-down manipulations, as high and low memory selectivity was calculated separately for each level of manipulation of top-down control. As an example, high memory selectivity in the short CSI condition would include smaller memory selectivity scores than high memory selectivity in the long CSI condition. Consequently, a main effect of the relevant manipulation of top-down control, rather than an interaction with memory selectivity would be expected.

Figure 3.11 shows RTs (upper panel) and error rates (lower panel) for memory selectivity scores in switch and repeat trials across the three experiments described in this chapter. Overall the patterns of the data resemble that of Experiment 2, in that switch trials seemed to be affected by memory selectivity more than repeat trials. Separate ANOVAs on the data of the three experiments indicated the following effects: In Experiment 3, the interaction between memory selectivity and switch was marginally significant in the RT data, $F(1, 15) = 3.41$, $p = .085$, and significant in the error data, $F(1, 15) = 7.56$, $p < .05$. In the RT data, switch trials descriptively showed an increase in RTs between the high and the low memory selectivity conditions, while there did not seem to be a difference between high and low memory selectivity repeat trials. In error rates, the interaction indicated that there was a significant effect of memory selectivity on switch trials, $t(15) = -3.29$, $p < .01$, but not for repeat trials, $t < 1$. In Experiment 4, the interaction between switch and memory selectivity reached significance in the RT data, $F(1, 15) = 7.23$, $p < .05$, but not in the error data, $F < 1$. Follow-up *t*-tests for the RT data indicated that there was a significant difference between the high and low memory selectivity switch trials, $t(15) = -3.95$, $p < .01$, but not between high and low memory selectivity repeat trials, $t < 1$, again replicating previous findings. Lastly, after excluding the outlying participant in the reward study, the ANOVA revealed a significant interaction between switch and memory selectivity in the RT data, $F(1, 13) = 7.26$, $p < .01$, as well as in the error rates, $F(1, 13) = 9.31$, $p < .01$. For RTs, there were significant differences between high and low memory selectivity switch trials, $t(13) = -4.96$, $p < .01$, but only a numerically smaller trend between high and low memory selectivity repeat trials, $t(13) = -1.94$, $p = .075$. In the error rate data, follow-up analysis revealed significant differences between high and low memory selectivity switch trials, $t(13) = -4.81$, $p < .01$, but did not indicate a difference between high and low memory selectivity repeat trials, $t < 1$. Accordingly, the switch by memory selectivity interaction was replicated across experiments.

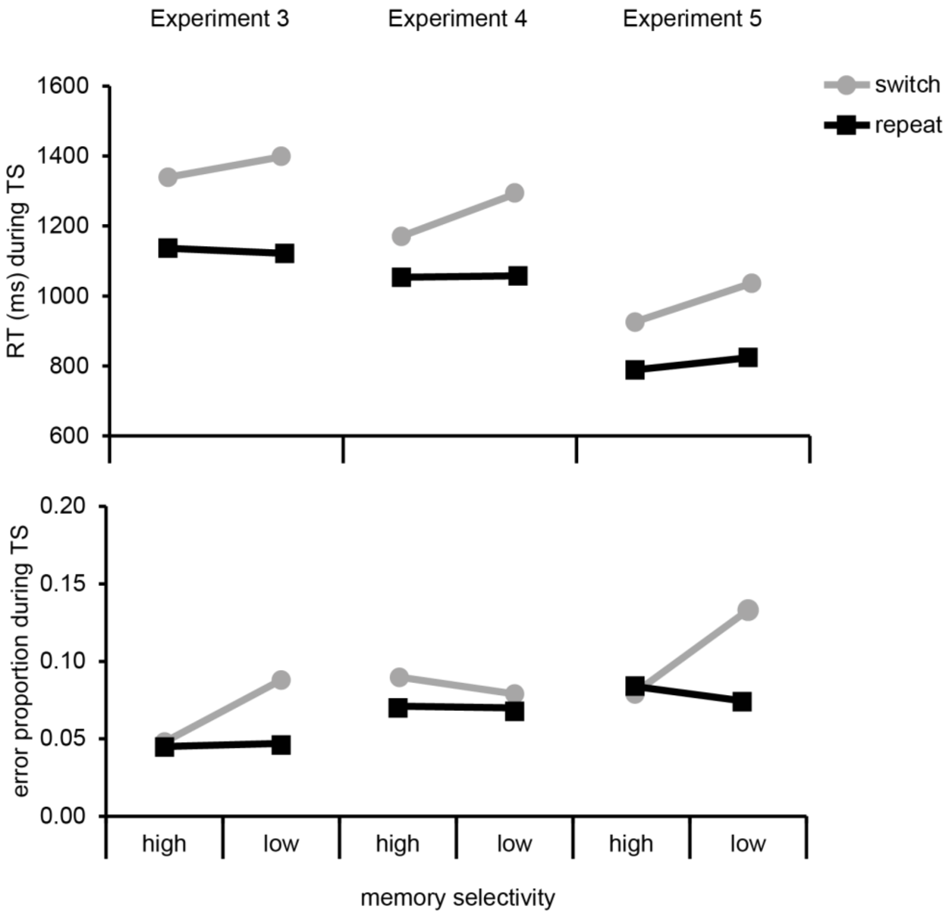


Figure 3.11: RTs (upper panel) and error rates (lower panel) for different high and low memory selectivity trials in Experiments 3 (CSI manipulation) Experiment 4 (voluntary task-switching manipulation), and Experiment 5 (reward manipulation).

Overall, therefore, the surprising observation that memory selectivity was only related to performance in switch trials, which was first reported in Experiment 2, was replicated very consistently across the three experiments of the current chapter. Together, these findings suggest that the interaction between memory selectivity and switch is stable, such that memory selectivity primarily influences performance in switch trials, with variation in the processing of the attended compared to the unattended items seeming to have little or no effect on task-switching performance in repeat trials.

3.5 General Discussion

The three experiments reported in this chapter were conducted to investigate whether systematic manipulations of top-down control affect task performance and memory encoding in a similar way. Overall, the manipulations of top-down control successfully induced performance improvements in task switching and the memory test. Where conditions exhibited reliable performance improvements during task switching, this effect was accompanied by reliable between-condition differences in memory selectivity. These effects did not differ for switch and repeat trials in Experiment 3 and 4, where enhanced top-down control improved task performance as well as the selectivity of memory to the same degree for both trial conditions. In Experiment 5, however, increased top-down control in the reward condition was associated with a decrease in switch costs during task switching, as well as increased selectivity in memory specifically for switch trials. Collectively, these results demonstrate that there is little evidence for competition between task control and memory encoding. Instead, task performance and encoding seem to share control mechanisms, reflected in the parallel effects of control (increased selectivity of processing) on task performance and memory. Together, these results suggest that memory can be employed as a measure of cognitive control. This conclusion was also supported by the analysis of memory selectivity across experiments: This chapter consistently replicated the findings from the memory selectivity analysis in Experiment 2: Memory can be used as a trial-by-trial index of cognitive control and "post-dicts" performance differences in RTs and error rates during task-switching in switch trials.

For theories of cognitive control, the findings of the current chapter thus support the conclusion from Chapter 2 that memory can be used as a reliable index of previous cognitive control. Moreover, increased employment of control increased the selectivity of processing, rather than affecting overall performance, evident in the results showing that top-down processing primarily increased later memory for attended information, whereas no reliable evidence for an overall increase in memory in association with enhanced top-down control was found. The results of this chapter also indicate that control can improve performance in different ways, by increasing overall attention to relevant information (as evident in the effects of preparation time and instructed compared to voluntary task switching), or differentially for switch and repeat trials (as seen in the manipulation of reward).

For theories of memory, the findings of the current chapter demonstrate that encoding is directly related to processing in the task-switching phase. It seems that a positive association between task performance and memory requires that the task taps onto the same processes as encoding. If control is divided between two completely independent tasks this is not the case, explaining previous findings of decreased memory associated with simultaneous task performance (Kensinger, et al., 2003; Uncapher & Rugg, 2005, 2008). Thus, if control is directed towards relevant stimuli, increased control demands do not seem to limit encoding of these stimuli, but actually support effective encoding. These findings are consistent with ideas about the relationship between attention and memory described in recent literature. In this context it has been argued that memory can be described as a “by-product of […] attentional processes” (Chun & Johnson, 2011, p. 520). When the same highly similar processes are engaged, as was the case in the experiments of this chapter, a close relationship between attention and memory should be observed, consistent with the findings described in this chapter.

Another interesting aspect of the data is that the memory selectivity analysis consistently indicated that switch trials are much more affected by selectivity of processing than repeat trials. In Experiments 3 and 4, however, no differences were found in the effect of top-down control on switch and repeat trials. These data suggest that even if selectivity increases in switch and repeat trials to a similar degree (as in the long CSI condition or the instructed trials), switch trials are still more vulnerable to performance declines than repeat trials. It therefore seems that an increase in selectivity of processing overall increases performance, but that this effect is independent from the fact that the task sets are still less stable (more flexible) in switch trials (Dreisbach & Wenke, 2011).

A last interesting question concerns why Experiment 5 showed differential performance improvements for switch and repeat trials, and similarly a differential effect of increased top-down control on later memory for information presented in these trials, whereas this effect was not seen in Experiments 3 and 4. The reward condition was the only manipulation of top-down control in which participants needed to increase their efforts to obtain good results. The reward criterion was strict, and became increasingly strict as participants' performance improved, and thus this condition likely required the most effective control. The other conditions, were in contrast somewhat more “relaxed”, in that poor performance was not associated with any negative effects (or a lack of positive effects such as reward). It is possible that in these conditions, participants did not try to improve performance to the same degree as they did in the reward condition. Thus, it may be that not only the possibility to successfully engage control processes, but also a control demanding situation are required for the effects described in Experiment 5. In the reward condition, increasing the effort to perform well might have been particularly effective on switch trials, possibly because the already high performance in repeat trials could not be improved further (i.e., a ceiling effect). Follow-up studies might usefully investigate whether less effortful reward conditions, or other more effortful manipulations of top-down control, lead to similar effects between the experiments.

In summary, the results reported in this chapter provide evidence that the control of a task does not limit the amount of information that is encoded, but affects selectivity. If controlled processing is enhanced, this enhancement is reflected in more selective memory for relevant compared to irrelevant information. The results of the current chapter thus replicated the key results of Experiment 2, and extended them to demonstrate directly that variations in top-down control during task performance affect the encoding of presented information.

Chapter 4:

Behavioural and Neural Correlates of Attention Switching and Memory Encoding

The previous chapters have demonstrated that switching affects the selectivity of processing and encoding (Chapter 2), and that the selectivity of processing can be influenced by manipulating participants' use of top-down control (Chapter 3). The effect of switching on the selectivity of processing manifested itself as a reduced difference in memory ratings between attended and unattended items in switch trials compared to repeat trials. Moreover, switch trials displayed increasing RTs with decreasing memory selectivity. Having established and replicated these effects in previous chapters, the next step was to investigate the neural correlates of this selective processing.

Previous research has indicated that processing differences that are predictive of later memory can be measured during encoding, a finding that has been referred to as the *subsequent memory* effect (Sanquist, et al., 1980). EEG subsequent-memory effects are apparent as differences in stimulus-locked potentials as a function of whether those stimuli are later remembered. A common finding is that this contrast is observed as a positive slow wave over fronto-central or centro-parietal electrodes (Karis, et al., 1984; Paller, et al., 1987). Subsequent memory effects seem to be more frontally distributed if elaborate or deep encoding strategies are used compared to rote encoding (Fabiani, et al., 1990). Centro-parietal effects have been linked to rote or perceptual encoding, and have been suggested to be less reliable than the frontal effects (Fernandez, et al., 1998).

Interestingly, more recent studies have indicated that subsequent memory effects are not only observed in stimulus-locked data. They can also be elicited by an earlier cue, preceding the to-be-remembered stimulus; that is, they are also evident during the preparation phase (Galli, et al., 2012; Otten, et al., 2006; Otten, et al., 2010; Padovani, et al., 2011).

The interest of the current investigation lies particularly in the more frontal subsequent memory effects that are observed in the stimulus-locked data, and that have been argued to reflect elaborative encoding. An unanswered question is what exactly these subsequent memory effects reflect: Are they the result of an overall increase in alertness that is beneficial for later memory (cf. Chun & Turk-Browne, 2007), or do they reflect enhanced cognitive control, such as active preparation to encode or select relevant information (cf. Gruber & Otten, 2010)? The present chapter addresses this question using EEG.

The previous experiments have explored the selectivity of processing, so in a first step the EEG correlates of selective encoding success were assessed, by investigating the neural correlates of memory selectivity. It is, however, also possible that frontal subsequent memory effects reflect more general encoding success, that is, they could be predictive of improved memory for attended as well as unattended items. For example, they could reflect differences in overall alertness in a deep compared to a shallow encoding condition. For this reason, the current chapter introduced a measure of general memory success, and the EEG experiment also investigated the neural correlates of this more general, global processing. This *global memory* measure was calculated in parallel to the memory selectivity measure, in that trials were divided into three bins based on the memory ratings that participants gave to the attended and unattended item of each bivalent trial. In contrast to the memory selectivity measure, which was based on the difference (attended – unattended) between these ratings, global memory was calculated as the sum of these ratings (attended + unattended). In this way, global memory indicates the amount of information successfully encoded, regardless of task-relevance.

The second objective of the current chapter was to replicate the previous behavioural results with a simpler form of task switching. In previous experiments, the attended stimulus material and the relevant classification rule (natural vs. man-made judgement and abstract vs. concrete judgment) changed simultaneously. Thus, it is not clear whether the switch of the attended material, the classification rule, or both were driving the observed effects. To demonstrate that the behavioural effects found in previous experiments do not require the combined switch of the task, as well as switch of attention, but can also be observed if only attention is switched between the two stimulus types, the classification rule was held constant in the current design.

It is noteworthy, however, that a combined switch of two factors is often implemented in behavioural studies of task switching, and the question which of these two factors is driving the effect does not change the interpretation of the behavioural results (that the selectivity of processing is a key factor in successful task performance and memory).

In certain research areas, however, potential differences between types of switching are more often considered. For example, such differences are frequently discussed in neuropsychological studies. In this context, it has been described that patients with frontal lesions may be selectively impaired in shifting attention between stimulus dimensions (such as shape, colour, or size) compared to controls, but are less impaired when shifting attention between different exemplars within a stimulus dimension (e.g., Owen et al., 1993). Some neuroimaging studies have also found differences between different kinds of switching. For example, they have shown that switching attention between visual stimulus attributes versus switching between motor-response sets activates dissociable brain areas (Rushworth, Paus, & Sipila, 2001).

On the whole, it has been shown that although different types of switching may activate distinctive brain regions more strongly than other kinds of switching, they also activate a very consistently overlapping set of regions, most prominently the inferior frontal junction and regions in posterior parietal cortex (Kim, Cilles, et al., 2011; Wager, et al., 2004; Witt & Stevens, 2013). Thus, even if differences are found, there is still significant overlap that is indicative of similarities between different task- or attention-switching designs, suggesting that it may be valid to study them collectively. Nevertheless, to simplify the interpretation of the EEG results, I decided to disentangle these two factors.

The findings described in the current chapter aimed to address this issue, by using a simplified design. Similar to previous chapters, participants switched between making judgements on objects and words, and they later completed a recognition-memory test. In contrast to earlier experiments, participants conducted the same task (natural vs. man-made judgment) on both objects and words. This change was implemented to demonstrate that switching only attention, while keeping the classification rule constant, results in similar behavioural effects to those observed in previous experiments in this thesis. More importantly, this simplification of the design makes the interpretation of the EEG experiment more straightforward, as the switch only affected the nature of the attended item—object or word— and not also the classification rule performed on that item.

Thus, the first experiment of this chapter will describe the development and evaluation of the simplified behavioural design. The key prediction is that the effects of switching on the later selectivity of memory described in earlier experiments of this thesis can be replicated when only the relevant stimulus is switched, and not both the relevant stimulus and classification rule. The second experiment assessed the neural correlates of attention shifting and subsequent memory. Of interest here were the EEG correlates of successful task performance and subsequent memory, their potential similarities, and how these effects would be affected by switching.

4.1 Experiment 6: Attention Switching and Memory Encoding

The designs used in previous chapters included switches between sets of task rules in addition to the switching of attention between stimuli. This leaves it somewhat ambiguous as to whether switching the task rules, switching attention, or the combined effect of both was driving the effects described. The first aim of the current experiment was to demonstrate that these effects can be replicated when only the to-be-attended stimulus is switched, and not the required classification rule. Such a finding would allow the interpretation that switching attention alone can cause effects reported in previous experiments of this thesis, and thereby allow for a more precise interpretation of the result. The second objective was to develop a stable paradigm for testing in EEG, to permit investigating the neural correlates of selective processing, as well as the nature of subsequent memory effects.

Task-switching experiments have used a range of different methods somewhat interchangeably to study cognitive control and attention (Monsell, 2003). Sometimes the task switch involves shifting attention between stimuli such as faces and words (Yeung, et al., 2006) or numbers and letters (Karayanidis, Coltheart, Michie, & Murphy, 2003). Sometimes different tasks are conducted on the same stimuli, for example, parity and magnitude judgements on a stream of numbers (Koch & Allport, 2006). In the task-switching literature, it is widely assumed that task switching and attention switching require the same processes, reflected in the interchangeable use of the terms (e.g., Wager, et al., 2004), which is the reason that these differences usually receive little attention. Moreover, behavioural studies show that all of these paradigms display the typical switch costs, also suggesting that similar processes may be involved. Thus, there is good reason to believe that switching only attention in the current experiment should lead to comparable behavioural results as those obtained when switching both attention and classification rule in previous experiments.

To demonstrate the validity of the conclusions of experiments conducted in this thesis, the design used in previous chapter was thus modified. Participants in the current experiments switched their attention between different stimuli, while performing the same classification rule (a natural vs. man-made judgement on objects and words). It was predicted that the results outlined in Chapter 2 should be replicated. Most importantly, it was expected that selectivity of processing would reduce with switching, evident as a reduced difference between memory ratings for attended and unattended items in switch compared to repeat trials. Moreover, effects of memory selectivity should be evident in the task-switching RTs and error rates.

In the experiments reported in Chapters 2 and 3, memory selectivity correlated with switch trial performance but seemed to have little effects on repeat trials. In these earlier studies, memory selectivity might have had little effects on repeat trial performance because different classification rules and different sets of response keys were used for the two tasks. When tasks differ in response sets in this way, it might be relatively easy to “shield” task sets against interfering processes (cf. Dreisbach & Haider, 2008; Yeung & Monsell, 2003), as this can be achieved by selecting the relevant classification rule and corresponding set of response keys. In the current design, the same classification rule and the same response keys were used for both material types. Therefore, it was possible that memory selectivity would affect repeat trial performance in the current experiment to a larger degree. This should be evident in a similar effect of memory selectivity in switch and repeat trials.

In addition to investigating the relationship between selective encoding success (memory selectivity) and task performance, the relationship between general encoding success (global memory) and task performance was also investigated. Global memory scores are based on the sum of the memory ratings of the attended and unattended item (attended + unattended) of each bivalent trial, in contrast to memory selectivity scores which are based on the difference (attended – unattended) between these ratings. Thus, global memory assesses the overall encoding success of items of a trial, whereas memory selectivity indicates the degree to which relevant information is more successfully encoded.

The findings of previous chapters have indicated that selectivity of processing increases task performance. Overall encoding success, however, did not seem to be affected by switching: Almost uniformly, no main effect of switching was found in the memory data. Moreover, overall memory did not seem to be affected by manipulations of top-down control in Chapter 3, but top-down control affected the selectivity of encoding. Hence, none of the measures found to influence task performance in the previous chapters had a consistent effect on overall encoding success. Whereas global memory, a measure of overall encoding success, might therefore not be related to previous task performance to the same degree as memory selectivity, it is nevertheless possible that global encoding success varies with effective task performance somewhat independently of the processes assessed so far. If this is the case, this variability should be captured at least in part by the measure of global memory.

4.1.1 Methods

Similar to previous studies, participants first switched between making judgments on objects or on words, and then later completed a recognition memory test that included items presented during the task-switching phase, as well as new items. In contrast to earlier studies, in the current experiment the same classification rule was used for both material types: a judgement of whether presented words and objects were natural and man-made. Thus, the classification rule previously used only for objects was now also applied to words. For this purpose, words referring to natural or man-made objects (e.g., shop, ocean, donkey) were employed instead of the abstract and concrete words used before. The object pictures were identical to those used in previous experiments. Picture and word stimuli referred to different sets of objects (i.e., the word and picture stimuli did not overlap – the word “ball” would not occur if a picture of a ball was used).

Participants. Ten male and six female participants with an average age of 23.1 years (*SD* = 4.2) took part in this experiment. They received course credits or payment for their participations and all gave informed consent.

Procedure. Participants completed 6 blocks of 50 trials in which they switched between making judgments on objects or words. The currently-relevant material type was indicated by coloured cues, similar to previous experiments (red indicated objects and blue indicated words). Also similar to previous experiments, the same number of switch and repeat trials were used. The task-switching phase consisted of a total of 300 trials, 200 of which were bivalent (an object picture and an overlaid word) and 100 of which were univalent (an object picture and a random character string, or a scrambled object and a word). I reintroduced univalent trials in this experiment, as it was intended to run this design in EEG later (Experiment 7), where univalent trials might be of relevance for analyses: Univalent trials display only the word and a scrambled object, or only the object and a random character string. Therefore, contrasting the two conditions might give a relatively pure measure of object- and word-related activity in the stimulus phase, in contrast to bivalent trials in which both an object and a word were presented simultaneously. In the current study, participants responded with the index fingers of both hands using the “x” (man-made) and “n” (natural) keys for both material types. CSI was set to be 500 ms, and an ITI of 500 ms was used. Otherwise the timing was the same as in previous studies.

The subsequent recognition memory test followed the usual design, with 8 blocks of 74 trials. The number of new items in the current experiment was reduced to have more stimuli available for the task-switching phase. Increasing the number of stimuli for task switching was necessary to maintain a sufficient number of bivalent trials for analysis given the re-introduction of univalent trials. The ratio of old to new items was therefore 5:1 in the current experiment.

4.1.2 Results

Task Switching

The first objective of the current study was to show that effects described in previous experiments would replicate in this simpler switching design. Previous experiments (see Chapter 2) have shown that bivalent trials lead to increased RTs and error rates. Therefore, performance in univalent versus bivalent trials was assessed. The results of this analysis are shown in Figure 4.1. An ANOVA with the variables switch (switch versus repeat) and mode (univalent versus bivalent) revealed significant main effects of switch, $F(1, 15) = 47.77$, $p < .01$, with faster RTs in repeat than switch trials (889 ms vs. 1060 ms), and of mode, $F(1, 15) = 13.21$, $p < .01$, with faster RTs in univalent than bivalent trials (950 ms vs. 999 ms). Furthermore, the interaction between switch and mode, *F*(1, 15) = 6.56, $p < .05$, reached significance in the RT data, indicating a larger switch cost for bivalent than for univalent stimuli. Follow-up *t*-tests indicated that the effect of switching was reliable with both bivalent, *t*(15) = -6.71, $p < .01$, and univalent stimuli, *t*(15) = -6.32, $p < .01$. Thus, a main effect of mode seen in Experiment 1 and 2 as well as the interaction between mode and switch, seen in Experiment 1, were found. These results indicate that conflict arose from the irrelevant material type on bivalent trials, which was increased during task switching.

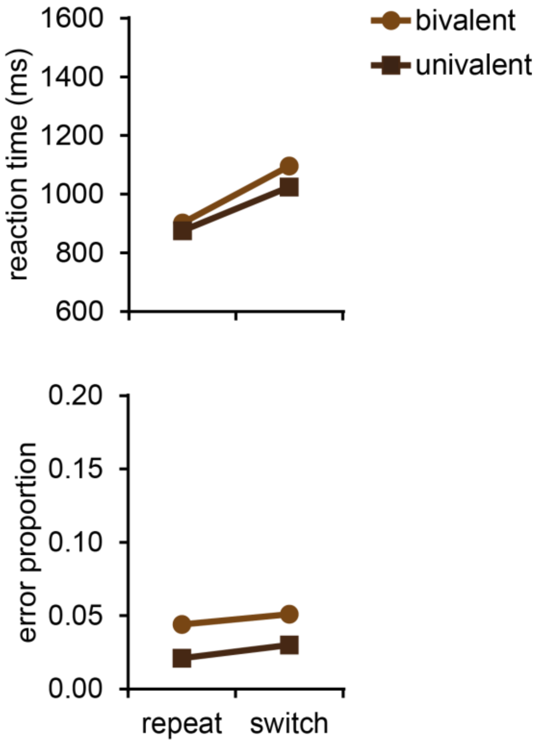


Figure 4.1: Reaction times (upper panel) and error rates (lower panel) for univalent and bivalent switch and repeat trials in Experiment 6.

A corresponding ANOVA on the error data revealed only a main effect of mode, *F*(1, 15) = 16.50, $p < .01$, with bivalent trials resulting in significantly more errors than univalent trials, similar to the results described in Experiment 2. Error rates were numerically higher on switch trials than repeat trials (4.1% vs. 3.3%), but the difference was not significant *F*(1, 15) = 2.02, $p = .175$.

Memory

Analyses of the memory data were conducted to assess whether the effects of switching on later memory could be replicated when the simplified design introduced in the current chapter was used. For this reason, the effect of switching attention on memory and the effects of memory selectivity were assessed.

Effects of Switching and Attention on Memory

A key objective for this experiment was to investigate whether the interaction between switch and attention (i.e., a smaller difference between the ratings of attended and unattended items in switch compared to repeat trials) would be replicated when only a switch of attention, and not of classification rules and attention, is performed. An ANOVA on the memory data with variables switch and attention revealed a main effect of attention, $F(1, 15) = 214.27$, $p < .01$, with higher memory scores for attended than unattended items (mean memory scores of 4.48 vs. 3.14). The main effect of switch did not reach significance, $F < 1$ (mean memory score repeat: 3.82 vs. switch: 3.81). Critically, the interaction between switch and attention was again significant, $F(1, 15) = 8.23$, $p < .05$. The difference in memory ratings between attended and unattended items was larger for repeat than for switch trials, replicating the effects of previous experiments, and thus demonstrating that this interaction can be observed even in this simplified design (see Figure 4.2). The significant interaction indicated that attended information in repeat trials was remembered better than attended information in switch trials, $t(15) = -2.79$, $p < .05$. There was a trend for the opposite effect for unattended items, which numerically were remembered worse in repeat than switch trials, $t(15) = 1.95$, $p = .07$. These findings support the claim that switching attention only between the different stimuli, while keeping the classification rule constant, interferes with the selective processing of task-relevant material, consistent with the results of previous experiments.

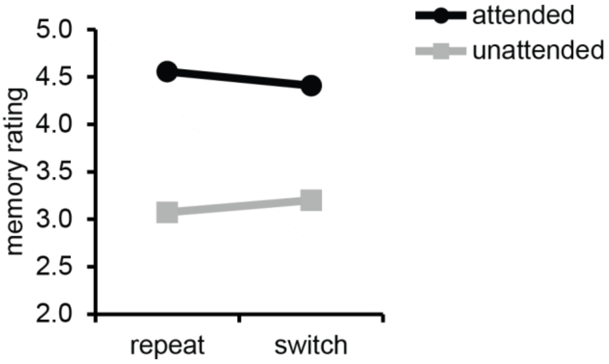


Figure 4.2: Memory ratings for attended and unattended items presented during repeat and switch trials in Experiment 6.

Memory Selectivity

The memory selectivity analysis aimed to explore performance differences in the task-switching phase based on later memory differences between the attended and unattended items. RT and accuracy during task switching was calculated as a function of later memory selectivity, after dividing bivalent task-switching trials into tercile bins according to the difference in memory rating for attended and unattended items appearing on those trials.

The analysis of memory selectivity was conducted to address two questions. First, it was assessed whether any effects of memory selectivity would be observed in this simplified version of the experiment. The second question of interest was whether these effects showed the same pattern as in previous studies. Specifically, I have suggested that memory selectivity might have had little effect on repeat trial performance in previous studies because different sets of response keys and classification rules were used for the two tasks. This could have led to a more successful shielding of the task set in repeat trials (cf. Dreisbach & Haider, 2008), as such a shielding could be achieved by selectively shielding the relevant response keys and rules. The current experiment used the same classification rule and response set for both material types, which should have eliminated this protective mechanism. If this was the case switch and repeat trials should be influenced by memory selectivity to a similar degree.

The ANOVA on the RT-memory selectivity data revealed a main effect of switch, *F*(1, 15) = 38.75 *p* < .01, reflecting the usual switch cost described above. Moreover, the main effect of memory selectivity, *F*(2, 30) = 6.74, *p* < .01, was significant, with a significant linear trend, *F*(1, 15) = 20.29, *p* < .01. This finding indicated an increase in RT with decreasing memory selectivity (mean RTs of 1030 ms for high, 1089 ms for medium, and 1134 ms for low memory selectivity trials). The interaction between switch and memory selectivity did not reach significance in the current experiment, *F* < 1. This was in marked contrast to previous experiments, in which the interaction between switch and memory selectivity was consistently replicated, and where it demonstrated an effect of memory selectivity in switch but not in repeat trials. The middle panel of Figure 4.3 displays the results of the ANOVA on the task-switching RTs. The upper panel shows the distribution of scores for comparison with the global memory data shown below (Figure 4.4). While the shape of the distribution looks slightly different to that presented in Chapter 2, the overall pattern is the same with a somewhat skewed distribution of memory selectivity scores, due to on average better memory for the attended than the unattended item.

To investigate the main effect of memory selectivity in more detail, separate one-way ANOVAs were carried out on the switch and repeat trial data. These ANOVAs indicated that the main effect of memory selectivity only reached significance for switch trials, *F*(2, 30) = 5.81, *p* < .01, linear trend, *F*(1, 15) = 12.69, *p* < .01, but not in repeat trials, *F*(2, 30) = 2.42, *p* = .106. Thus, even though the interaction between switch and memory selectivity did not reach significance in the current experiment, the effect on repeat trials did still seem to be somewhat less consistently observed across participants.

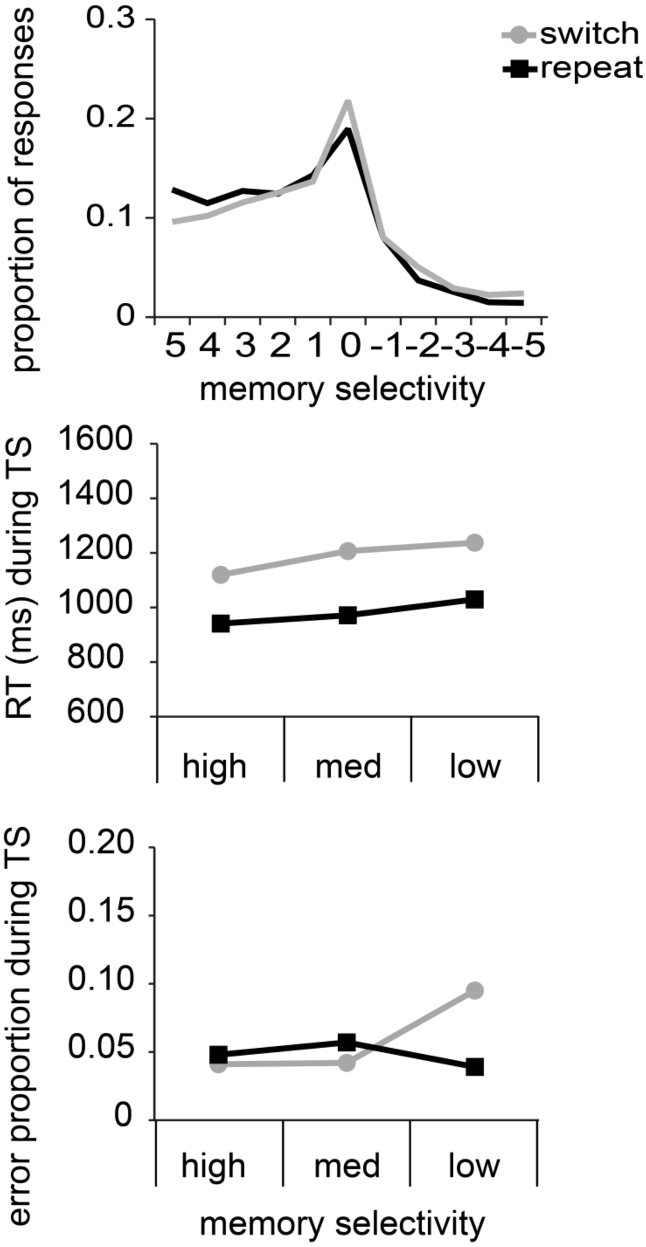


Figure 4.3: Distribution of memory selectivity scores as well as RTs and error rates for high, medium (med), and low memory selectivity trials separately for switch and repeat trials in Experiment 6.

Moreover, a corresponding ANOVA on the error data revealed a trend for a main effect of memory selectivity, *F*(2, 30) = 2.76, *p* = .079, with a significant interaction between switch and memory selectivity, *F*(2, 30) = 3.79, *p* < .05. Separate ANOVAs for switch and repeat trials revealed no significant effect of memory selectivity in repeat trials, *F* < 1, but a significant effect in the switch trial data, *F*(2, 30) = 5.66, *p* < .05, linear trend, *F*(1, 15) = 6.80, *p* < .05. These effects are shown in the lower panel of Figure 4.3.

It was argued that the use of the same classification rules and the same response keys for both material types in the current study should lead to an increase in conflict in repeat trials compared to previous studies. Such an effect should be reflected in a similar effect of memory selectivity in switch and repeat trials. The RT data of the current experiment showed a main effect of memory selectivity, but no interaction with switching, which may be consistent with the prediction that repeat trials might be affected to a larger degree in this experiment than in previous ones. However, the observed interaction between switch and memory selectivity in the error rate data suggests that effects of memory selectivity on repeat trials were still weaker than on switch trials.

Global Memory

In this chapter, a new measure of general memory performance is introduced. “Global memory” describes the overall encoding success across attended and unattended items. The global memory analysis was conducted in parallel to the memory selectivity analysis, with the only difference that memory ratings for the attended and unattended item of each bivalent task-switching trial were summed, rather than subtracted. The global memory scores thus ranged from 2 (if both items received a “sure new” rating) to 12 (if both items received a “sure old” rating). Task-switching trials were divided into three bins based on this score, separately for each participant and for switch and repeat trials. High global memory scores indicate overall high later memory for both the attended and unattended item; low scores indicate overall low memory. In a last step, the mean RT and error rate for each of these three bins in switch and repeat trials was calculated. The upper panel of Figure 4.4 displays the distribution of global memory scores.

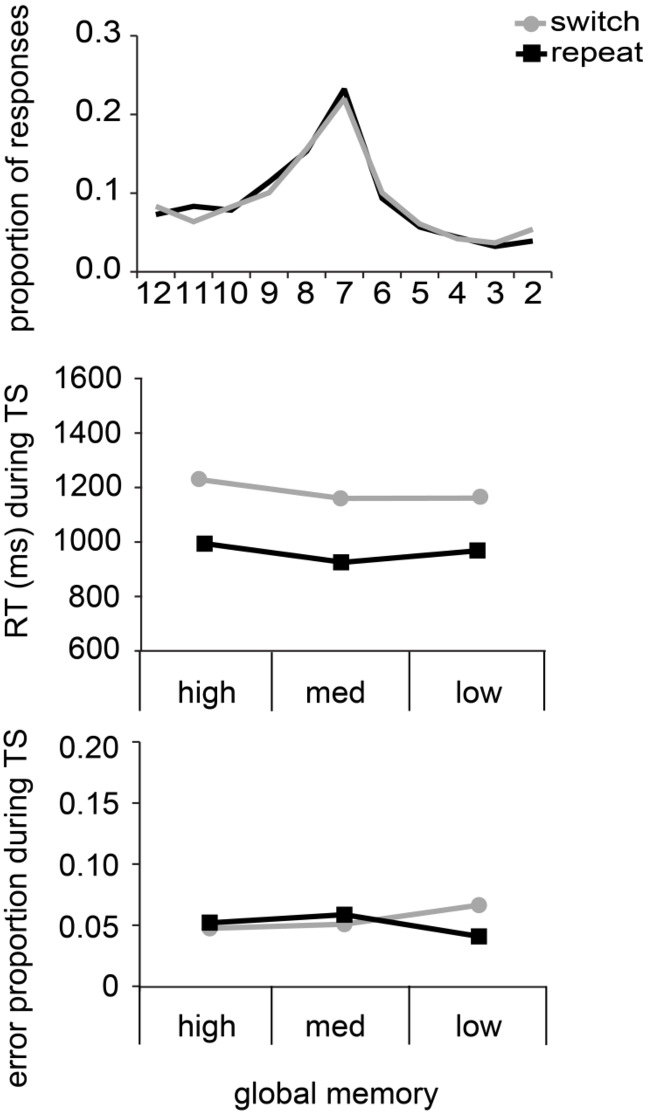


Figure 4.4: Distribution of global memory scores as well as RTs and error rates for high, medium (med), and low global memory trials separately for switch and repeat trials in Experiment 6.

Importantly, memory selectivity and global memory scores were not significantly correlated with each other across participants, $r = .014$, $p = .750$. Thus, even though their calculation was based on the same trials, there was no evidence that they were measuring related constructs. Therefore, the following predictions were made for the measure of global memory. In contrast to memory selectivity, global memory is not a measure of selective processing and thus should not be associated with differences in previous task-switching performance. This prediction was implicitly tested in previous experiments: These studies did not find changes in overall memory with switching, or with manipulations of top-down control. Based on these previous findings, it was expected that global memory would not be associated with differences in performance during the task-switching phase.

As expected, task-switching RT did not vary systematically with later global memory, $F(2, 30) = 2.60$, $p = .091$. The marginal effect of global memory indicated a decrease in RTs with decreasing global memory, opposite to the effect usually found for memory selectivity. Participants were at least as fast on trials in which they later remembered the attended and unattended item of a trial poorly, as on trials in which they had good memory for the two items (mean RTs of 1105 ms for high, 1038 ms for medium, and 1060 ms for low global memory trials). Only the main effect of switch (i.e., the standard switch cost) was significant, $F(1, 15) = 38.91$, $p < .01$. The interaction between global memory and switch did not reach significance $F < 1$. In the error rates, no significant effects were found, with error rates differing little as a function of global memory scores (mean error rates of 4.7%, 5.2%, and 5.1% for high, medium and low global memory trials, respectively). Thus, memory selectivity and global memory seemed to track different processes behaviourally, with memory selectivity showing a strong association with task-switching performance, whereas there was no reliable evidence for the same relationship with global memory.

Effect of Mode on Memory

Previous experiments have not suggested an effect of mode (univalent versus bivalent) on later memory. For completeness, effects of mode were assessed here. An ANOVA with variables switch and mode was conducted on only attended items as univalent trials did not include unattended items. This analysis yielded no significant main effect of mode on the memory data, $F(1, 15) = 1.19$, $p = .293$ (mean memory ratings of 4.54 for univalent and 4.48 for bivalent trials), and there was also no significant interaction between switch and mode in the memory data, *F* < 1. Thus, consistent with previous experiments, the current experiment did not show a significant effect of mode on the memory data, indicating that performance impairments associated with the presence of a distracting stimulus that were found during task switching were not reliably mirrored in later memory.

4.1.3 Discussion

The goal of this experiment was to demonstrate that the effects found in previous chapters can similarly be demonstrated when only attention between the stimuli is switched, but the same classification rule is performed across all trials. This finding would support the interpretation that the effects observed are due to a shift of attention.

Crucially, as in previous chapters, a significant interaction between attention and switching was replicated, with reduced selectivity in the memory ratings in switch compared to repeat trials. Thus, switching attention limited the selectivity of processing as suggested in previous experiments in this thesis. This finding aligns with work demonstrating that selective visual attention affects learning. For example, it has been shown that repeatedly attending to the same scene-pictures was associated with repetition attenuation – a measure of learning and memory (Yi & Chun, 2005). Apart from this neural measure, memory effects were also evident in behaviour, as participants also remembered these scenes better. The same effects were not found for unattended repeated stimuli, indicating that selective visual attention was associated with learning and memory. This finding, and the data of the current experiment, align well with the argument that the employment of selective attention calls upon processes that also affect memory encoding (e.g., Chun & Johnson, 2011). Moreover, the current results are also consistent with recent neuroimaging findings that suggest that selective attention is an important component of memory encoding (Uncapher & Rugg, 2009).

The behavioural data of the current experiment also revealed a significant relationship between memory selectivity and both task-switching RTs and error rates. The interaction between switch and memory selectivity did not reach significance in the RT data, a finding that might have suggested that repeat trials are less successfully shielded from interfering processes when the same response keys and rules are used (cf. Dreisbach & Haider, 2008). However, a significant interaction between switching and memory selectivity in the error rates suggested that repeat trials were still less affected by memory selectivity than switch trials.

Moreover, I was able to demonstrate that an alternative measure of memory success, global memory, did not systematically predict earlier task-switching performance, consistent with the idea that task-switching performance is related to selectivity of processing. Moreover, memory selectivity and global memory were not significantly correlated with each other, suggesting that they may be measuring independent constructs.

The effect of global memory was indirectly evaluated in previous experiments in this thesis, for example when the effect of switching on later memory was assessed: Previous experiments in this thesis failed to find a significant effect of switching or manipulations of top-down control on overall memory performance. Instead, only interactions between these variables and attention were detected. Thus, the finding that global memory is not related to previous task performance is consistent with the work described in earlier chapters.

Taken together, the results of this experiment replicated the key findings of previous experiments. This implies that cognitive control, operationalized as selective visual attention, affects selectivity of encoding. Moreover, the described experiment provides a stable design to be used in an EEG investigation of attention switching.

4.2 Experiment 7: EEG Correlates of Attention Switching and Memory Encoding

Experiment 7 used EEG to investigate the neural correlates of task preparation and subsequent memory effects. As a secondary goal, the current experiment also served to replicate the behavioural results reported in the previous experiment.

Subsequent memory effects (Sanquist, et al., 1980) reflect differences in the neural signal for items that are later remembered versus forgotten. In EEG studies, stimulus-locked subsequent memory effects often manifest as a positive slow wave over fronto-central and centro-parietal electrodes (Friedman & Johnson, 2000; Friedman & Trott, 2000; Paller, et al., 1987; Paller, et al., 1988; Sommer, et al., 1991).

Interestingly, recent studies have also identified cue-locked subsequent memory effects (Galli, et al., 2012; Otten, et al., 2006; Otten, et al., 2010; Padovani, et al., 2011). Some studies have found that prestimulus EEG correlates of encoding success manifest themselves in a negative frontal maximum (Otten, et al., 2006), and that these effects may be similar for different stimulus types such as visual and auditory words (Otten, et al., 2010). However, other studies have shown that prestimulus effects may display different topographies, depending on the encoding task (e.g., low versus high reward condition, Gruber & Otten, 2010; or emotional versus semantic task, Padovani, et al., 2011) or stimulus types used (e.g., visual versus auditory words, Galli, et al., 2012). Thus, although prestimulus subsequent memory effects have consistently been found in the recent literature, they seem to display less consistent topographic effects than stimulus-locked subsequent memory effects (although task-specific effects can also be observed in stimulus-locked data, see e.g., Otten & Rugg, 2001a).

Though subsequent memory effects are consistently reported in EEG studies of memory encoding, an unanswered question is what these subsequent memory effects reflect. For instance, one possibility is that frontal stimulus-locked subsequent memory effects, which are often associated with more controlled or elaborate encoding (Fernandez, et al., 1998), could reflect an overall increase in alertness that is beneficial for later memory (cf. Chun & Turk-Browne, 2007). Another possibility is that they reflect enhanced cognitive control, such as active preparation to encode (Gruber & Otten, 2010), or, as I propose here, selective processing. Previous studies were unable to answer this question as they mostly presented only one item at a time. These studies were therefore unable to investigate differences between selective and general encoding success.

Importantly, the current design can assess whether subsequent memory effects are specifically associated with the selective encoding of attended items relative to unattended items, or overall memory for attended and unattended items. The results of the previous experiment demonstrated dissociations between memory selectivity and global memory on a behavioural level. The current analysis also explores the EEG correlates of these differences by assessing the time-courses and topographies of the effects. By analysing the neural correlates of memory selectivity and global memory, this experiment aims to determine whether frontal subsequent memory effects are the result of more selective encoding, or whether they reflect less specific processes such as fluctuations in attention (Chun & Turk-Browne, 2007). Thus, one central goal of this EEG experiment is to contrast the effects of memory selectivity with those of global memory success.

A further interest in this experiment is to compare the neural correlates of encoding with the neural correlates of switching: The previous studies have indicated that switching reduces the selectivity of encoding. Therefore, an interesting question pertains to whether effects of switching and effects of low memory selectivity result in similar neural effects. Thus, this experiment assesses the well-known correlates of control processes in task switching (e.g., switch-related posterior positivity in the preparation phase, and stimulus-locked posterior negativity and frontal positivity effects, Karayanidis, et al., 2003; Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Kieffaber & Hetrick, 2005; Poljac & Yeung, 2012b), to compare them with control processes associated with memory selectivity.

The behavioural findings of the previous experiment suggested that memory selectivity is related to performance differences in the task-switching phase, but global memory is not. As memory selectivity is a measure of selective encoding, it was predicted that differences in later memory selectivity should be associated with differences in material-specific preparation and stimulus processing, in line with the idea that material-specific control and preparation processes occur when different material types are employed (Kieffaber & Hetrick, 2005; Yeung, et al., 2006). Furthermore, these differences should be modulated by whether the trial had to be switched or not. Global memory, which assesses overall encoding success, would similarly be expected to display subsequent memory effects. Such effects could reflect increased states of alertness, which are beneficial for later memory (Chun & Turk-Browne, 2007). As it does not relate to selective encoding, however, global memory was not predicted to show any such material-specific effects, or modulation by switching.

4.2.1 Methods

Participants. Participants in this experiment were eight male and eight female right-handed participants with a mean age of 21.9 years (*SD* = 4.1). They were all native English speakers and gave informed consent. They received payment or course credit for their participation.

Methods. The only changes to the previous behavioural experiment were that the CSI was extended to 1200 ms to be able to measure slow-wave preparation effects that develop between cue presentation and stimulus onset, and that the mapping of the cue-colours to the object and the word task was balanced between participants to control for differences elicited by cue-colour. EEG was recorded from the beginning of the task-switching phase of the experiment, and was continued until the end of the memory test.

EEG recording and analysis. Participants sat in a comfortable chair in an electrically shielded room. EEG data were collected with SynAmps2 amplifiers (Neuroscan, El Paso, TX), from 32 electrodes, using Ag/AgCl electrodes embedded in an elastic fabric cap at locations FP1, FPZ, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, POZ, O1, OZ, and O2. Two electrodes were attached on the outer canthi of both eyes, and another two electrodes were attached above and below the left eye to record blinks and eye movement activity. Electrodes were furthermore attached to the left and right mastoids, with the right mastoid serving as the reference electrode. The impedances of all electrodes were kept below 50 kΩ. A sampling rate of 1000 Hz, and an online filter of 0.1 Hz were used for the recording of the EEG data. Before analysis, the EEG data were downsampled to 100 Hz. Ocular artefact correction was conducted in Neuroscan using a regression approach (Semlitsch, Anderer, Schuster, & Presslich, 1986). The analysis of the EEG data focussed on the task-switching phase as it was intended to explore the neural correlates of successful task-performance and encoding. Accordingly, the continuous data were segmented from −500 ms to 2300 ms relative to experimental events of interest (cue or stimulus), time-locked to the presentation of the cue (cue-locked data) or the stimulus (stimulus-locked data). Cue- and stimulus-locked epochs were baseline corrected by subtracting the average activity of each channel during the -100 to 0 ms period prior to cue or stimulus onset, respectively. Artefact rejection was performed in Matlab (The Mathworks, Natick, MA). Trials were rejected if at least one electrode showed a difference of more than 150 µV from the beginning to the end of the predefined time window (0-1200 ms for cue-locked, 0-2300 ms for stimulus-locked data). A low-pass filter of 20 Hz was used for analysis using the “eegfilt” method implemented in the EEGLab toolbox. All further EEG processing was completed in MATLAB using the EEGLab toolbox and custom written routines.

Two participants were excluded from the EEG analysis because insufficient trial numbers were preserved for analysis after the artefact rejection, leaving 14 participants for the EEG analysis. In the cue-locked phase, the lowest number of trials included for a participant was 187 out of 300 trials (all other participants had more than 200 trials); in the stimulus-locked phase, due to the longer interval, the lowest number of trials included for a participant was 141 out of 300 trials (one other participant had 171 trials; all other participants had more than 200 trials).

Preliminary inspection of the data indicated that there were no consistent laterality effects. Therefore, for the sake of simplicity, analyses collapsed over lateral scalp locations, and focused instead on anterior-posterior differences in topography. Thus, electrodes were divided into two equal-sized clusters over frontal and posterior electrode sites. The frontal cluster contained electrodes F3, FZ, F4, FC3, FCZ, and FC4; the posterior cluster contained electrodes CP3, CPZ, CP4, P3, PZ, and P4. The EEG data were furthermore divided into 300 ms time windows, as it was predicted that switch- and memory-related preparation- and stimulus-related effects would develop over time. Another reason for this division into time windows was to test for differences in the time-course of memory selectivity and global memory effects. Such differences would provide a key indicator for determining the extent to which memory selectivity and global memory showed similarity with typically observed subsequent memory effects.

Analysis of the EEG data was limited to the task-switching phase as the key question in this study was to investigate neural correlates of successful task-performance and encoding. Moreover, EEG analysis focussed on bivalent trials, as these were the only trials for which the memory selectivity and global memory measures could be calculated. Univalent trials did not reveal consistent effects in a first exploratory analysis and were therefore not included in the analyses here. Where the assumption of sphericity was violated in reported ANOVAs, *p*-values based on adjusted degrees of freedom according to Greenhouse-Geisser will be reported with original *F*-values and original degrees of freedom, alongside the Greenhouse-Geisser Epsilon value.

4.2.2 Behavioural Results

Task Switching

The task-switching analyses assessed basic effects of switching on univalent and bivalent trials. In an ANOVA including variables mode and switch, the main effect of switch, $F(1, 15) = 29.92$, $p < .01$, (repeat = 958 ms vs. switch = 1171 ms), as well as the main effect of mode, $F(1, 15) = 7.39$, $p < .05$, (univalent = 1045 ms vs. bivalent = 1083 ms) were replicated. There was no reliable interaction between mode and switch in the RT data, $F < 1$, and no significant effects at all were found in the error rates, all *Fs* < 1 (mean error rates bivalent 4.2% vs. univalent 3.5%, and switch 4.0% vs. repeat 3.7%).

Memory

Effects of Switching and Attention on Memory

A first analysis assessed whether switching attention was reflected in less selective memory for attended and unattended items. The ANOVA on the memory data with variable switch and attention again replicated the main effect of attention, $F(1, 15) = 173.30$, $p < .01$, with better memory for attended than unattended items (mean memory ratings 4.48 vs. 3.14). There was again no significant main effect of switch, $F < 1$ (mean memory ratings repeat: 3.81 vs. switch 3.81). Moreover, the interaction between switch and attention reached significance, $F(1, 15) = 5.00$, $p < .05$, again indicating a reduction in memory selectivity in association with attention switching (see Figure 4.5). Descriptively, there was a decrease in memory for attended items between repeat and switch trials, but this effect failed to reach significance, $t(15) = -1.70$, $p = .110$. Similarly, the increase in memory for unattended items was only marginally significant, $t(15) = 1.96$, $p = .069$.

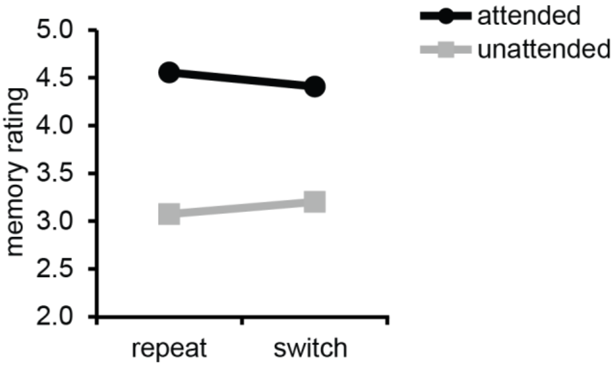


Figure 4.5: Memory ratings for attended and unattended items presented during repeat and switch trials in Experiment 7.

Memory Selectivity

The second ANOVA on the memory ratings assessed the relationship between memory selectivity and prior task-switching performance (see Figure 4.6). For this analysis bivalent task-switching trials were again divided into tercile bins according to later rating differences between the attended and unattended items. The analysis of the memory selectivity data resulted in the already described main effect of switch, *F*(1, 15) = 30.60, $p < .01$. In contrast to Experiment 6, the main effect of memory selectivity was only marginally significant in the current study, *F*(2, 30) = 2.93, $\varepsilon = .703$, $p = .083$, and the interaction between switch and memory selectivity reached significance in the RTs, *F*(1, 15) = 5.11, $p < .05$. Accordingly, the current ANOVA did not display a main effect of memory selectivity only, as was the case in Experiment 6, but replicated the interaction between switch and memory selectivity that was consistently described in previous experiments in this thesis.

Separate one-way ANOVAs were conducted for switch and repeat trials to follow-up on these effects. The ANOVA on the repeat-trial data revealed no significant effect of memory selectivity in these trials, *F*(2, 30) = 1.47, $p = .247$. The ANOVA on the switch-trial data, however, indicated an effect of memory selectivity on the RTs, *F*(2, 30) = 4.84, $p < .05$, with a significant linear trend, *F*(1, 15) = 6.03, $p < .05$.

There was no significant effect in the analysis of memory selectivity in the error rates (no main effect switch, $F < 1$, no main effect memory selectivity, $F < 1$, nor a reliable interaction between switch and memory selectivity, *F*(2, 30) = 1.22, $p = .309$). The error rates descriptively showed a similar pattern to previous studies: There was little variation in the error rates of repeat trials with decreasing memory selectivity (high, 4.0% vs. medium 4.0% vs. low 3.8%), but there seemed to be a slight increase in the error rates in switch trials with decreasing memory selectivity (high, 2.9% vs. medium 4.5% vs. low 5.7%). Overall, error rates were much lower than in other experiments (possibly due to the simplified design and the longer preparation interval), which might have contributed to the lack of significance of these effects.

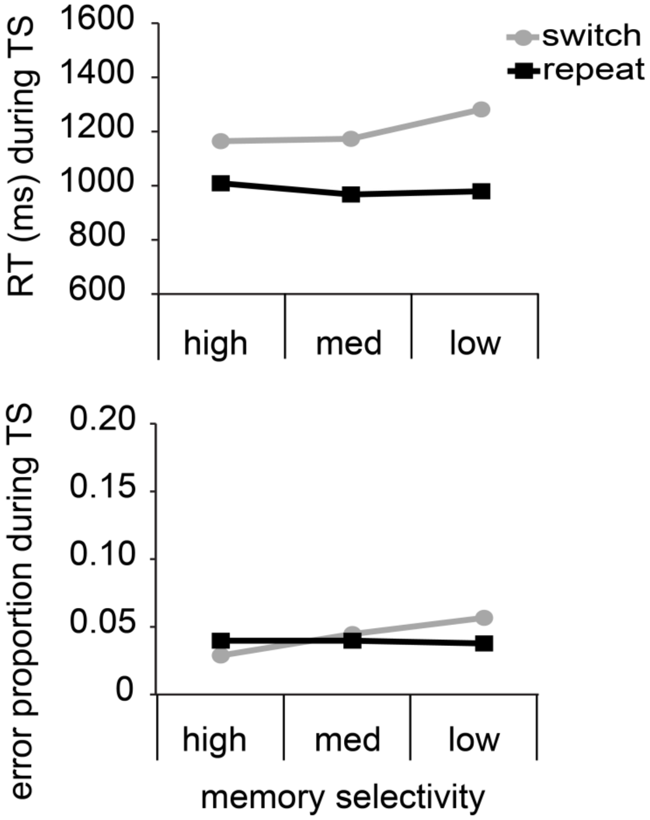


Figure 4.6: RTs and error rates for high, medium (med), and low memory selectivity trials separately for switch and repeat trials in Experiment 7.

Global Memory

The analysis of the global memory data again revealed only a main effect of switch in the RT data, $F(1, 15) = 32.43$, $p < .01$ (i.e., the switch cost), but not in the error rates, $F < 1$. There was no significant main effect of global memory in the RTs, $F < 1$, (mean RTs of 1079 ms for high, 1087 ms for medium, and 1103 ms for low global memory trials), and error rates, $F(2, 30) = 1.16$, $p = .329$ (mean error rates of 3.6% for high, 3.7% for medium, and 5.0% for low global memory trials), and no interaction between global memory and switching in the RTs, $F(2, 30) = 1.10$, $p = .345$, or error rates, $F < 1$. The numerical decrease in RTs with decreasing global memory that was observed in the marginal main effect of global memory in Experiment 6 was not observed here. The data of these analyses are plotted in Figure 4.7.

Lastly, the relationship between memory selectivity and global memory scores was again assessed across participants. As in the previous Experiment 6, no significant correlation was found across participants, mean *r* = .039, *p* = .165. Thus, memory selectivity and global memory not only showed differential effects with regards to behaviour, there was also again no evidence that they were measuring related constructs.

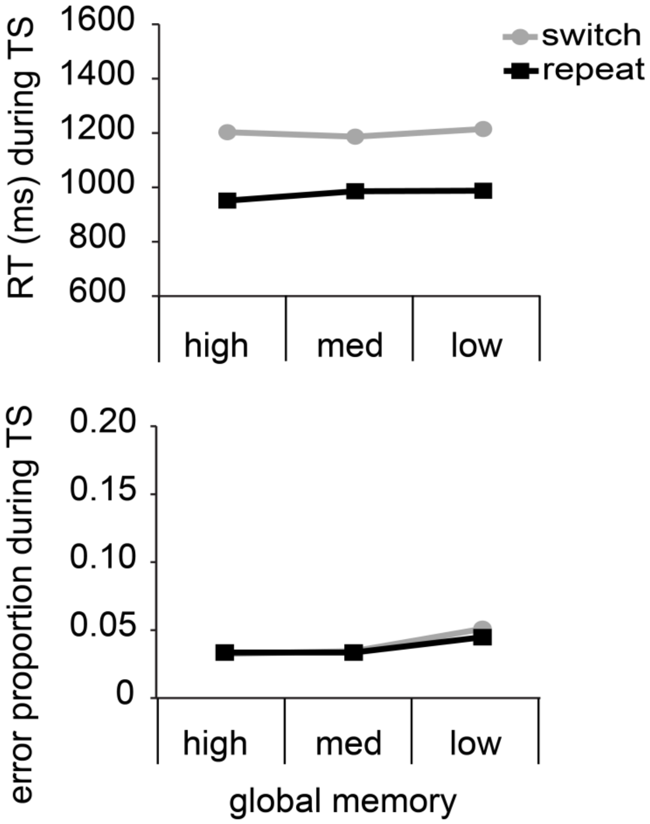


Figure 4.7: RTs and error rates for high, medium (med), and low global memory trials separately for switch and repeat trials in Experiment 7.

4.2.3 EEG Results

Analysis of the EEG data focused on cue-locked and stimulus-locked activity from the task-switching phase. Known correlates of task-switching were analysed as well as correlates of later memory success. Memory success was operationalized in the two measures of memory selectivity and global memory.

Cue-Locked Data

The following paragraphs will first review basic effects of switching, and will for this reason not include the memory measures as variables. The effects of memory selectivity and global memory will be explored in subsequent sections.

Switch-Related Effects

The first goal of this analysis was to investigate basic effects of switching, electrode location, and material over the time-course of the preparation phase. Specifically, it was expected to find a positive modulation of ERPs in switch compared to repeat trials over posterior electrode sites (switch-related positivity, e.g., Karayanidis, et al., 2003; Karayanidis, et al., 2011; Poljac & Yeung, 2012b). Moreover, it was assessed whether preparation to conduct the task on objects versus words would be reflected in characteristic topographies that could guide later analysis. Cue-locked ERP waveforms for the frontal and posterior electrode clusters are shown in Figure 4.8.

To analyse these effects, the data were entered in an ANOVA with variables switch (switch/repeat), time (0-300, 300-600, 600-900, and 900-1200 ms after cue onset), location (frontal/posterior), and material (object/word). The ANOVA revealed a significant main effect of switch, $F(1, 13) = 5.55$, $p < .05$, indicating overall more positive ERPs for switch versus repeat trials. Switching did not interact with material (i.e., there were no significant material-specific switch effects), and no other significant effects of material were seen. The topography for the difference between object and word trials is displayed in Figure 4.8. Note that in all ERP plots positivity is plotted downwards. Descriptively, objects versus words were associated with a positivity over left electrode sites, which was, however, not reliable and showed no sustained effects. As subsequent memory effects are typically associated with slow wave effects, subsequent analysis were not based on the topography of material. (Exploratory analysis of the univalent trials showed similar results, and as the key analyses focus on memory selectivity and global memory, which are based on bivalent trials, no further analysis of univalent trials will be reported).

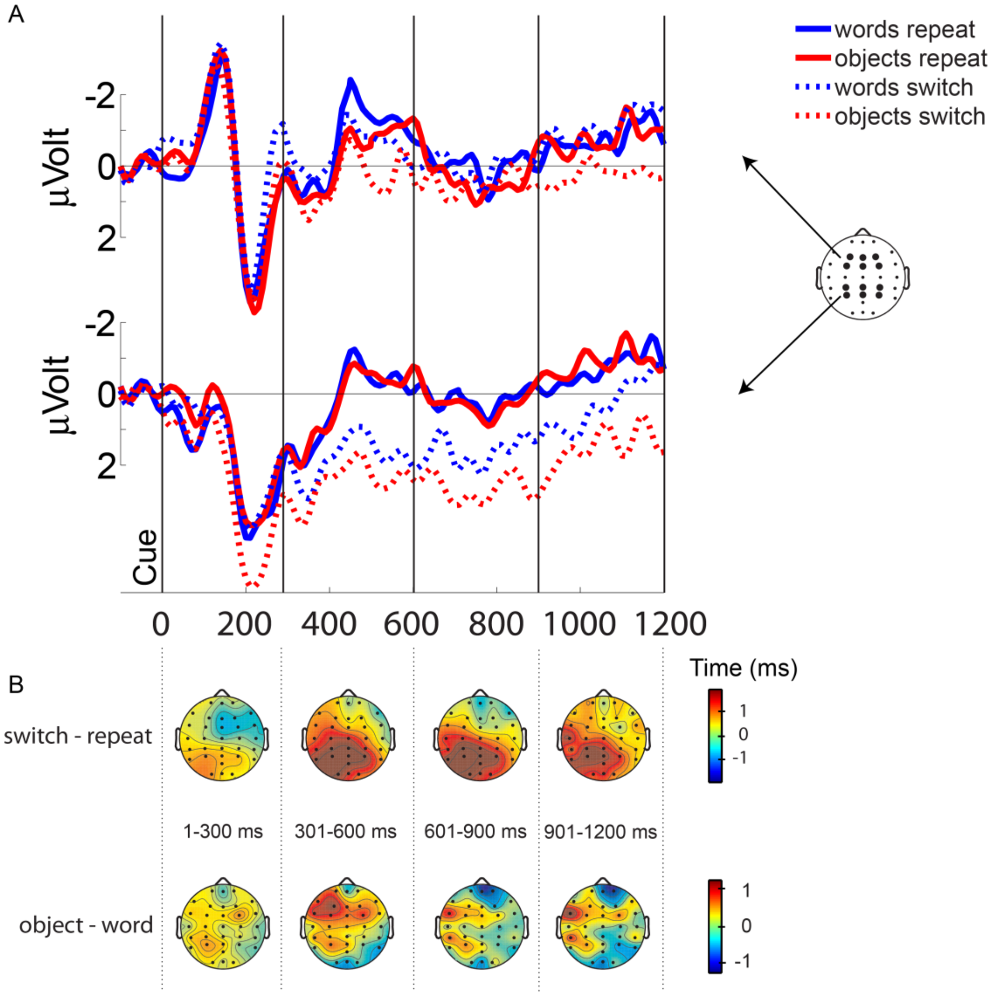


Figure 4.8: Grand average ERPs for switch (dotted line) and repeat (solid line) trials of the object (red) and the word (blue) task in Experiment 7. (A) Frontal ERP wave forms as measured at the electrodes F3, FZ, F4, FC3, FCZ, and FC4 (upper) and posterior ERP wave form as measured at electrodes CP3, CPZ, CP4, P3, PZ, and P4 (lower), both time-locked to the onset of the cue. (B) The scalp topography of the average signal differences between switch and repeat trials (upper) and object and word trials (lower) in steps of 300 ms starting with cue-onset.

There was a marginally significant interaction between switch and time, *F*(3, 39) = 3.21, ε = .447, *p* = .081, and the interaction between switch and location reached significance, *F*(1, 13) = 14.08, *p* < .01. These interactions were further qualified by a three-way interaction between location, switch, and time, *F*(3, 39) = 2.95, *p* < .05. Switch compared to repeat trials were more positive over posterior sites, and this effect peaked in the 300-600 ms and 600-900 ms time windows (switch-related posterior positivity, see e.g., Karayanidis, et al., 2003). Follow-up ANOVAs revealed no significant effects over frontal sites, whereas for posterior sites a significant interaction between switch and time was observed, $F(3, 39) = 4.96$, $\varepsilon = .499$, $p < .05$. Follow-up *t*-tests indicated that switch and repeat trials differed at posterior electrodes in the 300-600 ms time window, $t(13) = -6.16$, $p < .01$, the 600-900 ms time window, $t(13) = -3.82$, $p < .01$, and the 900-1200 ms time window, $t(13) = 3.18$, $p < .01$, but not significantly in the 0-300 ms time window, $t(13) = -1.09$, $p = .296$. Descriptively, the difference between switch and repeat decreased in the last time window, similar to effects described in previous research (Karayanidis, et al., 2003).

Analysis of Memory Selectivity and Global Memory Effects

Subsequent analyses focused on the effects of memory selectivity and global memory. These factors were analysed separately as it is problematic to compare them directly since they are based on the same data (memory ratings for attended and unattended items), just being computed in different ways (subtraction of unattended from attended scores for memory selectivity vs. addition of scores for global memory).

Memory Selectivity

In this analysis, it was investigated whether prestimulus subsequent memory effects can be detected using the measure of memory selectivity (difference in memory ratings between the attended and unattended items), as this would indicate that such anticipatory effects reflect preparation for selective processing. Moreover, it was assessed whether prestimulus memory effects additionally differ according to the material type relevant in a given trial, which would suggest that this preparation may at least in part be material-specific.

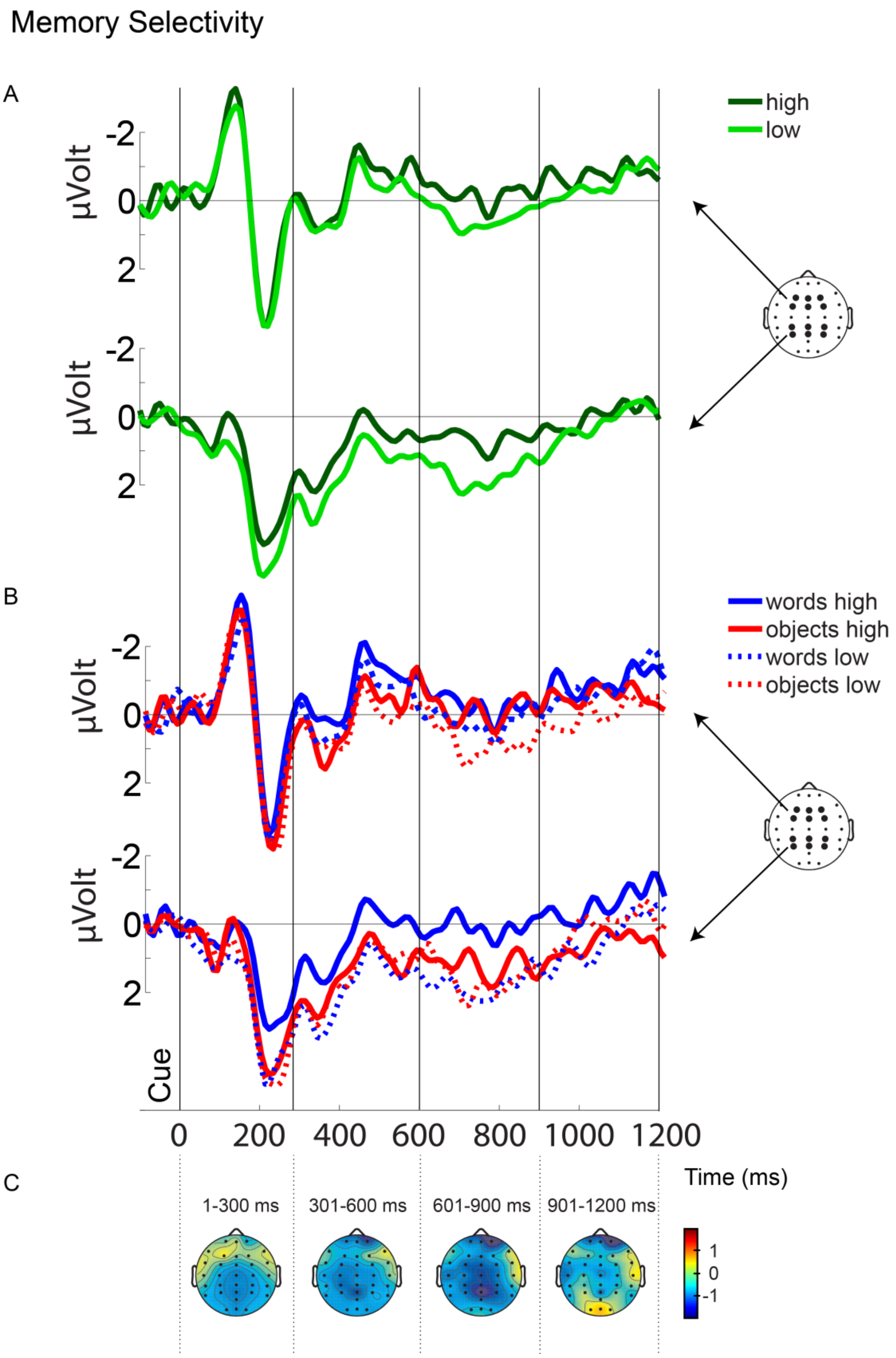


Figure 4.9: (A) ERP waveforms for high and low memory selectivity trials as measured at the frontal electrodes F3, FZ, F4, FC3, FCZ, and FC4 (upper) and posterior electrodes CP3, CPZ, CP4, P3, PZ, and P4 (lower), both time-locked to the onset of the cue in Experiment 7. (B) ERP waveforms for high (solid line) and low (dotted line) memory selectivity trials in the object and word condition at frontal (upper) and posterior (lower) electrodes. (C) The scalp topography of the average signal differences between high and low memory selectivity trials in steps of 300 ms starting with cue-onset.

To investigate the effects of memory selectivity and its interactions with other variables, the EEG data were entered in an ANOVA with variables switch (switch/repeat), time (0-300, 300-600, 600-900, 900-1200 ms after cue onset), location (frontal/posterior), material (object/word), and memory selectivity (high/low). Memory selectivity scores (and in the relevant later analyses, global memory scores) were split into two bins only (rather than tercile bins in earlier analyses of behavioural data) because fewer trials were available in this EEG analysis after artefact rejection. Cue-locked ERP waveforms for the frontal and posterior electrode clusters, as well as scalp topographies, are shown in Figure 4.9.

In contrast to effects described in the ANOVA assessing the switch effects, the main effects of switch was only marginal here (trend for more positive switch than repeat trials), and the main effect of location (trend for more positive posterior than frontal trials) was marginally significant, $F(1, 13) = 4.00$, $p = .067$, and $F(1, 13) = 3.77$, $p = .074$, respectively.

There was no significant main effect of memory selectivity, $F(1, 13) = 2.16$, $p = .166$, and no significant interactions, for example, between memory selectivity and switch, $F(1, 13) = 1.60$, $p = .228$, memory selectivity and time, $F(1, 13) = 1.03$, $p = .390$ or memory selectivity and location, $F < 1$. Interestingly, however, the 4-way interaction between time, location, material and memory selectivity was marginally significant, $F(3, 39) = 3.15$, $\varepsilon = .479$, $p < .08$. Descriptively, this effect indicated that high and low memory selectivity word trials differed at posterior electrode sites, especially between 600 ms and 1200 ms. However, there appeared to be no corresponding difference between high and low memory selectivity object trials. Thus, the hypothesized modulation of material-specific differences as a function of later memory selectivity was only evident at a descriptive level, and only for word trials. As it was predicted that memory selectivity should show preparation-related effects, and that these effects might differ according to the material type, I further explored this marginal effect.

Follow-up ANOVAs indicated that there was a significant interaction between location, material, and memory selectivity in the 600-900 ms, $F(1, 13) = 5.87$, $p < .05$, as well as in the 900-1200 ms time window, $F(1, 13) = 5.22$, $p < .05$. Further analyses indicated that the interaction between location, material, and memory selectivity in these time windows reflected an interaction between location and memory selectivity for words only, in both the 600-900 ms, $F(1, 13) = 7.02$, $p < .05$, and 900-1200 ms time windows, $F(1, 13) = 5.35$, $p < .05$. Pairwise t-tests indicated that there was a significant difference between high and low memory selectivity for word trials at posterior electrodes in the 600-900 ms time window. The trend for a similar effect in the 900-1200 ms time window did not reach significance $p = .183$. Thus, descriptively, there was only a trend for high and low memory selectivity word trials to differ at posterior electrode sites in the 600 to 900 ms window.

Global Memory

The effects of global memory, and its interactions with other variables, was also assessed for the cue-locked data: An ANOVA on the global memory data (including variables switch, time, location, material, and global memory), revealed no significant main effect of global memory, $F(1, 13) = 1.44$, $p = .251$, and no significant interactions between global memory and other variables (all Fs < 1.96 ps $> .136$), with the exception of a marginal interaction between time, location, material, and global memory, $F(1, 13) = 2.74$, $p = .056$, and a marginal five-way interaction between all variables, $F(1, 13) = 2.34$, $p = .088$.

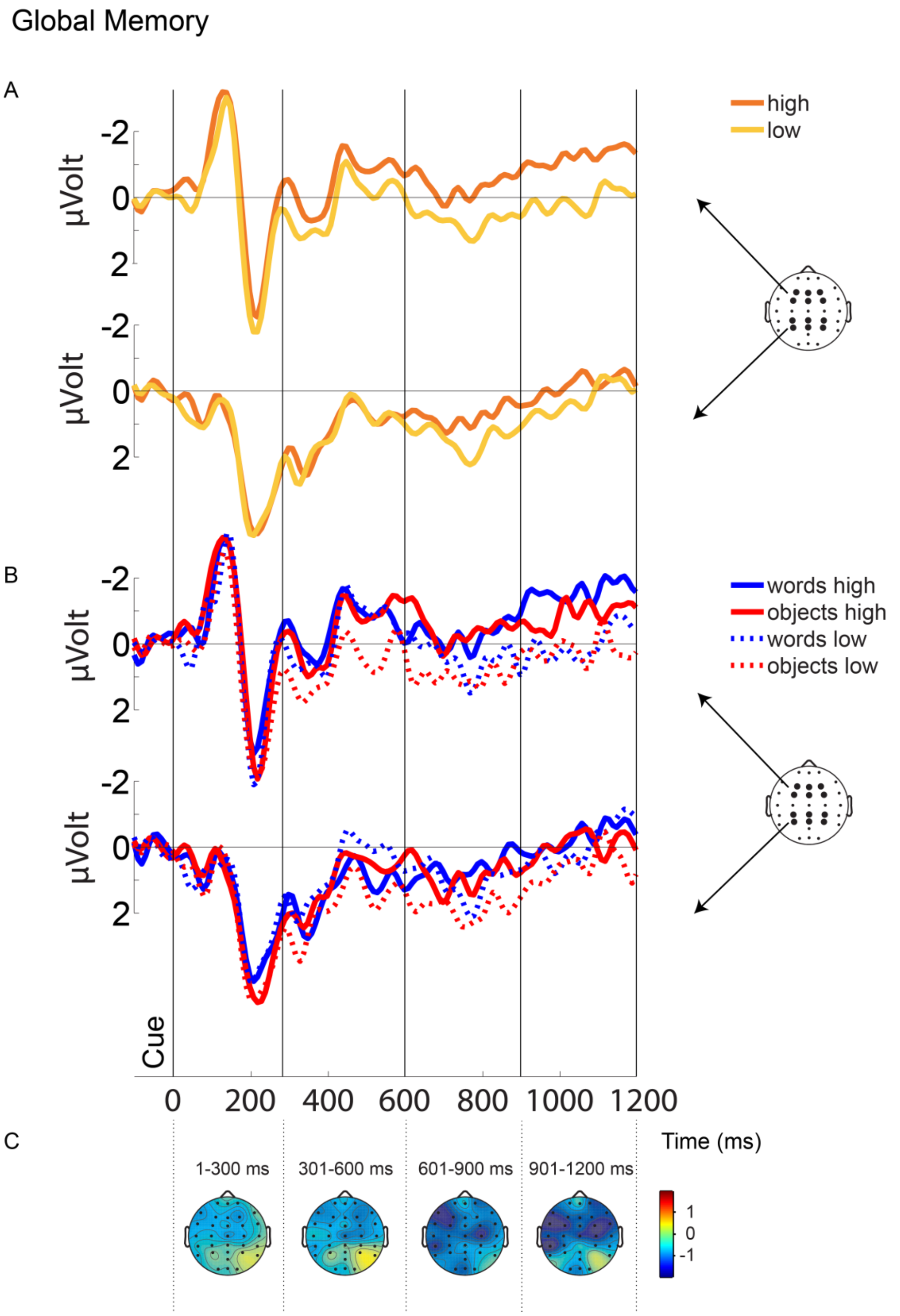


Figure 4.10: (A) ERP waveforms for high and low global memory trials as measured at the frontal electrodes F3, FZ, F4, FC3, FCZ, and FC4 (upper) and posterior electrodes CP3, CPZ, CP4, P3, PZ, and P4 (lower) both time-locked to the onset of the cue in Experiment 7. (B) ERP waveforms for high (solid line) and low (dotted line) global memory trials in the object and word condition at frontal (upper) and posterior (lower) electrodes. (C) The scalp topography of the average signal differences between high and low global memory trials in steps of 300 ms starting with cue-onset.

These effects did not seem to fit any obvious pattern: For example, the marginal four-way interaction seemed to be driven by the effect that high and low global memory word trials showed the largest difference at frontal sites in the 900-1200 ms time window. High versus low global memory object trials, in contrast, seemed to differ most at posterior sites in the earlier 600-900 ms window. Moreover, there were descriptively larger differences between low global memory object and word trials than high global memory object and word trials, specifically in the 600 to 900 ms windows. The marginal five-way interaction similarly did not show any clear trends. For the purpose of comparison with the memory selectivity data, the equivalent ERP plots and topographies are shown for global memory in Figure 4.10.

Together, the results of the preceding analyses suggest that the cue-locked EEG data display the well documented effects of switching. Overall, the subsequent memory effects assessed with the measure of memory selectivity and global memory were not very reliable in this phase.

Stimulus-Locked Data

The stimulus-locked data were analysed similarly to the cue-locked data, in that data were divided into 300 ms time windows (0-300, 300-600, 600-900 and 900-1200 ms after stimulus onset), separately for switch and repeat trials, location (frontal/posterior), and material (object/word). In the first section, I will describe the basic effects of switching. Then the effects of memory selectivity and global memory will be explored.

Switch-Related Effects

Similar to the analysis of the cue-locked data, an initial ANOVA investigated the basic effects of switching, material type, location, and time in the stimulus-locked data. ERP plots and topographies for this analysis are given in Figure 4.11. The ANOVA revealed main effects of location, $F(1, 13) = 6.95$, $p < .05$, with a more positive voltage at posterior sites, and of time, $F(3, 39) = 12.79$, $\varepsilon = .488$, $p < .01$. A significant linear trend indicated that the EEG signal increased in positivity over time, $F(1, 13) = 13.77$, $p < .01$. These main effects were qualified by several interactions.

The interaction between switch and location was significant, $F(1, 13) = 5.18$, $p < .05$, and indicated that scalp voltage was more positive over frontal electrodes on switch trials than repeat trials, whereas scalp voltage was more negative over posterior sites for the same contrast. Pairwise contrasts revealed that switch and repeat trials did not differ significantly at frontal, $t(13) = -1.14$, $p = .277$, or posterior, $t < 1$, sites. A significant difference was only observed for repeat trials between frontal and posterior electrodes, $t(13) = -3.01$, $p < .05$, and a marginal difference for switch trials between frontal and posterior electrodes, $t(13) = -2.03$, $p = .063$. These effects of switching might represent residual activity from the prestimulus phase (Elchlepp, Lavric, Mizon, & Monsell, 2012).

Moreover, the interaction between time and location reached significance, $F(3, 39) = 9.83$, $\varepsilon = .560$, $p < .01$, and the interaction between time and material was marginally significant, $F(3, 39) = 3.03$, $\varepsilon = .531$, $p = .08$. Both interactions were further qualified by a three-way interaction between time, location, and material, $F(3, 39) = 3.08$, $p < .05$. Follow-up analysis revealed a significant interaction between time and material at posterior electrodes, $F(3, 39) = 3.68$, $p < .05$, but not at frontal electrodes, $F(3, 39) = 2.32$, $\varepsilon = .541$, $p = .131$. Scalp voltage was more positive on object trials than word trials in the 300-600 ms time window at posterior electrodes, $t(13) = -2.63$, $p < .05$. Differences between objects and words were not significant in any of the other time windows (all other $t < 1.76$, $ps > .10$).

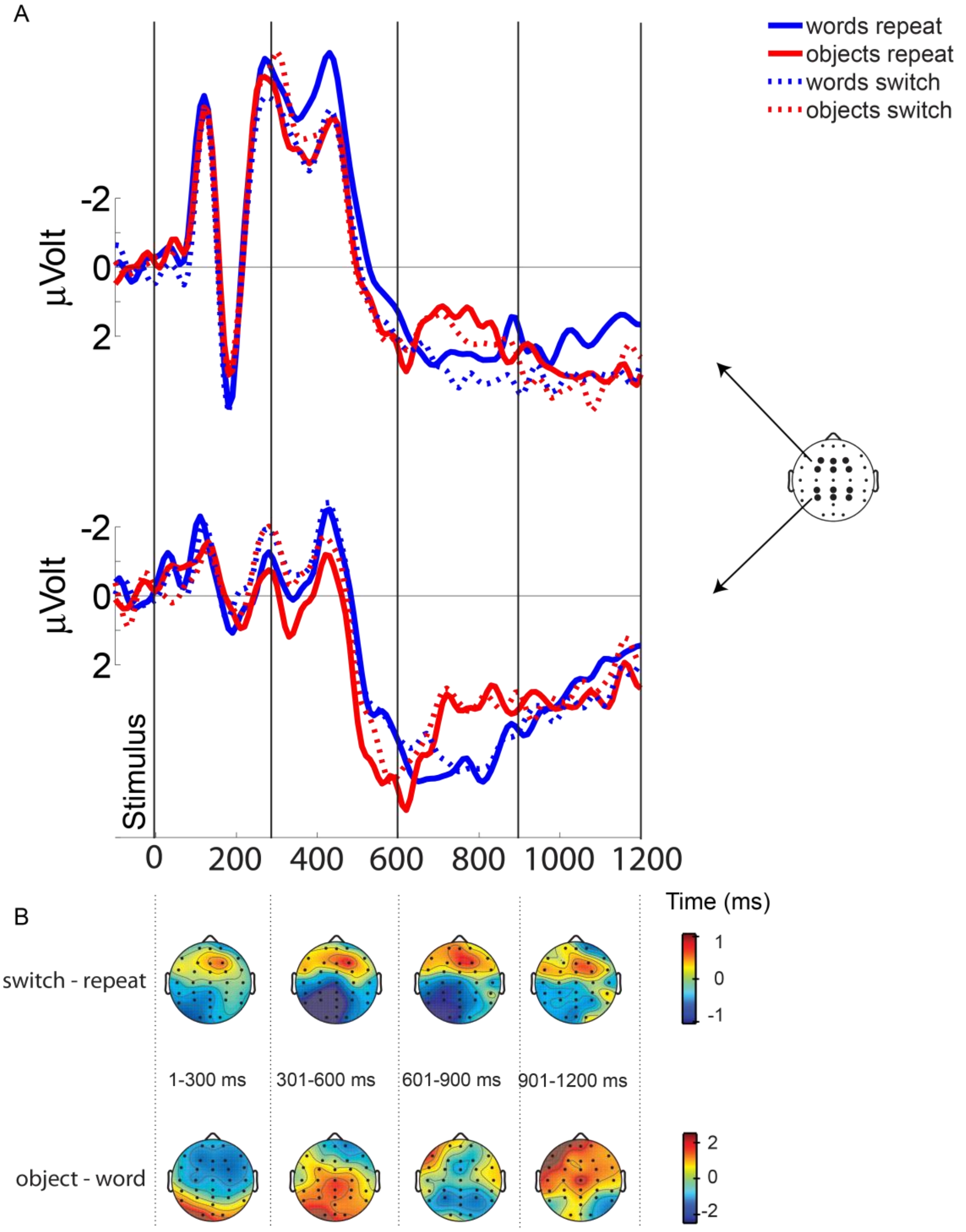


Figure 4.11: (A) Grand average ERPs for switch (dotted line) and repeat (solid line) trials of the object and the word task as measured at frontal electrodes F3, FZ, F4, FC3, FCZ, and FC4 (upper) and as measure at posterior ERP at electrodes CP3, CPZ, CP4, P3, PZ, and P4 (lower) both time-locked to the onset of the stimulus in Experiment 7. (B) The scalp topography of the average signal differences between switch and repeat trials (upper) and object and repeat trials (lower) in steps of 300 ms starting with stimulus-onset.

Memory Selectivity

A second ANOVA applied to the stimulus-locked data was conducted to investigate whether memory selectivity effects resembled the well-documented stimulus-locked subsequent memory effects, which are often observed as frontal or fronto-central positive slow waves (Fabiani, et al., 1990; Karis, et al., 1984). Moreover, it was assessed whether effects of memory selectivity would differ according to the material type relevant in a given trial, and according to whether the task switched or repeated, similar to the investigation of the cue-locked data. ERP plots and topographies for this analysis are given in Figure 4.12.

This ANOVA with variables switch, time, location, material, and memory selectivity, revealed no significant main effect of memory selectivity, $F < 1$. Critically, however, this analysis revealed a significant interaction between time and memory selectivity, $F(3, 39) = 4.26$, $\varepsilon = .651$, $p < .05$, indicating that high memory selectivity trials were more positive than low memory selectivity trials in the 900 to 1200 ms time window, $t(13) = -2.31$, $p < .05$, with a descriptively similar trend in the 600 to 900 ms window, $t(13) = 1.70$, $p = .113$, but no corresponding effect apparent in the 0-300 ms window, $t(13) = -1.62$, $p = .129$, or the 300 to 600 ms window, $t(13) = .478$, $p = .641$. Thus, the effects of memory selectivity resembled previously described frontal slow-wave subsequent memory effects (Fabiani, et al., 1990; Karis, et al., 1984).

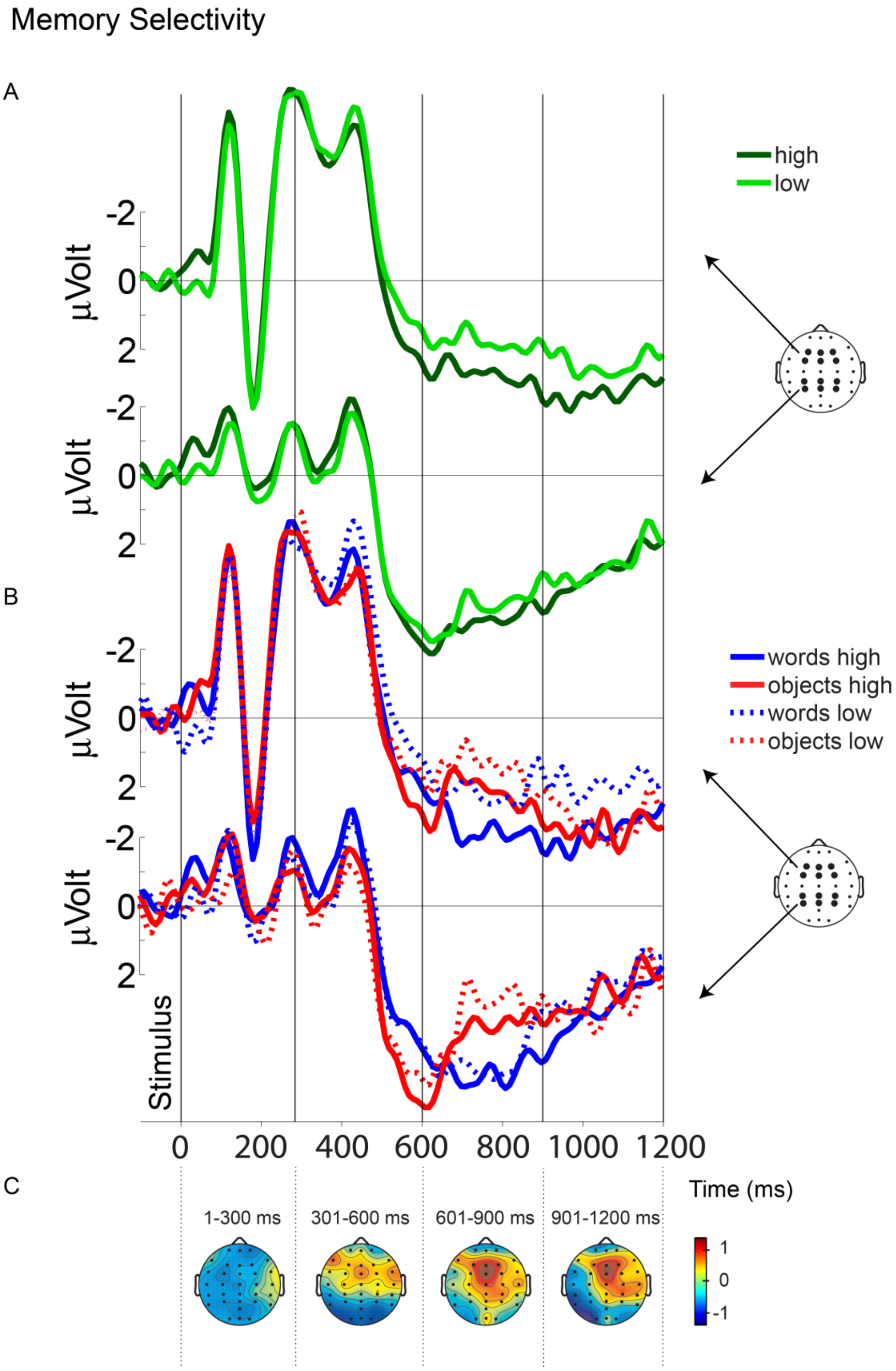


Figure 4.12: ERP waveforms for high and low memory selectivity trials as measured at the frontal electrodes F3, FZ, F4, FC3, FCZ, and FC4 (upper) and posterior electrodes CP3, CPZ, CP4, P3, PZ, and P4 (lower), both time-locked to the onset of the stimulus in Experiment 7. (B) ERP waveforms for high (solid line) and low (dotted line) memory selectivity trials in the object and word condition at frontal (upper) and posterior (lower) electrodes. (C) The scalp topography of the average signal differences between high and low memory selectivity trials in steps of 300 ms starting with stimulus-onset

Lastly, the interaction between switch, location, material, and memory selectivity was marginally significant, $F(1, 13) = 4.56$, $p = .052$. There was a trend for a difference between high and low memory selective word repeat trials at frontal electrodes (with high memory selectivity trials eliciting a more positive response than low memory selective trials), as well as posterior electrodes (here with the opposite pattern, with low selectivity word repeat trials more positive than high memory selectivity word repeat trials). Lastly, there was a trend for high memory selectivity object switch trials to be more positive than low memory selectivity object switch trials at frontal electrode sites with no corresponding effect posterior sites. All other differences were numerically small. Overall there seemed to be no clear pattern to these effects.

Global Memory

The corresponding ANOVA on the global memory data with variables switch, time, location, material, and global memory revealed no main effect of global memory, and no significant interactions between global memory and time, $F < 1$, global memory and switch, $F < 1$, or global memory and location, $F(1, 13) = 1.46$, $p = .248$. Only a significant interaction between location, material, and global memory was found, $F(1, 13) = 5.31$, $p < .05$. Follow-up ANOVAs revealed that there was a significant interaction between location and global memory only in word trials, $F(1, 13) = 5.89$, $p < .05$, but not in object trials, $F(1, 13) = 2.39$, $p = .146$. Follow-up *t*-tests revealed that there was no significant difference between frontal or posterior electrodes on high versus low global memory word trials, both $t < 1$. Instead, there was only a significant difference between frontal and posterior electrodes for word trials when global memory was low, $t(13) = -2.80$, $p < .05$, and a marginal difference between frontal and posterior electrode sites for word trials when global memory was high, $t(13) = -2.12$, $p = .054$.

Furthermore, there was a marginally significant interaction between time, location, and global memory, $F(3, 39) = 2.39$, $p = .083$. Descriptively, high compared to low global memory was associated with a more positive scalp topography mainly in the 300-600 ms and 600-900 ms time windows at frontal electrodes. This effect was thus earlier than similar effects in the memory selectivity analysis, which were primarily observed in the 900 to 1200 ms time window. ERP plots and scalp topographies for the global memory data are given in Figure 4.13.

Visual inspection of the topographic plots indicated that effects of global memory were largest at central electrodes (C3, Cz, C4). The way that electrodes were divided for analysis in frontal and posterior clusters excluded this electrode cluster. To ensure that the comparison of memory selectivity and global memory effects was not biased by the way the electrodes were divided for analysis, the EEG signal of these centreline electrodes was entered into an additional, simplified ANOVA. This ANOVA with variables global memory and time only revealed a significant effect of time, $F(3, 39) = 15.49$, $\varepsilon = .485$, $p < .01$, with increasing positivity of the scalp voltage over time, but no main effect of global memory, $F < 1$, nor any interaction between time and global memory $F(3, 39) = 1.31$, $\varepsilon = .652$, $p = .286$. Thus, altogether the stimulus-locked data showed little evidence for systematic subsequent memory effects associated with the measure of global memory.

Overall, the results of the above analyses suggest that the stimulus-locked EEG data display less consistent effects of switching than the cue-locked data. Importantly, however, the stimulus-locked data showed significant subsequent memory effects when assessed with the measure of memory selectivity. The measure of global memory did, however, not show meaningful effects in this phase.

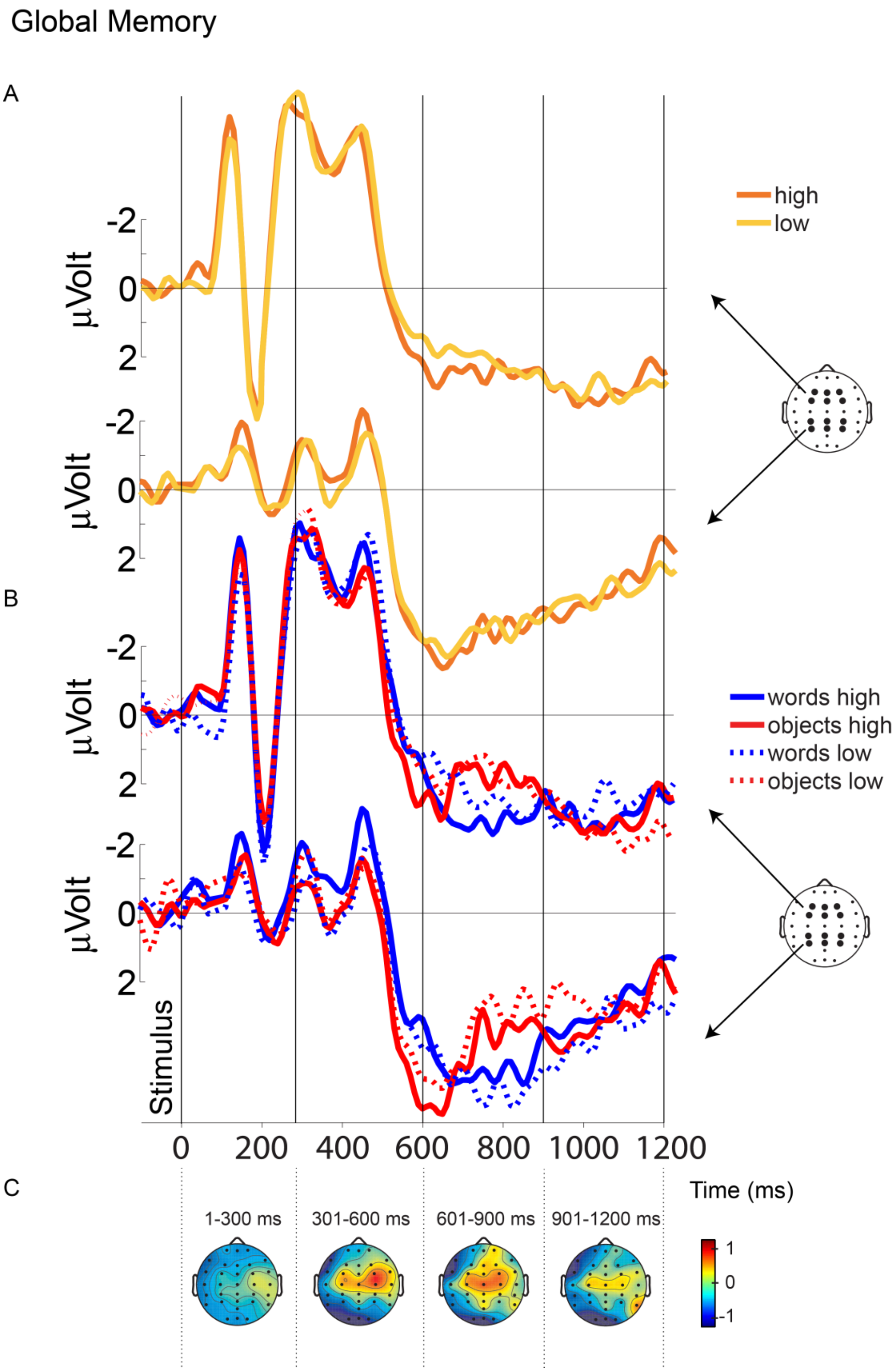


Figure 4.13: ERP wave forms for high and low global memory trials as measured at the frontal electrodes F3, FZ, F4, FC3, FCZ, and FC4 (upper) and posterior electrodes CP3, CPZ, CP4, P3, PZ, and P4 (lower) both time-locked to the onset of the stimulus in Experiment 7. (B) ERP wave forms for high (sold line) and low (dotted line) global memory trials in the object and word condition at frontal (upper) and posterior (lower) electrodes. (C) The scalp topography of the average signal differences between high and low global memory trials in steps of 300 ms starting with stimulus-onset.

4.2.4 Discussion

The behavioural data of the current experiment replicated important effects of Experiment 6. First, a significant modulation of later memory by switching attention was found. Secondly, the current study replicated effects of the memory selectivity analysis, which demonstrated that later memory can be used to predict earlier task performance in switch trials. Thirdly, and in contrast, global memory showed no relationship with previous task performance. Thus, later overall memory success was again unrelated to task performance. Together with the finding that memory selectivity and global memory scores were uncorrelated, these results indicate that effects of global memory and memory selectivity are at least partly dissociable on a behavioural level.

The main interest of this study was, however, the EEG analysis. The present EEG study investigated the neural correlates of successful encoding and successful task performance. Specifically, two measures of memory success – memory selectivity and global memory – were used to assess whether previously described frontal subsequent memory effects are the result of selective encoding processes (memory selectivity), general encoding success (global memory), or both. Moreover, it was explored how neural correlates of successful encoding relate to control processes observed in task switching. The next sections will first provide a comparison of the effects of memory selectivity and global memory, and then review the effects of both measures separately and discuss how they relate to previously described subsequent memory effects. Thereafter, similarities in the neural correlates of successful encoding and switching will be discussed.

4.2.5 Dissociation between Effects of Memory Selectivity and Global Memory

Subsequent memory effects are most frequently reported for stimulus-locked data in the encoding phase of memory studies. Such subsequent memory effects usually show a fronto-central or centro-parietal positive topography (Fabiani, et al., 1990; Paller, et al., 1988; Sanquist, et al., 1980; Sommer, et al., 1991). These effects have sometimes been observed to start as early as 400 ms (Paller, et al., 1987), and have often been documented to last for over a second (Fernandez, et al., 1998; Neville, et al., 1986). Both memory selectivity and global memory are measures of encoding success, and therefore it was not surprising that both measures displayed similar fronto-central and central topographies in the stimulus phase. The key finding of the current chapter was, however, that these superficial similarities did not hold up with more careful inspection.

Whereas memory selectivity seemed to increase over the course of the trial in the stimulus-locked data, reaching a significant difference between high and low memory selectivity trials in the last, 900-1200 ms window, global memory peaked in a time window around 500 to 700 ms and then diminished. Importantly, elaborative encoding tasks, such as the natural vs. man-made task used in the current experiment, are more typically associated with frontal subsequent memory effects. Only the topography of the memory selectivity effect was focussed around frontal or fronto-central electrodes, whereas the global memory effect peaked somewhat more posteriorly, on central electrodes.

Thus, the findings of the current study suggest that effects of memory selectivity and global memory are dissociable, and that the usually observed frontal subsequent memory effects are possibly more related to selective processing (memory selectivity) than a general measure of memory success (global memory).

4.2.6 Memory Selectivity

On the basis of previous literature (cf. Otten, et al., 2006; Otten, et al., 2010; Padovani, et al., 2011), it was expected to find preparation-related memory effects in the cue phase. The exact nature of the expected topography was difficult to predict as prestimulus-memory effects have sometimes been shown to vary with the task or stimuli employed (Galli, et al., 2012; Padovani, et al., 2011), and sometimes not (e.g., Otten, et al., 2010).

In the current study, cue-locked effects of memory selectivity were overall weak and statistically unreliable. Memory selectivity displayed mostly posterior negative effects in the cue phase. While no significant main effect of memory selectivity was found, a marginal effect indicated that there was a descriptive difference between high and low memory selectivity word trials, whereas high and low memory selectivity object trials did not seem to differ. These marginal material-specific preparation effects for words are potentially interesting for theories of memory, as there has been some debate on whether prestimulus-memory effects reflect a general “favourable state of mind” (cf. Chun & Turk-Browne, 2007), or other processes such as active preparation (Gruber & Otten, 2010). The current data might be more consistent with the interpretation of active, material-specific preparation processes, as no such material-specific processes would be expected for general effects such as overall alertness. However, the statistical unreliability of the effect and the fact that no comparable effect for object trials was found make an interpretation difficult.

One possible reason that only a modulation of word trials was found (on a descriptive level) might be the nature of the word task: Although there was no systematic modulation of the key experimental effects by material across previous experiments presented in this thesis, word trials were generally perceived as more difficult than object trials by participants, and led to longer RTs and more errors (cf. Chapter 2). Words were also generally better remembered than objects. It is therefore possible that word trials demanded different, or more extensive preparation processes than object trials, leading to the described differences between objects and words in the EEG findings (cf. Kieffaber & Hetrick, 2005; Otten & Rugg, 2001a).

Previous literature has suggested that cue- and stimulus-locked subsequent memory effects are dissociable from each other in that they do not necessarily co-occur (Otten, et al., 2006; Otten, et al., 2010). Consistent with this idea, memory selectivity effects in the stimulus phase seemed to be of more general nature than in the preparation phase: There was no reliable modulation of memory selectivity by material in the stimulus phase, but a significant modulation of memory selectivity effects over time possibly indicating task-general processes.

Effects of memory selectivity increased over the course of the stimulus interval, and reached significance in the final 900 to 1200 ms time period. This effect resembled the pattern and time course of previously described subsequent memory effects (Fernandez, et al., 1998; Friedman & Trott, 2000; Neville, et al., 1986; Otten & Rugg, 2001a), though some studies have also reported earlier time windows, around 400 to 800 ms (e.g. Paller, et al., 1987). Accordingly, the stimulus-locked data is consistent with the prediction that neural correlates of subsequent memory selectivity should be detectable in the stimulus phase. Overall, this effect of memory selectivity indicated that selective encoding might be a key factor in subsequent memory effects observed in elaborative encoding tasks.

4.2.7 Global Memory

Global memory did not show significant interactions with material in the cue-locked data. This finding was not surprising considering that global memory, as a general measure of encoding success, should not be related to material-specific preparation processes. The fact that no effects of global memory were found in the preparation phase at all is, however, somewhat surprising. Even though global memory was not expected to show material-specific effects, it would have been conceivable to see a general effect of later global memory on the EEG data, possibly reflecting a “favourable state of mind” (cf. Chun & Turk-Browne, 2007). Although the topography of the global memory data, with a primarily frontal negative pattern, showed some similarity to previously described prestimulus subsequent memory effects (Otten, et al., 2010) the effects of global memory seemed to be unreliable here. Thus, later overall memory success does not seem to be associated with significant prestimulus subsequent-memory effects.

Similarly, while memory selectivity showed significant effects in the stimulus phase (i.e. subsequent memory effects), global memory again failed to show any compelling significant effects. The only significant effect involving global memory was that global memory interacted with material and location. There were, however, no significant differences between high and low global memory trials in any of the subconditions. The cause of this interaction was instead a difference between frontal and posterior electrodes in low global memory word trials, which does not call for an obvious interpretation. Even when only the centreline electrodes were investigated, at which the effect of global memory seemed to peak, no significant effect of global memory was found. However, the marginal interaction between time, location, and global memory which showed a more posterior pattern was similar to centro-parietal subsequent memory effects sometimes observed (Paller, et al., 1987; Sanquist, et al., 1980). These effects, which are often less reliable than the frontal subsequent memory effects (Fernandez, et al., 1998), have been related to rote or perceptual encoding processes. These may be factors that are influencing global memory as well.

Together with the finding that global memory also did not show any behavioural effects, the EEG results are consistent with the argument that frontal subsequent memory effects are the result of selective processing in elaborative encoding tasks: If a measure of global memory is used, no effects on task performance are observed, and EEG-subsequent memory effects are unreliable and descriptively more posterior. Overall, therefore, frontal subsequent memory effects associated with elaborate encoding do not seem to be related to global memory.

4.2.8 Switching and Memory Selectivity

One of the goals of this study was to contrast the neural correlates of switch-related processes with subsequent memory effects. In the cue-locked data, the switch effects on posterior sites resembled previous findings that have been interpreted as increased preparation processes in switch trials (e.g., Karayanidis, et al., 2003; Poljac & Yeung, 2012b). As in previous studies with long preparation intervals, the switch effect descriptively started to diminish towards the end of the preparation interval (Karayanidis, et al., 2003), likely indicating that preparation processes were approaching completion.

Comparing the topographies of memory selectivity and switching in the cue-locked data, the most obvious difference was that the switch effect showed a positive posterior topography, while memory selectivity displayed a negative posterior topography. This difference might be explained by the fact that switch trials usually result in lower selectivity than repeat trials, and therefore the switch effect (generally lower selectivity switch minus higher selectivity repeat trials) effectively plots the inverse of the memory selectivity effect (high minus low memory selectivity). Thus, effects of memory selectivity (though weak) and switching resembled each other in the cue-locked data in topography and timing.

One interpretation of the similarity of the switch and memory selectivity effects in the cue-locked data might be that they reflect similar processes. This could also explain the lack of an interaction between switching and memory selectivity in the EEG signal: If similar processes occurred in preparation for switch and repeat trials no interaction would be expected. The finding that switching and memory selectivity interact on a behavioural level could then indicate that the success of these preparatory processes might differ in switch and repeat trials, reflected in differences in behavioural effects.

Whereas preparation processes seemed to be similar for memory encoding and switching, correlates of memory selectivity and switching differed in the stimulus phase. In contrast to the findings of the cue-locked data, memory selectivity and switching effects showed different time-courses in the stimulus-locked data, and the polarity of the topographic effects did not match. This divergence indicates that control processes associated with switching and memory encoding differ in the stimulus phase. Memory selectivity effects increased after stimulus onset, which might indicate a reactive employment of control processes (Braver, 2012).

Moreover, stimulus-processing might be more relevant for later memory, as the memory test required a judgment on the specific stimuli presented during encoding. The importance of stimulus processing for memory might also be reflected in the difference between cue-locked and stimulus-locked memory selectivity effects: Some processes that are beneficial for later high memory selectivity possibly cannot be completed in the cue-phase, but are dependent on stimulus presentation.

4.3 General Discussion

The results of Experiment 6 and 7 indicated that a simple shift of attention between stimuli affected the selectivity of processing and later memory. As in previous experiments of this thesis, switching did not significantly affect overall memory. Previous work in this thesis has shown that cognitive control is less selective when tasks are switched. The experiments of the current chapter have demonstrated the same effect for a specific sub-set of cognitive control, visual selective attention. This similarity of effects suggests that the conclusions drawn in previous chapters also apply for this specific case: switching attention results in performance declines due to less selective processing of information.

Moreover, the results of this chapter indicate that a measure of overall encoding success, global memory did not significantly predict earlier task performance. In both studies, memory selectivity and global memory were not correlated with each other, suggesting that they measure different constructs. Consistent with these behavioural results, the EEG data indicated that memory selectivity, but not global memory, showed significant frontal subsequent memory effects in the stimulus-locked data.

The work described in this chapter has important implications for theories of attention and memory. Previous studies have shown subsequent memory effects in EEG, but were unable to determine whether these effects are related to selective encoding or general encoding success, as they did not explore the processing of unattended material. Importantly, the current results demonstrate that such frontal subsequent memory effects seem to be the result of selective encoding processes, suggested by the finding that memory selectivity, but not global memory showed significant frontal subsequent memory effects. This result indicates that subsequent memory in elaborative encoding tasks is at least partly the result of attentional focussing and selective stimulus control.

The cue-locked EEG data showed a switch-related positivity. This effect has been interpreted as the need for increased preparation in switch compared to repeat trials in previous studies (e.g., Karayanidis, et al., 2003; Poljac & Yeung, 2012b). Interestingly, the memory selectivity effect (high minus low memory selectivity) in the cue-locked data resembled an inverse switch effect. This descriptive similarity could suggest that comparable mechanisms might underlie both effects. A possible interpretation would be that decreased memory selectivity (a small difference between the rating of the attended and unattended item) is caused by similar processes that cause increased preparation demands in switch trials, such as increased between-task interference.

This similarity between EEG correlates of switching and correlates of memory selectivity was not found in the stimulus-locked data. Here, the two effects differed in timing and topography, suggesting that these effects were somewhat independent of each other. Frontal subsequent memory effects in the stimulus phase have been argued to reflect “deep” processing of some items compared to other, evident in the finding that this frontal effect is often found in the comparison between deep and shallow encoding tasks (e.g., Mangels, Picton, & Craik, 2001). These effects have also been associated with “meaning-based attentional orientation” (Paller & Wagner, 2002), and distinguished from centro-parietal effects (Paller, et al., 1987; Sanquist, et al., 1980), which seem to be related to rote-encoding and perceptual-encoding processes (Fernandez, et al., 1998). These descriptions share in common that they refer to operations performed on the stimulus. processes necessarily have to wait until the stimulus is presented, which might explain the dissociations in topographies between cue-locked (with a more negative scalp voltage at posterior sites) and stimulus-locked (fronto-central positivity) subsequent memory effects.

The requirement for stimulus-based processing might also be the reason for the dissociation between stimulus-locked memory selectivity and switch-specific effects. It has been suggested that stimulus-locked switch effects, such as the parietal negativity described in the current study, may be reduced with increasing preparation (Kieffaber & Hetrick, 2005). This observation suggests that preparation can reduce the need for switch-specific control processes in the stimulus-phase. Preparation might, however, not reduce the need for stimulus-locked processes associated with memory: Activity in the stimulus phase may be more related to later memory, as the processing of the specific stimulus is of more central relevance here.

Overall, the data of the EEG experiment suggest that selective attention to relevant material is a key determinant of subsequent memory effects in deep encoding tasks, consistent with current theories that emphasize the role of selective attention in memory (Chun & Johnson, 2011; Uncapher & Rugg, 2009). Moreover, the similarity between cue-locked switch and memory selectivity effects could provide interesting insights into the nature of control processes during task switching, although the unreliability of this effect means that it must be interpreted with caution: A replication of this effect would suggest that preparation is necessary for the successful selection of relevant information upon stimulus presentation.

Chapter 5:

Retrieval Orientations – Task Sets in Memory

The goal of the research presented in this chapter was to demonstrate further the role of cognitive control in memory, while changing the focus of investigation from that of previous chapters. Whereas my preceding work has investigated the effect of switching between tasks during encoding, the current chapter aims to investigate switching during the process of memory retrieval.

Task-switching studies are based on the idea that a person has to enter a specific mental state to perform a task. This state is referred to as “task set”. A task set consists of a relevant set of stimuli, a specified set of responses, and rules that map the stimuli to correct responses. The need to enter a specific mental state has also been suggested when a memory needs to be retrieved. In the memory literature, mental states entered when performing a retrieval task have been referred to as retrieval mode (Tulving, 1983) and retrieval orientation (Rugg & Wilding, 2000). The former, retrieval mode, distinguishes the mental state a person enters to retrieve episodic knowledge (i.e., recalling a specific event, like your last birthday) versus retrieving semantic knowledge (i.e., a general fact, like the date of your birthday). Retrieval orientation can be understood as a subset of retrieval mode. For example, recalling the guests that attended your last birthday party would make you engage in a different retrieval orientation than recalling the songs that were played at this party.

In research on retrieval mode, an episodic memory task (e.g., old/new judgment) is compared to a semantic task (e.g., living/non-living judgment) (Phillips, et al., 2009). In research on retrieval orientation, participants are required to not only indicate whether an item was presented before (simple old/new judgement), but also to remember whether it was presented in a specific task-relevant format (e.g., auditory, pictorial, or in writing). For example, participants may be presented at encoding with a list of auditory words and a series of object pictures. In a later retrieval phase they may then be presented with visual words. In some retrieval blocks they will be asked to make an old judgment only to items that were encoded as auditory words, while in other blocks they may be asked to indicate that an item is old only when they have seen the object named as a picture (e.g., Hornberger, Rugg, & Henson, 2006). If a retrieval orientation is adopted successfully, participants can focus their retrieval attempts on items encoded in the format relevant for the current retrieval task (Herron & Rugg, 2003). In the following I will refer to studies of retrieval orientation and retrieval mode collectively as studies of retrieval set.

Conceptual overlap between the ideas of task sets and retrieval sets has been suggested previously (e.g., Morcom & Rugg, 2002; Sakai, 2008). For example, in an early EEG study, Morcom and Rugg (2002) investigated whether they could find item-related activity that differentiated between episodic and semantic “task sets” in trials in which the task was switched compared to repeated. Sakai (2008, p. 226) suggested that “Retrieval mode and retrieval orientation can be considered as task sets for memory retrieval”, based on the fact that previous studies had found sustained activity associated with episodic retrieval that did not differ depending on the episodic retrieval task (retrieval mode), as well as neural activity that was dependent on what kind of information was recalled (retrieval orientation). Moreover, fMRI studies have indicated that retrieval orientation tasks compared to simple old/new recognition tasks show similar neural activity as task switching, for example in areas of lateral frontal cortex and in regions of inferior lateral and superior medial parietal cortex (e.g., Dobbins, Foley, Schacter, & Wagner, 2002; Woodruff, et al., 2006).

The research presented in the current chapter is motivated by the hypothesis that task sets and retrieval sets are not only conceptually similar, but are also comparable functionally in important respects. Specifically, I hypothesise that common cognitive and neural mechanisms underlie the establishment of task sets (a set of relevant stimuli, specific response sets, and mappings between stimuli and responses) and retrieval sets (a subset of episodic memories, response sets, and mappings between these memories and responses).

Similar to task-switching studies, in studies of retrieval sets participants conduct two or more different tasks: either episodic and semantic retrieval tasks, or different episodic retrieval tasks. Moreover, several studies have also required participants to switch between these tasks. Thus, studies of retrieval set sometimes also display methodological similarity to task-switching research, although switching effects are assessed generally less frequently, and mostly with EEG, and not fMRI. Overall, however, switching has not been a main focus in studies of retrieval set. This is because studies of retrieval set are typically more interested in the correlates of these different memory sets than in processes of switching. This is in contrast to studies of task-switching which have focussed much more on the control of task sets, but have been less interested in correlates of these different sets. This might explain why, while extensive research has been conducted on both task sets and retrieval sets, findings in the two fields have rarely been compared directly.

This chapter presents two approaches to contrast task switching with switching during retrieval. The first approach is a meta-analytic comparison of brain activations in task-switching studies with brain activations in studies in which participants conducted different retrieval tasks. Showing that brain activations in task-switching studies and studies that assess different retrieval sets overlap, is a crucial first step in demonstrating that the brain mechanisms involved may be similar. In the second part of this chapter, I will present a behavioural study that assesses task switching and switching between retrieval tasks in the same participants to establish similarities on the behavioural level.

5.1 Meta-Analysis

The aim of the current meta-analysis was to compare fMRI studies of task switching with studies that investigated switching during retrieval. Unfortunately, very few fMRI studies have assessed switching during retrieval directly. Indeed, a majority of retrieval set studies have used blocked designs and not investigated the switching between different retrieval orientations. However, a few studies have used switches between different retrieval tasks, for example between episodic and semantic tasks (Kompus, et al., 2009; Phillips, et al., 2009), between judging the context an item was presented in versus its recency (Dobbins, et al., 2003; Dobbins & Wagner, 2005), or between simple old/new judgments versus more specific judgments, like whether an item was presented in a different size than at encoding, or in which task context it was presented (Dobbins & Han, 2006; Ranganath, et al., 2000). However, even when switches between tasks were used in the designs, analyses of the effects of switching have rarely been reported.

When switches between these tasks were analysed, however, they have been shown to activate areas comparable to those active in task switching (Phillips, et al., 2009). Phillips et al. (2009, supplementary analyses) had participants switch between an episodic and a semantic task and found that switching not only resulted in a cost in RTs for recognition judgements (cf. switch cost), but also activated regions including the superior parietal lobe (SPL) and the inferior frontal junction (IFJ), which, as outlined in Chapter 1, are regions that are very consistently reported in task-switching fMRI studies. Other studies in which participants alternated randomly between different retrieval orientations, even if this switching was not directly assessed, similarly find activity in regions that are described to be active during task switching (Dobbins & Han, 2006; Dobbins & Wagner, 2005): lateral frontal activations including ventrolateral prefrontal cortex (VLPFC), dorsolateral prefrontal cortex (DLPFC), IFJ, anterior prefrontal cortex (anterior PFC) regions, as well as superior parietal regions are reported in these studies.

Although the research reported above provides some initial evidence that similar brain regions may be involved in adopting task and retrieval sets, one caveat is that these regions are, of course, also reported in a wide range of other control demanding tasks (Duncan & Owen, 2000; Naghavi & Nyberg, 2005). Furthermore, although similarities are reported, this does not necessarily mean that overlapping areas are activated in both tasks. A direct comparison of activations between two tasks may show that similar, but consistently non-overlapping foci of activation are found. To compare more directly activations found in task-switching and memory-switching studies, I conducted an ALE-meta-analysis on task-switching and retrieval-set data.

5.1.1 Methods

Activation likelihood estimation (ALE) meta-analysis (Laird et al., 2005; Turkeltaub, Eden, Jones, & Zeffiro, 2002) of 33 fMRI task-switching studies and 15 retrieval set studies was conducted using GingerALE 2.1.1 software. Using this method, overlapping foci of activation from independent fMRI studies were identified by modelling each of these foci as a 3-dimensional Gaussian probability distribution with an empirically determined full-width half-maximum value (Eickhoff et al., 2009). That is, activation foci are not represented as single points, but as probability distributions centred around the reported foci. On the basis of the probability distributions of all included studies, each voxel was assigned an “activation likelihood estimate” which describes the probability that activity in a given data set lies within this voxel. The resulting ALE maps were then thresholded at $p < .05$ applying false discovery rate to correct for multiple comparisons. A minimum cluster size of 100 mm^3 was applied for all analyses. The ALE maps were then displayed onto the ‘‘colinbrain’’ template (Kochunov et al., 2002) using Mango software (www.ric.uthscsa.edu/mango). Coordinates reported in Talairach space or MNI were used. MNI coordinates were translated into Talairach coordinates using a conversion tool (Lancaster et al., 2007).

In a first step, two separate ALE analyses were performed: one on the task-switching data and one on the retrieval-orientation data. Then conjunction and subtraction analyses were conducted to compare the two resulting sets of foci and identify statistically significant differences in convergence.

Study Selection

The meta-analyses on task-switching and retrieval switching studies included fMRI studies published between 2000 and 2012. Studies were identified via searches on Pubmed and Google Scholar. Only studies reporting contrasts of healthy, young adults were included. For those studies that included comparisons with other participant groups (such as patients or older adults), only the data of the young healthy adults was used. Studies employing either blocked or event-related designs were included. On the basis of these criteria, the studies reported in Table A1and Table A2 (see Appendix) were chosen.

Task-Switching Studies

In the task-switching studies, mostly switch versus repeat trial contrasts are reported, although a few studies are included that reported a contrast between mixed-task blocks and single-task blocks as well (i.e., blocks in which participants switched between tasks vs.

blocks in which participants repeated the same task). Most of the studies included are cued task switching studies in which an instructional cue at the beginning of each trial was presented before the stimulus. This cue indicated which task to perform, or whether to switch or repeat the task of the previous trial. Tasks in most studies could switch on a single-trial basis, but sometimes longer minimal trial sequences were chosen for example to encourage the establishment of stable task sets (Yeung, et al., 2006). A minority of the studies used predictable trial sequences (Dreher, Koechlin, Ali, & Grafman, 2002; Kimberg, Aguirre, & D'Esposito, 2000), or voluntary task-switching designs (Forstmann, Brass, Koch, & von Cramon, 2006; Walton, Devlin, & Rushworth, 2004).

A broad variety of task-switching studies were included, for example requiring participants to switch between classifications of different stimulus types (Wylie, et al., 2006; Yeung, et al., 2006), different classification rules applied to the same stimulus type (Forstmann, Brass, Koch, & von Cramon, 2005; Kimberg, et al., 2000; Liston, et al., 2006; Luks, Simpson, Feiwell, & Miller, 2002), or between different responses made for the same categorization (Crone, et al., 2006; Dove, Pollman, Schubert, Wiggins, & von Cramon, 2000; Pollman, Dove, von Cramon, & Wiggins, 2000). In contrast to other recent meta-analysis of task-switching (Kim, Cilles, et al., 2011; Wager, et al., 2004), I did not differentiate between these different types of switching studies, because I was interested in the overall contrast between switch and repeat trials, independent of the type of tasks used.

Retrieval-Set Studies

In the retrieval-set studies, switching paradigms were used less often. Even when participants switched between retrieval tasks, switch-repeat contrasts were often not reported (e.g. Dobbins & Han, 2006). In fact the only study that directly assessed switching reported this comparison in the supplementary analysis section (Phillips, et al., 2009). For this reason, a broader range of contrasts was included in the meta-analysis on retrieval set, including comparisons between different retrieval orientations such as judging the context in which an item was presented versus its recency (e.g., Dobbins, et al., 2003; Dobbins & Wagner, 2005), between adopting a retrieval mode versus conducting a semantic task (e.g., Kompus, et al., 2009), and lastly including the actual contrast of switching (Phillips, et al., 2009). In some studies, different retrieval sets were adopted in different blocks (Hornberger, et al., 2006; Woodruff, et al., 2006), and in other studies participants were cued to the retrieval task in shorter sequences (Dobbins, et al., 2003; Dobbins & Wagner, 2005). Thus, the contrasts included in the retrieval set meta-analysis will likely reflect a broader range of processes, and not only processes associated with the switching between different retrieval sets.

5.1.2 Results

The results of the meta-analyses are shown in Figure 5.1 and 5.2. Regions marked in red in Figure 5.1 were consistently activated by studies of task switching. In Figure 5.2, blue shading indicates regions active in studies of retrieval sets, and purple indicates an overlap in regions activated in task-switching studies and studies of retrieval set, as revealed by conjunction analysis.

As expected from previous research (Kim, Cilles, et al., 2011; Wager, et al., 2004), task switching activated a large network of clusters in parietal and frontal regions, importantly including the IFJ (BA6/44) and SPL (BA7), which are key regions reported in task-switching research. There was a large cluster of activation in left parietal areas, including the temporo-parietal junction (BA39), the inferior and superior temporal cortices (BA40 and BA7), and extending into mesial areas where activation in the precuneus (BA7) was found. In the right parietal lobe, activations were overall weaker, consistent with previous studies (Kim, Cilles, et al., 2011). Activity in the right hemisphere was found in the precuneus (extending inferior and posterior into BA31 and BA19) and SPL. As expected, frontal regions also showed consistent activations and included the left middle frontal gyrus (BA9/46), and the precentral gyrus (BA6). Activations also extended to mesial areas, where activity was found in dorsal anterior cingulate cortex (BA32). Again a weaker pattern of activations was found in the right hemisphere. Moreover, several smaller activations were detected, including bilateral activations in the insula (BA13/47), and, likely the result of visual stimulus material used in the majority of the studies, bilateral activations in occipito-temporal cortex (BA18/19).

The meta-analysis on the retrieval-set data revealed overall less pronounced activations than that of the task-switching data. This finding might be due to the fact that considerably more studies entered the task-switching analysis than the retrieval-set analysis, as well as the fact that retrieval-set studies did not often employ switching in their designs, or did not report switch-specific contrasts. Importantly, however, even though activations are much more limited in the retrieval-set analysis, overlap between retrieval-set and task-switching data was apparent in several regions. These regions include the two key regions reported in the task-switching literature as being consistently activated: the IFJ (BA6/44) and the SPL (BA7). In addition to these regions, overlapping activity was also found in DLPFC (BA9/46), in the insula (BA13), and the pre-SMA (BA6). A last common area of activation was detected in the inferior temporal cortex (BA37), possibly due to the fact that visual stimuli were used frequently across studies of both task switching and retrieval set.

Differences between studies of task and retrieval set were revealed with subtraction analysis. Areas more consistently activated in studies of task switching than in studies of retrieval set are displayed in yellow in Figure 5.2. Only one of region, the right precuneus (BA7), was reliably more active during task switching than retrieval orientation.

Studies of retrieval set conversely observe activity in regions that are less consistently activated in task switching. These regions are marked in green in Figure 5.2. One of these regions lay in the middle frontal gyrus (BA6). In studies of episodic memory, this region has been reported in contrasts between old (recognised) versus new items (Takahashi, Ohki, & Kim, 2008), for correct old judgments versus incorrect old judgments (Dobbins, et al., 2002; Iidaka, Matsumoto, Nogawa, Yamamoto, & Sadato, 2006), and for source recognition versus simple old/new distinctions. These findings suggests a role of this region in source monitoring and evaluation processes in memory, a function that is probably more central for retrieval processes than task switching.

Moreover, a region in the anterior inferior frontal gyrus (BA10) was more consistently active in retrieval-set than task-set studies. This region has been associated with selection and control processes in memory (Badre & Wagner, 2007; Young & Shapiro, 2011), specifically during the early stages of retrieval (Simons, Gilbert, Owen, Fletcher, & Burgess, 2005).

Activity in this region has also been found when participants engage in retrieval of items that are only weakly associated with the retrieval cue (Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005). Controlled retrieval processes are usually not required in simple task-switching designs, as participants receive repeated practice on the task rules and make their decisions on stimuli presented to them during the task. This account could explain the more consistent activation of this region in memory studies.

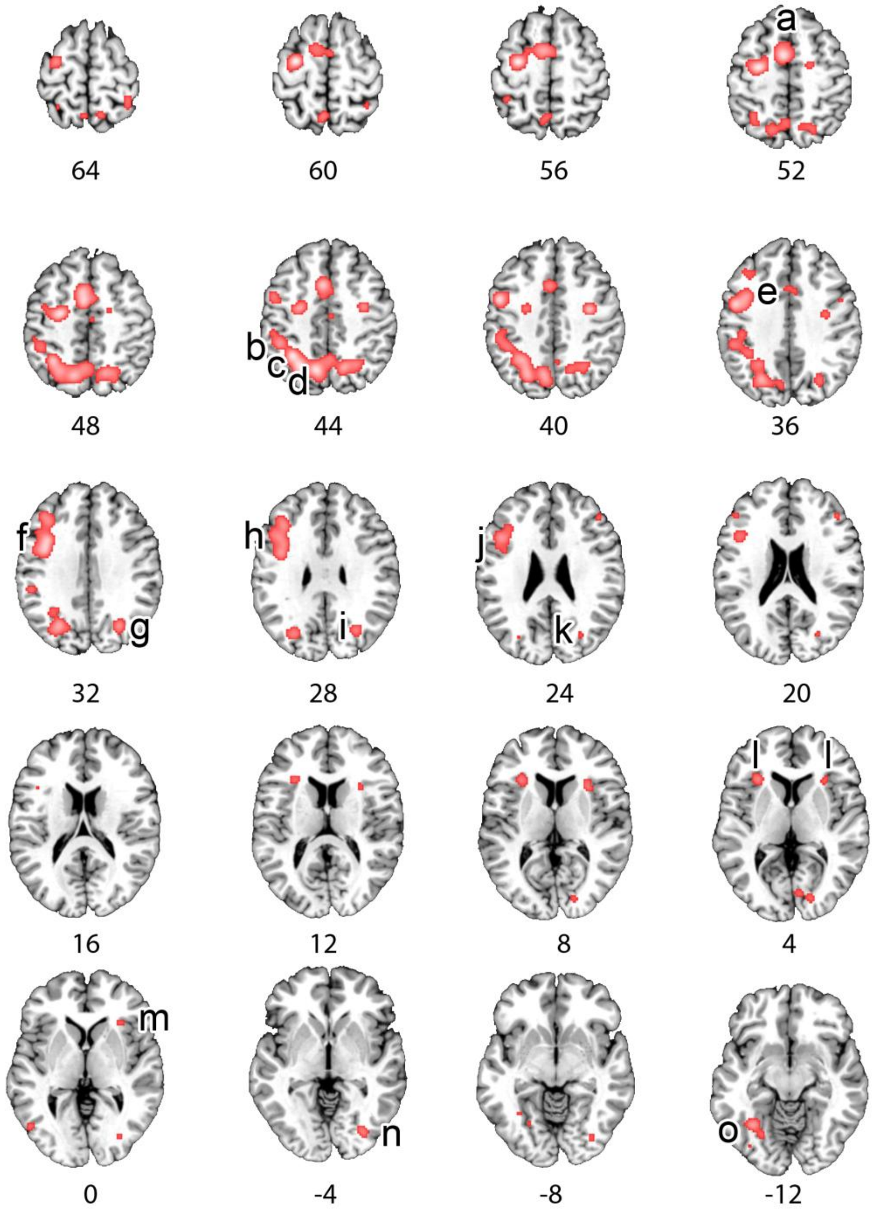


Figure 5.1. Results of the ALE meta-analysis of 33 fMRI task switching studies. Letters a-p mark the areas closest to activation peaks described in the main text: (a) BA6, Medial Frontal Gyrus; (b) BA40, IPL; (c) BA40/7, SPL; (d) BA7, Precuneus; (e) BA32, Cingulate Cortex; (f) BA9/6, Middle Frontal Gyrus; (g) BA19, Precuneus; (h) BA9, Middle Frontal Gyrus; (i) BA7/31, Precuneus; (j) BA46, Middle Frontal Gyrus; (k) BA31, Precuneus; (l) BA13, Insula; (m) BA13/47, Insula; (n) BA18, Middle Occipital Gyrus; (o) BA19, Inferior Occipital Gyrus/Fusiform Gyrus.

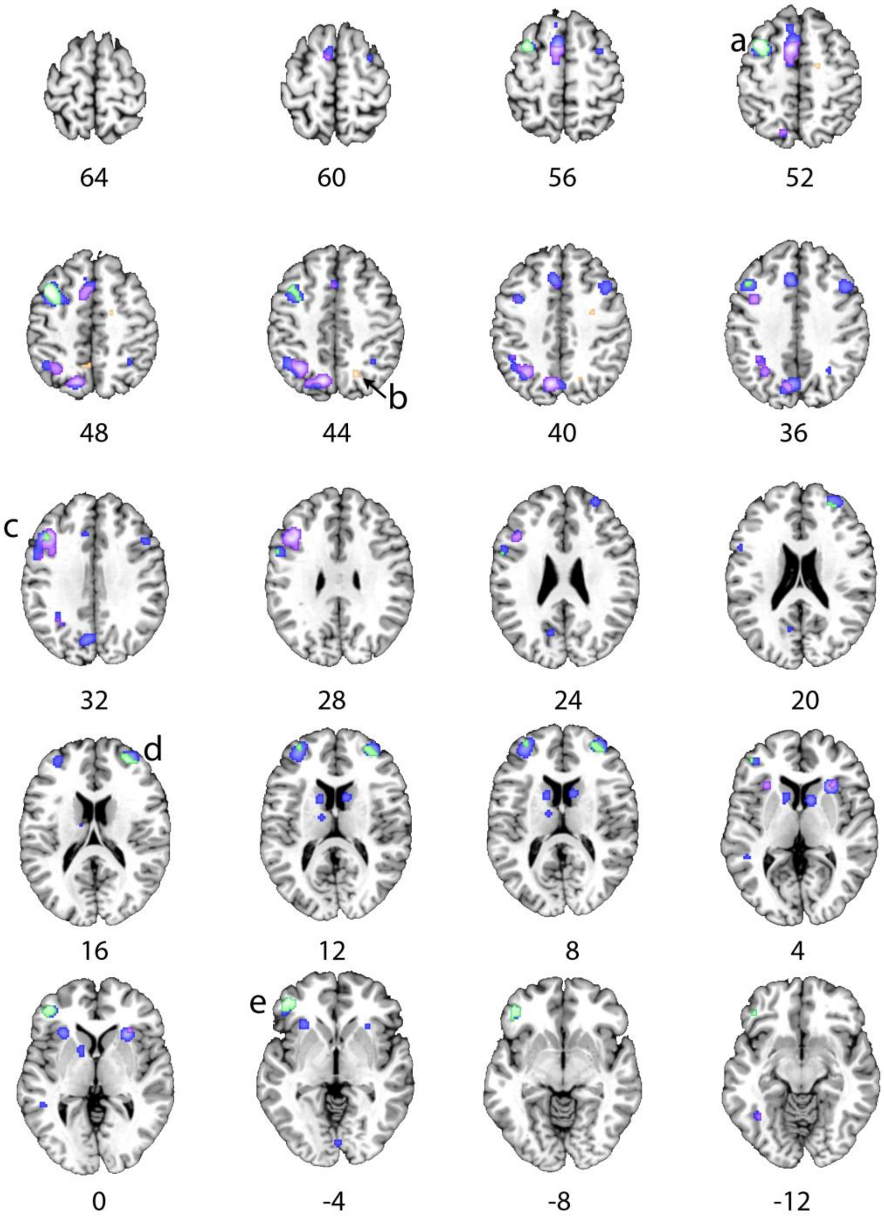


Figure 5.2. Results of ALE meta-analysis of 15 studies of retrieval set, and conjunction with activation foci in task switching. Blue regions indicate areas consistently activated in published studies of retrieval set, purple regions indicate overlap between these regions with those activated during task switching. Yellow regions indicate more consistent activity in task switching than retrieval orientation studies. Green regions indicate more consistent activity in the retrieval studies than in task switching. Letters describe the closest areas to the peaks of activation in the following regions: (a) BA6 (retrieval orientation > task switching); (b) BA7 (task switching > retrieval orientation); (c) BA9 (retrieval orientation > task switching); (d) BA10 (retrieval orientation > task switching); (e) BA10 (retrieval orientation > task switching).

5.1.3 Discussion

The results of this meta-analysis reveal considerable overlap between the neural correlates of the control of task sets and of retrieval sets. Importantly, overlap was identified in key areas discussed in the task-switching literature, in particular the IFJ and the SPL (e.g., Kim, Cilles, et al., 2011). This similarity in consistently activated regions is a notable finding given that several of the retrieval orientation studies have not directly assessed switching. Activity in the IFJ and the SPL has been associated with the retrieval and maintenance of task rules in task switching (Brass & von Cramon, 2004). Given the nature of the retrieval orientation tasks, it is relatively easy to translate the concept of such task rules to the memory domain: Retrieval-set studies also require the retrieval and temporary storage about what information is currently task relevant and, in cases in which retrieval tasks are cued (cf. Dobbins & Han, 2006), the maintenance of cue-rule associations. Accordingly, the conceptual and oftentimes methodological overlap between task-switching studies and retrieval-set studies seems to be reflected in shared patterns of brain activation.

Thus, the current meta-analysis is consistent with the hypothesis that similar mechanisms are involved in the control of task sets and retrieval sets. For research on task switching, this result indicates that the literature needs to expand the concept of task sets and task rules to memory processes: task sets are not limited to stimulus-response mappings, perceptual stimulus attributes, or abstract task rules, but neurally similar mental sets are also used to engage in episodic retrieval. Accordingly, task sets should incorporate the idea of mental representations as well. The translation of some ideas, such as the concepts of “task” and “response” is fairly straightforward, whereas other concepts such as “stimuli” and “stimulus-response mappings” may require adaptation of currently used definitions, to incorporate mental representations more broadly defined. This need for adaptation of terms also applies to the interpretation of regional brain activity, where similar terms have been used to describe the role certain regions fulfil (e.g., “updating of task representation” for the IFJ, or “providing of stimulus-response associations” for parietal regions, Brass & von Cramon, 2004).

Moreover, task-switching research has traditionally focussed on the difference between switch and repeat trials and has rarely investigated material-specific differences (but see e.g., Yeung, et al., 2006). Studies of retrieval set have a much richer tradition of focussing on these material-specific differences, as these studies are often contrasting the correlates of different retrieval sets. Analysing task-specific processes in task-switching research could provide a more detailed understanding of cognitive control: Task-specific brain activity could be used to pose questions about the nature of interference. For example, task-specific activity could help to identify situations that promote interference from the irrelevant task, as well as mechanisms that are employed to resolve this interference. Between-task interference can, for example, be identified on a trial-by trial level by analysing task specific activity to assess task strength and task-activation. Moreover, methods such as functional connectivity can be used to analyse task-specific interaction between control and task-relevant regions (cf. Stelzel, et al., 2011), which could provide important information about how control is exerted in different conflict situations. Together these analyses can likely help to extend existing theories about task control and between-task conflict.

For the memory domain, the present findings indicate that it might be possible to apply ideas and interpretations from the rich field of task-switching research to questions in memory research. Task-switching studies have systematically investigated the properties of cognitive control, such as the effect of switching on the stability of mental sets – a topic that has been gradually taken up in studies of retrieval set, though mostly to date in research using EEG (see below). This research demonstrates the possible fruitfulness of exchange of ideas between both fields. For example, it has been investigated how the stability of retrieval sets is affected by frequency of switches (Herron & Wilding, 2006b; Wilding & Nobre, 2001), or how memory tasks of different strength interact (Benoit, Werkle-Bergner, Mecklinger, & Kray, 2009), similar to the discussion of asymmetrical switch costs in the task-switching literature (Allport, et al., 1994). Open questions would concern what factors hinder or support the formation of stable memory sets, or how these sets are influenced by factors known to affect task-switching, such as preparation time or associations between stimuli and responses, and how these manipulations could be translated into the memory domain. Accordingly, it seems that there is great potential for both fields to benefit from each other's research.

To conclude, the meta-analyses described above provide evidence for shared neural mechanisms between task-set control and retrieval-set control. In a next step, I aimed to extend these findings by comparing task-switching and retrieval switching experimentally: Experiment 8 investigates behavioural similarities in switching between task sets and retrieval sets.

5.2 Experiment 8: Switching Task Sets and Retrieval Sets

The meta-analysis described above is an important step in demonstrating that overlap between mental sets in task-switching and memory retrieval not only applies at the conceptual level, but also is apparent in an overlap in brain activity across studies. There is, however, still little experimental evidence that connects these two directly.

Accordingly, I performed a behavioural study with the aim of establishing a direct link between task switching and retrieval-set switching.

Similar to previous experiments reported in this thesis, participants completed a task-switching encoding phase followed by a memory test. In contrast to the previous experiments, this memory test included two retrieval-orientation tasks, between which participants switched randomly: they either had to indicate whether they had seen a person's face during task switching, or whether they had seen a person's name. The key prediction was that similar effects of switching, in particular costs in RT and accuracy, would be found when participants were required to switch between retrieval sets. More specifically, in parallel to the effect that switching had on memory encoding, the key prediction was that the cost associated with switching reflects increased between-task competition, evident in less selective processing in memory switch trials.

To investigate the effects of switching between memory tasks on retrieval-orientation performance, an important first step was to demonstrate that reliable effects of retrieval orientation can be elicited in this study. In the experiment, participants were presented with pictures and names of famous people during task switching. For example, in a given task-switching trial they might be presented with a picture of Madonna and the name "Barack Obama". In the later memory test, they were presented with these people again. In some trials they were cued to only treat as targets people whose face they had previously seen (retrieval orientation face), and in others people whose name they had previously seen (retrieval orientation name). If faces are the target material, for example, they would have to indicate that Madonna was seen before, but would have to indicate that Barack Obama was not seen before. Effects of retrieval orientation will then be evident in higher memory ratings to old items previously presented in the relevant format (face or name), than to old items that were presented in the alternate, irrelevant format. Once this effect was demonstrated, the key question of this experiment concerned the effect of switching on memory performance.

Switching has previously been assessed mostly in EEG studies of retrieval set. This research demonstrated that EEG correlates of different retrieval sets can only be observed when switches between tasks are limited, such that a minimum of two trials was argued to be necessary to establish a retrieval set (Herron & Wilding, 2006b; Morcom & Rugg, 2002; Wilding & Nobre, 2001), indicating that switching affects the stability of memory task sets. Moreover, this research has also shown other parallels with the task-switching literature. For example it has been shown that memory tasks of different strength interact (Benoit, et al., 2009), and lead to asymmetrical switch costs a findings consistently reported in the task-switching literature (Allport, et al., 1994).

The switch cost is the key behavioural effect reported in task-switching studies. If task switching and retrieval-set switching require similar processes, then we would expect to find similar behavioural costs of switching in retrieval tasks as well. Behaviourally, retrieval-switching studies have in fact reported switch costs in the RTs, such that trials in which the retrieval task switched were associated with longer RTs than repeat trials (e.g., Herron & Wilding, 2004; Herron & Wilding, 2006b; Werkle-Bergner, Mecklinger, Kray, Meyer, & Duzel, 2005), or that mixed-task blocks were associated with longer RTs than continuous task blocks (Benoit, et al., 2009). These findings suggest some similarities in the behavioural correlates of switching.

Throughout this thesis, it has been demonstrated that switch cost during standard task-switching reflect increased between-task competition in switch compared to repeat trials. If switching between retrieval tasks similarly leads to conflict because of between-task competition, this effect should also be reflected in the accuracy of memory ratings. Correct ‘old’ judgments (hits) should be decreased in switch compared to repeat trials.

Moreover, interference from the opposite task should increase the rate of incorrect ‘old’ judgments to task-irrelevant items. Accordingly, the selectivity of processing should be decreased in switch trials, reflected in the fact that participants show a tendency to fail to rate task relevant-material as old, and incorrectly judge task-irrelevant material as old.

There is, however, at best very weak evidence for the effect of switching on such memory accuracy. Some studies have found no effect of switching on the accuracy of memory judgments (Herron & Wilding, 2004, 2006b; Morcom & Rugg, 2002), or have not reported evidence for such behavioural effects (Wilding & Nobre, 2001). Other studies have reported a decrease in hit rates with switching, but no decrease in correct rejections (Herron & Wilding, 2006a). Lastly, a decrease in correct rejections, but no effect on hit rates, has been reported, but this effect was limited to only one of two material types used in the study (Johnson & Rugg, 2006). Accuracy has also been assessed with the discrimination index Pr (Snodgrass & Corwin, 1988), which relates the rate of hits and false alarms (to new items) to each other (pHit – pFA). This research has similarly shown that recognition accuracy is decreased in mixed-task blocks compared to continuous task blocks (Benoit, et al., 2009) or on a single-trial level (Benoit, et al., 2009; Werkle-Bergner, et al., 2005). Although this measure is a somewhat better way to measure accuracy, because it takes false alarms into account, these findings still provide no indication about the possible source of decreases in accuracy in retrieval switch versus repeat trials. To show that switching results in deficits due to interference from the previous task, it is necessary to show that switch trials are associated with decrease in dissociation between the retrieval tasks. Thus, this experiment assessed whether switching between memory tasks leads to a performance decline evident in decreased selectivity of retrieval; that is, a dissociation between the ratings given to old items presented in the relevant and irrelevant format for a given retrieval-orientation task.

5.2.1 Methods

Participants: Sixteen participants (seven male) with an average age of 23.4 years (*SD* = 2.6) took part in this study. All gave informed consent and received course credits or payment for their participation.

Material: In contrast to previous experiments, pictures and names of famous people were used in this study. This change was made for the following reasons. First, people are highly trained in differentiating faces. Moreover, the exclusive assignment of a specific name to a specific face makes well-known people more suitable stimulus material than the pictures and words used before: It is easy to imagine an identical object picture that two participants could refer to by different names. For example, a cup could also be referred to as a mug, or reading the word “bow” could lead one participant to imagine a ribbon, and another one the bow of a ship, and so on. This ambiguity of referents considerably limits the number of objects that have a close to unique name/picture association, a limitation that is not present with people. Another advantage of using pictures and names of famous people is that face stimuli and verbal stimuli show some of the most differentiable patterns of brain activation and are therefore especially suitable for later testing with fMRI, an important planned follow-up of the present behavioural study (e.g., Hasson, Levy, Behrmann, Hendler, & Malach, 2002; McDermott, Buckner, Petersen, Kelley, & Sanders, 1999).

Procedure: This study consisted of four different parts which were conducted on two consecutive days. All participants took part in a familiarisation phase (Part 1), a practice phase (Part 2), the main experiment (Part 3), and a post-test (Part 4).

To increase the participants' familiarity with the famous people used as stimuli in the study, participants completed a familiarisation task on the first day (Part 1). This was important because participants needed to link each person’s name and face correctly to be able to complete the retrieval-orientation memory task successfully. In the familiarisation task, they were presented either with the face or the name of a person and the sentences: “Do you know this person's name?” when a face was presented, or “Do you know what this person looks like?” when the name was presented. After giving their answer, they were presented with both the face and name, and indicated whether or not they were correct in their previous response. They then had time to encode the person's face and name, and could move on to the next trial by pressing the space bar (i.e., the learning phase was self-paced). Participants completed 4 blocks of this task, and then were again presented once with the people they had failed to recognize previously (re-learn phase). Overall, participants were presented with 300 people in the familiarisation phase, and spent around 45 minutes on this task. On average they indicated familiarity with the person’s face or name in 68.6% of cases (*SE* = 2.61).

On the first day, participants also completed a practice phase (Part 2) of the task-switching paradigm that was later conducted in the main experiment. In this practice, pictures and names of “The Simpsons” cartoons were used instead of famous people to keep the number of persons available for the main experiment high. Participants reported no difficulties in transferring this practice onto the task in the main experiment, which was conducted on the names and faces of the famous people.

In the practice phase, participants conducted a simple gender discrimination task on either the face or the name presented to them. Similar to previous experiments, the task they had to perform in a given trial was cued with red or blue frames, with assignment of colour to task counterbalanced across participants. Cues were presented for 500 ms, followed by a black screen for 800 ms, resulting in an overall CSI of 1300 ms. Following the CSI, the stimulus was presented for 300 ms. The stimulus always consisted of a face and overlaid name, and thus all stimuli were bivalent. A blank screen followed this stimulus presentation. There was no time limit for the participants’ response, but they were instructed to respond as quickly and accurately as possible. The next trial started after an ITI of 500 ms, following the response. The “x” key was used to indicate that a person was male, the “n” key to indicate whether a person was female. On the first day, participants completed one block in which they performed the gender discrimination paying attention to the face, and one block in which they performed the gender discrimination task on the name that appeared, with the Simpsons’ characters as stimuli (single-task blocks). They then conducted two blocks in which they switched between the face and the name task across trials in random order (mixed-task blocks).

The second session of the experiment was always completed on the following day (with the exception of one participant who was tested 1 week later; this person’s data did not differ in any obvious way from the data of other participants). At the beginning of the second session, participants again completed two mixed blocks of the task-switching practice to remind them briefly of the experiment requirements. Following practice, participants completed the main experiment (Part 3), comprising 5 blocks of 25 trials of task switching. In contrast to the practice blocks, which used the Simpsons’ characters, this task was conducted with names and photographs of the famous people. Across the four blocks, the faces and names were trial unique, that is, if they were presented with a person's name or face, that person’s name or face would not be presented again during the task-switching phase (see Figure 5.3).

Participants then entered a retrieval-orientation-based memory test (see Figure 5.3). In the memory test, they were either presented with faces or names of famous people. The cue presented on each trial now indicated whether the participants had to perform a face or a name retrieval-orientation task. The mapping of the cue colour to the tasks was the same as during the task-switching phase. When conducting the face task, participants were instructed to indicate that a person was old/seen before only if they had seen this person’s face in the gender-discrimination task-switching phase (i.e., they had to indicate “new” if they had seen the person’s name, or if they had not seen the person’s name or face). Similarly, when performing the name task, they were instructed to indicate that a person was old/seen before only if they had seen this person’s name during the previous task-switching phase (and indicate “new” if they had seen only the person’s face, or had seen neither their face nor their name). Participants answered on a scale from 1 to 6. A “1” response indicated that they were sure the person presented was not seen during task switching (new) or was presented in the currently irrelevant format (face or name; no match with retrieval orientation). A “6” response indicated that they had seen a person in the task-relevant format during task-switching (match with retrieval orientation). Participants were told that they were presented with either the face or the name of a person during task switching, not both. Moreover, they were informed that they would be presented with famous people they did not see at all in the task-switching phase (new stimuli). They also knew that they would have seen all of the famous people (old or new) during the familiarisation task on the day prior to the memory test.

Previous research has indicated that establishing a retrieval set can take several trials (Herron & Wilding, 2006b). Moreover, pilot testing indicated that participants found it difficult to switch between retrieval orientations when they were cued randomly across trials. For this reason, “miniblocks” were introduced into the memory test. That is, in the recognition memory phase, participants were cued to perform the same retrieval-orientation task for miniblocks of 3 successive trials, before a cue indicated the retrieval orientation required in the next miniblock. Another attempt to make the retrieval phase easier was that the material participants were presented with was held constant within a block. In a name block they would only be presented with names as retrieval cues, and were required to switch between the two retrieval orientations (i.e., deciding for each name whether they had previously seen that person's name before or had seen that person's face before). Conversely, in a face block, they would only be presented with faces as retrieval cues, while again switching between the two retrieval orientation tasks (see Figure 5.3 *B* and *C*). Participants completed 4 blocks with 24 miniblocks of 3 trials each in the memory phase of the main experiment. The ratio of old to new items in the memory phase was 5:1.

Before starting the memory test, participants first practised both retrieval-orientation tasks on 12 items (4 miniblocks). Each miniblock in the practice and the main experiment started with the presentation of a cue for 500 ms, and was followed by a blank screen for 800 ms resulting in an overall CSI of 1300 ms. The face or name stimuli were then presented for 5000 ms each, followed by a 500 ms inter-stimulus interval. Participants were instructed that they could only respond while the retrieval cue (name or face) was on the screen, and that they should try to avoid late responses. Trials were separated by an ITI of 500 ms.

After completing the main experiment, participants conducted a post-test. This test was conducted to measure how well participants knew the people presented to them after they had completed the familiarisation task and subsequent memory test. In this post-test they were presented with either the face or name of the famous people and rated on a scale from 1-6 how well they knew each person. A "1" response indicated that they did not know what a person looked like (if the stimulus was the person's name) or what a person's name was (if the stimulus was the person's face). A "6" response indicated that they immediately knew who the person presented to them was. The average rating given to the items in the post-test was 5.02 (SE = 0.09). On average 82.0% of items received a rating higher than 3 (SE = 2.00).

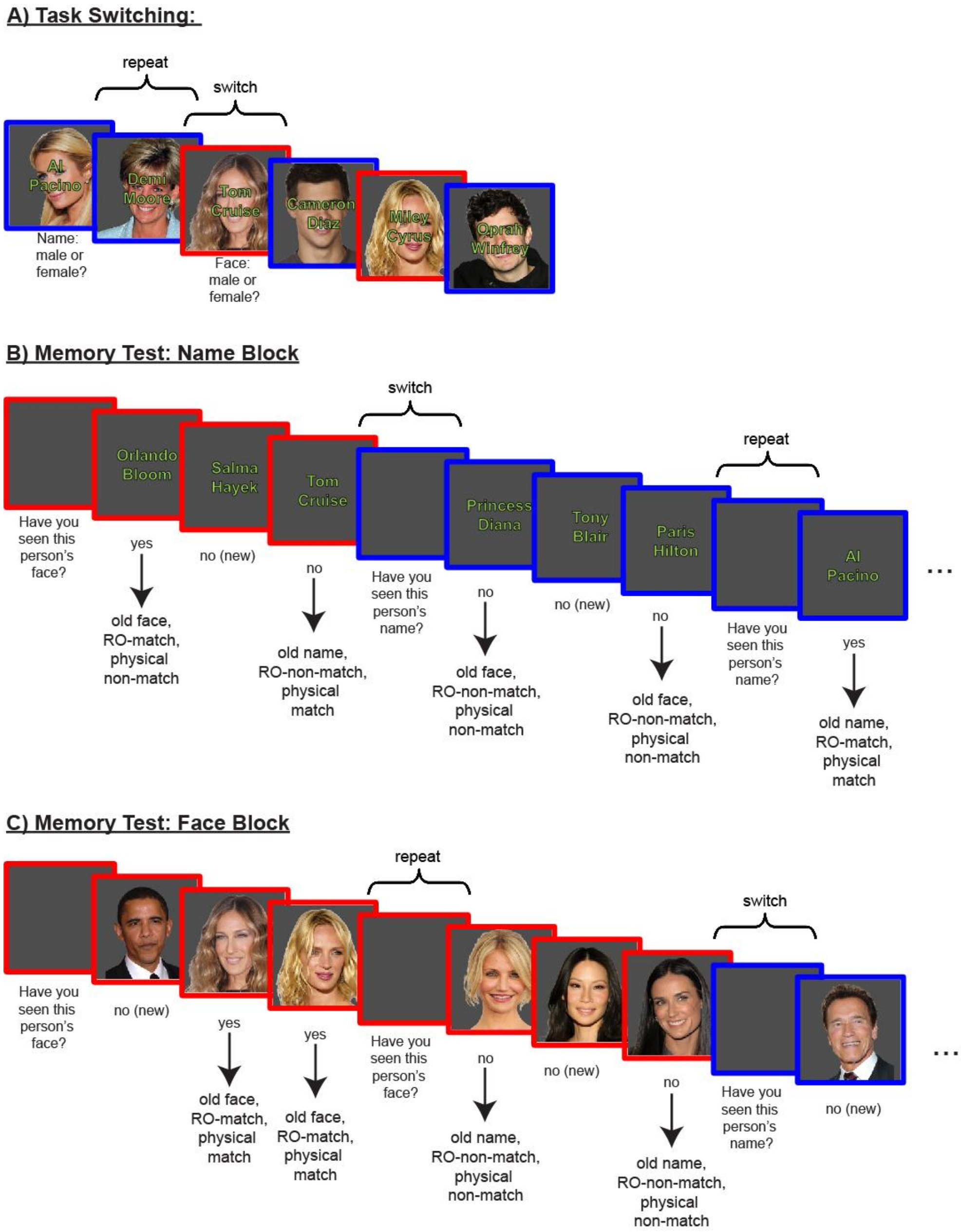


Figure 5.3: A) Illustration of the tasks used in the task-switching phase of Experiment 8. Participants were cued by a coloured frame preceding the stimulus (not shown here) to attend to either the face or the name presented to them, and to indicate the person's gender. B) Illustration of a name block in the memory phase. A cue preceded each miniblock and instructed the participant whether to perform the face or name retrieval orientation task. After cue presentation, participants performed three trials of the same retrieval orientation task before the next cue was presented. Depending on the history of the person presented, different conditions resulted which are outlined in the text. C) Similar to B), but showing a face block in the memory test.

Note on terminology: new = person was not presented during task switching; old face/old name = face/name was presented during task switching; retrieval-orientation (RO) match/non-match = person has been presented in the relevant/irrelevant format during task switching; physical match/non-match = person was presented in the same format (face/name) during task switching and in the memory test.

5.2.2 Results

For the analyses of the task-switching data, RT outliers (3 *SD* above the mean) and post-error trials were excluded. For the analysis of RTs, error trials were also excluded. In the analyses of the memory data, trials answered incorrectly during task-switching were excluded.

In the following, I will first give an overview of the performance in the task-switching encoding phase, followed by an RT analysis of the retrieval data, and a comparison between this data and the task-switching encoding phase data. After these analyses, memory performance will be assessed based on the memory ratings.

Encoding: RT and Accuracy

A first analysis investigated the basic performance during the task-switching encoding phase. As observed in the previous studies of this thesis, I expected to find typical switch costs. An ANOVA with the factors encoding switch (repeat vs. switch during encoding), and material (face vs. name), revealed a main effect of encoding switch in the RTs, $F(1, 15) = 16.11$, $p < .01$, with higher RTs in switch than repeat trials (1139 ms vs. 971 ms). A similar trend in the error rates did not reach significance, $F(1, 15) = 1.49$, $p = .242$ (5.1% vs. 3.8%). Moreover, a main effect of material, $F(1, 15) = 6.92$, $p < .05$, indicated that faces were responded to faster than names (1006 ms vs. 1105 ms). There was no significant interaction between material and switch in the RTs, $F < 1$, or error rates, $F < 1$.

Retrieval: RT Effects of Retrieval Switching

In a next step, the basic effects of retrieval switching on RTs in the retrieval phase was assessed. As the trials were grouped in miniblocks during retrieval, this analysis focusses on the RTs separately for the different positions within the miniblocks. It would be expected that the effect of switching is most pronounced in the first trial of a switch-miniblock, and that RTs become more similar to those of repeat-miniblocks in subsequent trials (Rogers & Monsell, 1995; Yeung, et al., 2006).

An ANOVA that assessed the RT during retrieval as a function of whether the retrieval-orientation task was repeated or had changed compared to the previous miniblock (retrieval repeat vs. switch) and the position within the miniblock (first, second, or third item within the miniblock) revealed the following effects (see Figure 5.4). The main effect of retrieval switch, $F(1, 15) = 22.68$, $p < .01$, as well as the main effect of position within the miniblock, $F(2, 30) = 13.79$, $\varepsilon = .566$, $p < .01$, were significant. These main effects were further qualified by an interaction, $F(2, 30) = 19.24$, $p < .01$. Separate ANOVAs for switch and repeat miniblocks revealed no significant effect of position in repeat trials, $F < 1$, with comparable RTs at all three positions within the miniblock. The ANOVA on the switch trials, however, revealed a significant effects of position, $F(2, 30) = 23.68$, $p < .01$, with a significant linear trend, $F(1, 15) = 24.95$, $p < .01$, indicating that RTs decreased with increasing position within the miniblock. Accordingly, a clear switch effect on the RTs in the memory test was seen, and this effect was most pronounced in the first trial. RTs of subsequent trials within the retrieval switch miniblocks decreased and became more comparable to RTs in repeat trials, as would be expected with increasing repetition of the same task within the miniblock.

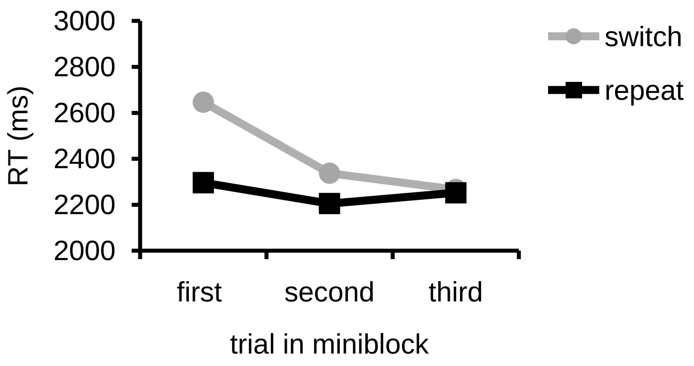


Figure 5.4: RT in the retrieval phase dependent on the trial number within the miniblock separately for retrieval switch and repeat trials in Experiment 8.

Comparison between Task Switching and Retrieval Switching

Given that both encoding switching and retrieval switching caused significant RT-costs, in a next step I wanted to assess the relationship between switch costs during encoding and switch costs during retrieval. If task switching and switching in memory rely on similar processes, it would be expected that switch costs in the task-switching phase of the experiment and switch costs in the retrieval task would be correlated. For this reason, a correlation was calculated between the mean switch costs in task switching and switching in memory across participants.

Switch costs in task switching were calculated as the difference in RT between switch and repeat trials. For the switch cost in the memory phase the difference in RT to the first trial in switch and repeat miniblocks was calculated. A Pearson correlation revealed that there was no significant correlation between switch costs in memory and task-switching, r = .027, p = .921. However, inspection of Figure 5.5 makes clear that there was a strong outlier in the dataset, whose task switching cost and memory switch cost both fell >2 *SD* away from the mean of the group as a whole, whereas all other participants' data fell within this boundary. When this outlying participant was excluded from the analysis, the correlation reached significance, r = .578, p < .05. Thus, participants that showed a strong effect of switching in task switching also were affected by switching in the memory test to a stronger degree.

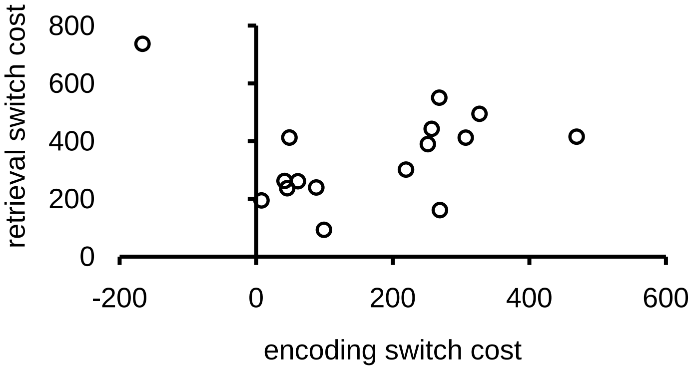


Figure 5.5: Scatterplot of switch costs in encoding (x-axis) and retrieval (y-axis) for all 16 participants in Experiment 8.

Retrieval: Memory Ratings

The next analysis assessed how successfully participants were able to switch between different retrieval orientations (ROs). The dependent variable in this analysis was the memory rating that participants gave to each item. The first factor included in the analysis was retrieval-orientation match (RO-match vs. RO-non-match), which described whether a particular person had appeared in the currently task-relevant format (face or name) during encoding. For example, if a person's name was presented during task switching, and the participant is presented with this person when doing the name task in the memory test, this would be an RO-match trial. If the participant was performing the face task in the memory test, this stimulus would be a RO-non-match trial. Thus, RO-match indicates the rating an item should receive (6 or 1 respectively, for the examples given). The variable physical match (match vs. non-match) described whether a person was presented in the same way (face or name) during task switching and in the memory test. The variable RO-task described the task participants were conducting in the memory test, that is, whether the coloured cue frame indicated that faces (face task) or names (name task) were the currently task-relevant material. The variable encoding switch indicated whether participants performed a switch or a repeat trial when they were presented with a person in the task-switching encoding phase of the study. Retrieval switch similarly indicated whether participants repeated or switched the task with regards to the previous miniblock in the memory test. Lastly, the variable attention (attended vs. unattended) described whether an item was attended or ignored during the task switching encoding phase.

Overall Performance in the Memory Test

Memory ratings were significantly higher for old items presented in the matching RO (mean memory rating “RO-match” $M = 3.42$, $SE = 0.92$), than old items presented in the non-matching RO (mean memory rating “RO-non-match” $M = 2.83$, $SE = 0.11$), $t(15) = -9.60$, $p < .01$, indicating that participants were able to adopt the relevant RO. Old items presented in the non-matching RO were, however, still rated higher than new items ($M = 2.56$, $SE = 0.14$), $t(15) = -3.83$, $p < .01$, suggesting that participants were sometimes distracted by old items that had previously been presented in the currently irrelevant format.

In the analyses described below, only old items were included (i.e., items that were presented during task switching). In these analyses, the effects of RO and its interactions with other variables are assessed in more detail. Given that there were six variables of interest (RO-match, physical match, RO-task, encoding switch, retrieval switch, and attention), resulting in 64 conditions, the data was entered in two separate ANOVAs to allow for adequate cell sizes. Both ANOVAs contained the variables RO-match, physical match, encoding switch, and retrieval switch. The first ANOVA additionally included the variable RO-task, and the second ANOVA the variable attention.

Retrieval Orientation: Switching Effects at Encoding and Retrieval

The first ANOVA assessed how the RO-effect was modulated by switching between retrieval tasks (variable retrieval switch). This analysis tested the key prediction that performance in switch trials should be associated with less selective memory ratings compared to performance in repeat trials. It was furthermore expected that effects of RO would be modulated by the correspondence of presentation between task-switching and memory test (i.e., physical match): If a stimulus is presented in the memory test the same way as during task switching (e.g., as a face on both occasion), the retrieval task might be expected to be relatively easy and, thus, the effects of RO stronger.

The ANOVA included the following variables: RO-match (old item is presented in the matching/task relevant vs. non-matching/task-irrelevant format), physical match (person is presented in the same format as during task switching vs. person is presented in a different format than during task switching), RO-task (remember persons seen as faces vs. persons seen as names), encoding switch (repeat vs. switch trial during encoding) and retrieval switching (repeat vs. switch miniblock during retrieval). This analysis revealed a significant main effect of RO-match, $F(1, 15) = 62.28$, $p < .001$: Persons that were seen in the currently task-relevant format during task switching received higher memory ratings than persons previously presented in the format that is not currently task relevant (3.45 vs. 2.88). Moreover, a main effect of physical match, $F(1, 15) = 8.39$, $p < .05$, indicated that persons presented in the same physical format as during task-switching received higher memory scores than persons presented in a different way (mean memory ratings of 3.22 vs. 3.12).

Critically, the interaction between RO-match and retrieval switch also reached significance, $F(1, 15) = 11.11$, $p < .01$, indicating that participants performed better in repeat than switch miniblocks (Figure 5.6). Descriptively, in switch miniblocks there was a decline in the ratings to RO-match items (i.e., hits) and an increase in ratings to RO-non-match items (similar to false alarms to old items), consistent with the prediction that switching between memory tasks should induce a behavioural cost in the form of reduced selectivity. There was a significant difference between RO-match and RO-non-match retrieval-repeat trials, *t*(15) = -6.87, *p* < .01, as well as between RO-match and RO-non-match retrieval-switch trials, *t*(15) = -5.83, *p* < .01, indicating that participants were still able to perform the task in switch trials. Moreover, there was a marginal difference between RO-non-match retrieval-switch and retrieval-repeat trials, *t*(15) = -2.08, *p* = .055). A numerically opposite trend for the RO-match trials did not reach significance, *t* < 1. Thus, switching during retrieval reduced the selectivity of processing, similar to the effect of switching in the encoding phase. The marginal effect on the RO-non-match items indicated that this interaction might be driven by interference from the currently irrelevant retrieval orientation.

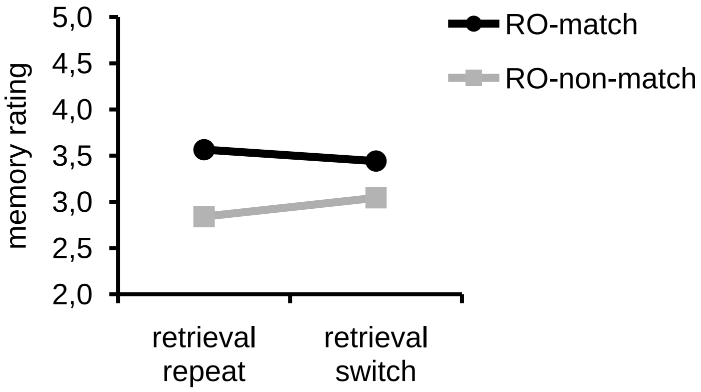


Figure 5.6. Memory ratings for retrieval-orientation match and non-match items presented in repeat and switch miniblocks in Experiment 8.

The ANOVA also revealed a reliable two way-interaction between RO-match and physical match, *F*(1, 15) = 25.68, *p* < .001, qualified by a three-way interaction between physical match, RO-match, and RO-task, *F*(1, 15) = 4.88, *p* < .05. Surprisingly, the RO-effect was weaker, not stronger, when there was a physical match between the items appearing during task switching and later memory retrieval, evident in a numerically smaller difference between RO-match and RO-non-match items in physical match than physical non-match trials (Figure 5.7). The three-way interaction indicated that this unexpected result was stronger in the face- than the name-task trials. One possible interpretation of this effect is that even if a participant is familiar with an item, they might not confidently attribute this sense of familiarity to the correct source (see Discussion). In particular, participants might have a high sense of familiarity to a physically matching stimulus, which appears to overwhelm their decision in the RO-task, such that participants are unable to attribute the source of this familiarity to having seen a person during task-switching.

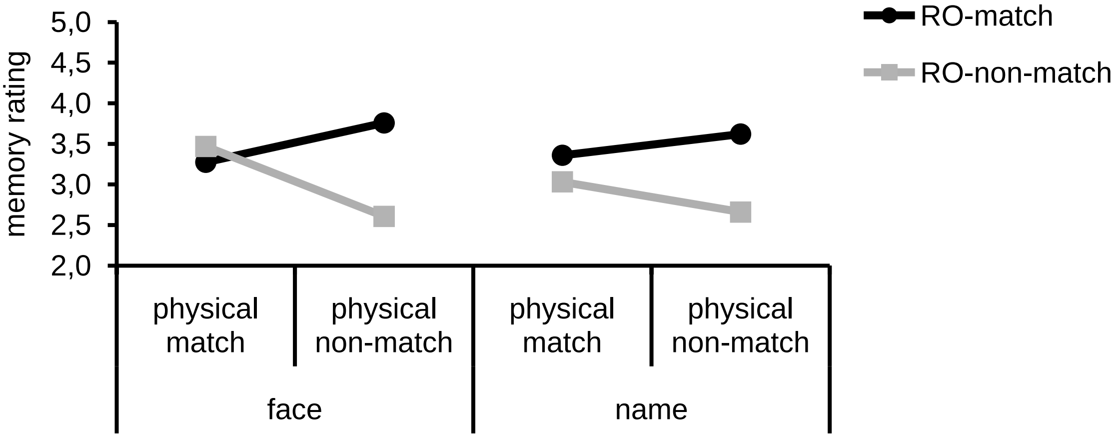


Figure 5.7. Memory ratings for retrieval-orientation match and non-match items separately for physical match and physical non-match items and the retrieval-orientation name and face tasks in Experiment 8.

Retrieval Orientation: Effects of Attention at Encoding

The final analysis assessed how attention during encoding modulates retrieval orientation performance. Specifically, it was expected that attended items would show larger RO-effects (larger difference between RO-match and non-match items). An ANOVA was conducted with variables: RO-match, physical match, attention (attended or unattended during task switching), encoding switch, and retrieval switch. In addition to effects already presented, this ANOVA revealed a main effect of attention, $F(1, 15)$ =

57.39, *p* < .01, which indicated that attended stimuli received on average higher ratings than unattended stimuli (mean memory ratings of 3.39 vs. 2.89). Importantly, this main effect was further qualified by an interaction with RO-match, *F*(1, 15) = 27.53, *p* < .01, indicating better RO-performance for attended items (*Figure 5.8*). Nevertheless, there was a significant difference between RO-match and non-match ratings for both attended, *t*(15) = -7.78, *p* < .01, and unattended items, *t*(15) = -3.19, *p* < .01. Thus, participants performed overall better on attended items, as would be expected, but were still able to perform the RO-task on unattended items.

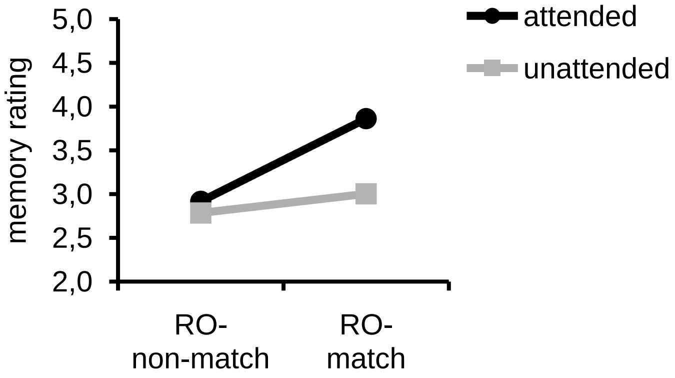


Figure 5.8. Memory ratings for attended and unattended items separately for RO-non-match and RO-match trials in Experiment 8.

Moreover, a four-way interaction between physical match, RO-match, attention and encoding switch, *F*(1, 15) = 5.01, *p* < .05, reached significance (Figure 5.9). This complex interaction indicated that memory ratings were influenced by attention and physical match only for RO-match trials (right hand parts of Figure 5.9) and that, for this sub-set of trials, attention during encoding had different effects as a function of whether a physical match existed between the items appearing at encoding and retrieval. On physical non-match trials (rightmost points in Figure 5.9), there was a numerically greater difference in memory ratings for attended than unattended items when the encoding task repeated than when it switched, *F*(1, 15) = 3.94, *p* = .066. This result is notable as it is a conceptual replication of the main result reported throughout this thesis: Memory was less selective when the task switched at encoding than when it repeated. On physical match trials, in contrast, no such interaction between attention and switching was observed, $F < 1$. This result provides further evidence of the way in which, in this experiment, participants' ability to perform a RO-discrimination was disrupted by the existence of a physical match between the stimulus seen at encoding and the memory-cue seen at retrieval.

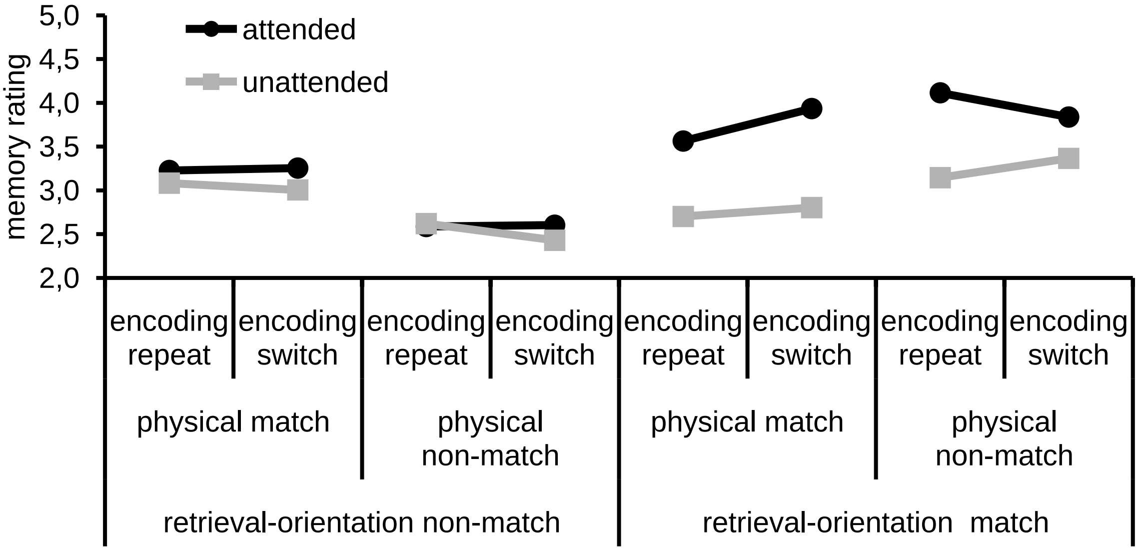


Figure 5.9: Memory ratings for attended and unattended persons separately for encoding repeat and switch trials, retrieval-orientation match (match vs. non-match), and physical match (match vs. non-match) conditions in Experiment 8.

5.2.3 Discussion

The current experiment extended the paradigm originally introduced in this thesis by also investigating switching during memory retrieval. There were several objectives for the current experiment. The first was to develop a paradigm in which retrieval-orientation effects could be robustly observed, so that switching between task sets and memory sets could be studied side-by-side. Moreover, and most importantly, the experiment aimed to assess whether switching between memory tasks would be associated with a reduced selectivity in processing, similar to the effects observed for memory encoding in previous experiments.

The memory data showed clear effects of retrieval orientation. Items presented in the format that was relevant for the current retrieval orientation task received higher memory ratings than new items or items presented in the irrelevant task. Thus, participants were able to flexibly switch between the different retrieval-orientation tasks. This basic finding provided the foundation for further investigation of the effects of switching between the relevant orientations during memory retrieval. First, there was a significant correlation in switch costs during task switching and retrieval-set switching across participants when a participant with outlying data was excluded. This result provided initial support for the claim that task and memory switching rely on similar processes.

Importantly, the predicted effect of switching during retrieval on performance in the retrieval-orientation-based memory test was also found in the memory data. This finding indicated that participants were less able to decide whether they had seen a person in the task-relevant format or not in retrieval switch trials, suggesting that switching during memory retrieval was also associated with a decreased selectivity in processing, similar to switching during the encoding phase.

Evidence for switch effects on accuracy in retrieval orientation studies has so far been weak, with several studies reporting no effect at all (Herron & Wilding, 2004, 2006b; Wilding & Nobre, 2001), or only selective effects in either hit rates (Herron & Wilding, 2006a), or correct rejections, but in this case only in one of two tasks (Johnson & Rugg, 2006). Studies that have used the Pr index (Snodgrass & Corwin, 1988) have not been able to investigate the source of the switch cost because they have measured false alarms for new items (Benoit, et al., 2009), or as a mixture of new and old items (Werkle-Bergner, et al., 2005), and thus were not able to relate these performance decrements to a lack in selective task processing. The current study therefore provides novel evidence that the selectivity of memory retrieval is affected when retrieval orientations are switched. This finding suggests that participants did not effectively select the memory task that was currently relevant following a retrieval-orientation switch. In this way, the current results also suggest some striking parallels to the previous work presented in this thesis: the selectivity of processing is the key factor in successful task performance, whether in task-switching, encoding, or retrieval. Thus, the current study provides important support for the idea that retrieval switching is associated with very similar mechanisms as standard task switching.

Perhaps consistent with the idea that previous studies lacked the sensitivity to detect switching effects on retrieval orientation, switching has recently been shown to affect the accuracy of source memory judgments but not old/new judgments in a recent study: Wilckens et al. (2011) conducted two experiments. In the first, participants were required to make recognition old/new judgments in an episodic task that was intermixed with a semantic task. In the second experiment, participants switched between two episodic source retrieval tasks in which they either indicated the memory source (location or task during encoding) or indicated that an item was new. The authors found no effect of switching in the first experiment in which only an old/new judgment was required. In the second experiment, however, they detected decreased hit rates (correct source judgments) in switch trials. This experiment thus indicates that switching can affect source accuracy judgments, which might be more sensitive to the manipulation of switching than the simple old/new decisions. The current study extends the findings reported by Wilckens et al. (2011), by demonstrating specifically that the selectivity of processing is affected.

Several other interesting effects extended the results of the current study. Participants show larger retrieval-orientation effects to attended than unattended information, indicating that attention during encoding improves performance in later retrieval-orientation tasks (cf. Rock & Gutman, 1981).

An unexpected finding was that items that were presented differently in the encoding and retrieval phase (physical non-match) were actually associated with better performance in the retrieval-orientation tasks than physically matching items. A possible explanation for this surprising effect is that when presented with a retrieval cue in the same format as during encoding (physical match), the current presentation “overrides” the memory of the previous presentation. These interpretations are connected to ideas of source monitoring that suggest that participants sometimes accurately recognize an item, but fail to correctly attribute its source, particularly when differences in context were limited (Johnson, Hashtroudi, & Lindsay, 1993). Here contextual differences of all items were limited, as the presentation of the stimuli in task switching and the memory test was similar (persons were presented in front of a grey background with a coloured frame surrounding them). The finding that this effect appeared to be stronger for the face task might be due to the fact that faces could generally exhibit more perceptual detail than names.

To conclude, the current experiment successfully demonstrated an effect of switching on memory performance, in both RTs and accuracy of the memory response. The underlying effects seemed to be similar to those of previous studies in this thesis: a decrease in the selectiveness of processing was evident as a less selective rating of retrieval-orientation match and non-match items. Moreover, a relationship was apparent between the costs of switching during encoding and in the later memory retrieval phase, at least when the outlying data of one participant were excluded. These findings provide support for the hypothesis that similar processes are involved in the switching between retrieval orientations as in traditional task switching. Methodological, the present findings suggest that the paradigm introduced here provides a stable method with which task switching and retrieval switching can be studied in the same participants.

5.3 General Discussion

Collectively, the results presented in this chapter demonstrate that the strong conceptual overlap between task sets and retrieval sets can be substantiated when both are compared more directly. The neuroimaging meta-analysis indicated that overlapping brain regions are activated in fMRI studies of task switching and of retrieval orientation. These findings suggest substantial overlap on the neural level. The behavioural experiment presented in this chapter provided further support indicating the strong parallels between task switching and switching between retrieval sets. Task switching and switching between retrieval sets resulted in significant behavioural costs in the RTs, replicating previous findings. Moreover, participants’ switch costs in the task switching and the memory part of the study were correlated when an outlying participant was excluded, suggesting that performance differences between participants in task switching and memory switching may reflect similar processes. In particular, the results demonstrate that switching between retrieval tasks reduces the accuracy of memory retrieval, crucially by reducing selectivity of memory. In this way, the findings in the current chapter align closely with the research presented in previous chapters suggesting that the selectivity of processing is a key factor in successful task and memory performance.

The decrease in selectivity in the memory ratings with switching during retrieval is likely due to similar processes as the corresponding effect of task switching. In earlier chapters, the finding of reduced selectivity of processing in switch trials was taken as evidence for increased between-task interference. In the task-switching literature, it has been argued that this interference is the result of biases in stimulus-response associations from the previously relevant task set (cf. Waszak, et al., 2003), such that stimuli to some degree still cue the response associated with the previously relevant task. One possibility is that something similar is happening here: Stimuli in the memory test might activate response rules associated with a specific, but no longer relevant, retrieval task, and control is needed to counteract this bias. In this sense, biased competition/guided activation theories (Desimone & Duncan, 1995; Miller & Cohen, 2001) could also be applied to the domain of memory retrieval (cf. Levy & Anderson, 2002; Miller & Cohen, 2001). Thus, the current studies suggest that between-task interference might also be of relevance for memory retrieval. This finding is moreover consistent with previous research that has demonstrated interference from irrelevant associated single *items* in memory retrieval (Anderson, et al., 1994). However, the present findings extend these ideas by providing evidence that interference similarly operates at the level of tasks in memory retrieval.

The findings presented here have important implications for research on cognitive control and memory. The task-switching literature must incorporate the concept of retrieval sets into the general discussion about mental sets that allow task performance. Task sets need to incorporate the idea of mental representation of information in addition to externally presented stimulus-material, and tasks need to be extended to include memory tasks. Related to this, the results of the meta-analysis suggest that some of the interpretations of regional brain activity associated with task switching need to be extended significantly. For example, the role of the SPL has been described as a region responsible for “stimulus-response remappings”. However, activation of this region in retrieval switching suggests that it might be more adequately described as a region associated with “external or internal representation-response remapping”.

Task-switching research might also benefit from the methods used in retrieval set studies: Retrieval switching studies have focussed on material-specific differences to explore the establishment of material-specific retrieval sets. Material-specific differences are rarely discussed in the task-switching literature (but see e.g., Yeung, et al., 2006). Studying task-specific processes could be used to address questions about the nature of conflict in the task-switching design: Studying task-specific activation could be helpful in addressing questions about the factors that influence task strength, and how conflict between tasks is resolved. This approach could address major questions in the task-switching literature with a different method to traditional task-switching analyses, which typically focus on the difference between switch and repeat trials. Moreover, the nature of the task sets themselves can be addressed. How are task sets established in the brain, how are stable task sets implemented when the task is switched or repeated, and what are the neural sources of effects such as passive decay of task sets, or asymmetrical switch costs?

Similarly, research on memory retrieval can benefit from research and theories in task-switching. Concepts developed in the field of task switching likely apply to questions in memory research as well. For example, task-switching research has a rich tradition in studying how task sets are controlled, and how costs of switching between tasks can be reduced. Such research questions also apply to memory research, where the successful control of memory may rely on similar processes. Investigations of questions regarding the stability of retrieval sets (e.g., Herron & Wilding, 2006b; Wilding & Nobre, 2001), interactions between retrieval sets of different strength (cf. Benoit, et al., 2009), as well as variables that influence this stability, will also benefit the understanding of control processes in memory. As outlined in the discussion of the meta-analysis results, this integration of task-switching and memory results might require the adaptation of some of the ideas, such as the definition of stimulus-sets and stimulus-response mappings, discussed in the control literature to the memory domain. In the past, however, other concepts of control have been applied successfully to different domains such as task switching and memory (e.g., the idea of inhibition, Anderson & Spellman, 1995), indicating that this explanation of the results of both fields in an integrated theory should be possible.

Chapter 6:

General Discussion

The research presented in this thesis addresses the complex relationship between cognitive control and memory. The current chapter will tie together the findings and their theoretical implications, while also considering limitations of the research presented. The first section of this chapter will summarize the experimental findings presented in the preceding chapters and will explore how these findings can help to answer the research questions outlined in the introduction. This section will also discuss possible limitations of this research. In the next section, I will explore the implications of the experimental findings for theories of cognitive control and memory. Finally, I will discuss potentially important avenues for future research.

6.1 The Control of Task Sets and Long-Term Memory

6.1.1 Experimental Findings

The work presented in this thesis addressed a number of questions regarding the relationship between cognitive control and memory. The overall goal of the research presented in the different chapters was to investigate how control processes lead to effective task performance and successful later memory by studying how control and memory interact. Moreover, it was explored how studying memory can inform our understanding of cognitive control. These questions were investigated by combining task-switching paradigms, traditionally used to study executive processes in the cognitive control literature, with recognition memory tests.

Chapter 2 of this thesis documented the development of the main paradigm used to study the relationship between cognitive control and memory, and thus provided the methodological foundations for subsequent experiments. The research in this chapter explored how switching between two tasks affected later memory for items encountered during this switching phase. The rationale for the experiments conducted here was that, if control and memory are strongly intertwined, it should be possible to explore the nature of the relationship between cognitive control and memory by studying them in a combined paradigm. The key methodological aspect was the use of compound stimuli, comprised of a superimposed word and object: Using these stimuli made it possible to assess separately the processing and memory of attended and unattended information in all subsequent analyses.

The research in Chapter 2 demonstrated that switching during the earlier task-switching phase resulted in less selective memory in the later recognition test. This result provided evidence for theories of task switching and memory that argue that the relationship between the processing of task-relevant and task-irrelevant information is a key factor in successful task performance and memory (cf. Allport, et al., 1994; Uncapher & Wagner, 2009). The findings do not support theories that argue that switch costs are the result of unfinished time- and resource-consuming reconfiguration processes that are specifically necessary in switch trials (Rubinstein, et al., 2001), and theories that argue that switching tasks should limit resources available for memory and thus should decrease the amount of information encoded (cf. Otten & Rugg, 2001b; Reynolds, et al., 2004). Further exploration of this effect showed that it was possible to use later memory selectivity as a measure of performance during earlier task switching. This observation indicated that later memory was directly related to earlier task-switching performance, and provided some evidence that selective processing improved earlier task switching.

In a further analysis, I was able to demonstrate that a similar effect on task-switching performance could be measured if the salience of the stimulus material was considered. This effect of salience indicated that bottom-up processes also affected performance. Importantly, partialling out the effects of salience from the memory selectivity scores did not affect the significance of the memory selectivity effect: Thus, it seemed that memory selectivity was at least partly independent of the bottom-up salience effects and is therefore driven by other bottom-up or top-down factors. An interesting aspect of the analysis of the memory-selectivity and salience data was that the relationship between later memory and earlier task performance was only evident in switch trials. This finding indicated that the stable establishment of task sets (cf. Dreisbach & Haider, 2008) can counteract negative effects associated with later low memory selectivity and adverse effects of stimulus salience.

In Experiments 1 and 2 presented in Chapter 2, the effect of control was, however, only assessed indirectly by assessing the effect of fluctuations of control across trials. If the interpretation of results in Chapter 2 were valid, and top-down control indeed results in increased selectivity of memory encoding, then it should be possible to induce systematic differences in task performance and later memory by varying the degree to which participants employed top-down control. This was the goal of the experiments of Chapter 3.

Three methods were used to influence top-down control in Chapter 3. Manipulation of preparation time (by varying the cue-stimulus interval, CSI) was chosen because variations in preparation time are one of the best documented manipulations of top-down control in task-switching research. The voluntary task-switching manipulation introduced a motivational component, and furthermore enabled the study of interesting questions regarding the nature of task control in voluntary task-switching paradigms. Lastly, the reward condition was the most control-demanding of all three conditions, and therefore was the most thorough test of the question whether enhanced use of top-down control induces competition between task control and encoding.

The key finding of this chapter was that manipulations of top-down control during encoding that were associated with performance improvements in task switching were also reflected in later memory. Importantly, increases in task control improved encoding by increasing selectivity, not overall memory, and the effects of control during task switching were mirrored in parallel improvements in memory: When the manipulation of top-down control improved switch and repeat trial performance to a similar degree during task switching, this improvement was reflected in the recognition test in increased memory for attended information, but no interaction with switching (as in Experiment 3 in which preparation time was varied, as well as Experiment 4 in which voluntary and instructed switching were compared). If the manipulation of top-down control instead reduced the switch cost, as was the case in the Experiment 5 (reward manipulation), an interaction with switching was also found in memory (although here only after an outlying participant was excluded). Importantly, the manipulations of top-down control, similar to the fluctuations of top-down control investigated in Chapter 2, always affected the selectivity of processing – never overall memory. Thus, the results of Chapter 3 extended the findings of Chapter 2 in important ways, by demonstrating that variations in control can simultaneously influence the success of task performance as well as memory.

Whereas Chapters 2 and 3 provided behavioural evidence for the close relationship between cognitive control and memory, Chapter 4 investigated the neural correlates of this relationship. In published studies, there is notable evidence for ERP correlates of successful task preparation and successful memory encoding – both preparatory and stimulus-related – but to date little direct comparison between the two. As successful task performance and memory encoding were associated with each other in previous experiments, it is plausible that they might rely on similar neural mechanisms. For this reason, the EEG correlates of switching and selective encoding (evaluated with the measure of memory selectivity) were compared.

The results of the EEG experiment demonstrated notable similarities between preparation effects in the task-switching paradigm and (although somewhat weaker) preparation effects associated with memory selectivity. These effects of memory selectivity and switching resembled each other in topographies and timing, suggesting that they may be the result of similar underlying mechanisms.

Another main analysis concerned the nature of subsequent memory effects. Here the question was whether frontal subsequent memory effects associated with elaborative encoding tasks reflect selective encoding or general encoding success. To answer this question, two potential measures of subsequent memory were explored. One assessed later overall memory for the information presented in each trial (i.e., combined memory for attended and unattended information, global memory); the other used the memory selectivity measure. The EEG analysis revealed that memory selectivity and global memory displayed fronto-central and central topographies in the stimulus-locked data, similar to effects found in earlier subsequent memory studies. Importantly, only increased selectivity was associated with significant frontal subsequent memory effects, suggesting that previously-measured frontal subsequent memory effects might be at least in part driven by selective encoding processes. The dissociation of the EEG results was consistent with the behavioural data of both experiments, which indicated that the measures of memory selectivity and global memory were not correlated, and were differentially related to task performance: Whereas memory selectivity predicted earlier task performance in switch trials, global memory did not show an association with earlier task performance.

This chapter additionally addressed the question whether variations in the selectivity of processing associated with switching that were described in previous chapters could be replicated when the switching requirements were simplified. The behavioural data of Chapter 4 demonstrated that the effects found in the earlier experiments were not dependent on the combined switching of the classification rule and the attended material. The interaction between attention and switching was replicated when only visual attention between stimulus features was switched across trials.

The final experimental chapter extended the theoretical and methodological approach of research presented in previous chapters. Whereas earlier chapters investigated switching during memory encoding, Chapter 5 additionally assessed switching during memory retrieval. Two approaches were chosen to explore the relationship between mental sets in memory and cognitive control. First, ALE meta-analysis was conducted on published fMRI studies of task switching and studies investigating retrieval sets. The results of this meta-analysis demonstrated that areas activated in studies of retrieval set overlapped substantially with those activated in studies of task switching. Crucially, activity overlapped in key regions identified to be relevant for task switching in imaging studies, the inferior frontal junction and superior parietal lobe. This was a striking finding given the smaller number and larger diversity of studies that investigated retrieval sets. Therefore, the results of this meta-analysis provided some initial evidence of the overlap in neural correlates associated with studies of task sets and retrieval sets.

Second, Experiment 8 studied task switching and retrieval switching in one paradigm in the same participants. The main methodological difference from the experiments presented in previous chapters was that participants switched between tasks not only in the task-switching encoding phase but also in the memory-retrieval phase. The manipulation of retrieval orientation was successful in the behavioural experiment, evident in the finding that participants successfully distinguished between the two retrieval tasks in their memory ratings. The findings also showed that switching between two different retrieval tasks affected the RTs as well as accuracy. Importantly, the latter was reflected in a reduced selectivity of processing during retrieval. This reduction in selective processing with a switch was similar to what was shown for task switching and encoding processes in earlier chapters. Moreover, there was also a significant correlation across participants between task-switching costs and retrieval switching-costs when an outlying participant was excluded, suggesting the possible involvement of similar mechanisms in task switching and retrieval switching.

6.1.2 Limitations

The preceding section summarises the results of the experiments presented in this thesis. Before considering the theoretical implications of this research, notable weaknesses and limitations of this research should be acknowledged.

A first limitation is that the current design leaves open two possible interpretations of the interaction between attention and switching, due to the fact that the unattended material was always relevant in the preceding trial. The interpretation given throughout this thesis has been that unattended information is processed more in switch trials because it was relevant on the previous trial, an interpretation based on between-task interference accounts of the switch cost (Allport, et al., 1994). It is possible, however, that in switch trials any kind of irrelevant information is processed to a larger extent as control has to be reoriented and is not as strongly focused on relevant information. That is, participants could encode the unattended information better in switch trials because the switch caused them to focus control less effectively towards relevant information, so that spare cognitive resources were directed in a non-discriminatory way to any other information (cf. Lavie, et al., 2004). The difference between these two interpretations is that one suggests that unattended information is processed because it was relevant in the previous trial, while the latter interpretation suggests an indiscriminate encoding of any available information. A way to address this issue in future research would be to include a third material type: If information is encoded because it was relevant before, only unattended information that was relevant in the previous trial should lead to an increase in memory, whereas currently unattended information that was also not relevant in the previous trial should not show this effect. Importantly, recent research provides support for the interpretation given throughout the current thesis, that processing of unattended material depends on its recent task relevance. A recent eye-tracking study found that participants biased their spatial attention on previously relevant information, but not a third material type that was irrelevant in the previous trial, when the tasks switched compared to repeated (Longman, et al., 2012). Nevertheless, it still needs to be demonstrated that the same holds true for memory effects.

It is also important to keep in mind the generalizability of conclusions drawn from the experiments presented here. In the case of the current thesis, variants of the same basic paradigm were used for all the experiments for reasons of comparability across studies. Therefore, it needs to be considered whether the current results would generalise to other experimental situations, such as a change in the nature of the encoding tasks, of the encoding conditions, and of the retrieval test.

First, one of the main conclusions in this thesis was that memory encoding and task performance do not compete for cognitive resources. This interpretation specifically applies to the situation when the task is performed on information that later has to be remembered. Previous research suggests that different results may be expected if the control-demanding task (e.g., identification of a change in sound pattern in an auditory discrimination task) is irrelevant for later retrieval (e.g., of simultaneously encoded visual words) (Kensinger, et al., 2003).

Second, all memory tests used here were conducted on incidentally-encoded material. Accordingly, the findings of the current thesis may not generalize to intentional encoding. Nevertheless, memory has often been shown to be comparable for incidental and intentional encoding tasks (e.g., Hyde & Jenkins, 1973). Moreover, the amount of information presented here, and the difficult task-switching paradigm that participants completed simultaneously with encoding, means that participants would have had difficulty in encoding the available information even if they had known about the later memory test. For this reason it seems that performance likely would have been similar with an intentional encoding paradigm.

Third, the research presented in the current thesis used recognition-memory tests. Previous research has shown that recall tests often show different effects on later memory compared with recognition tests (e.g., Baddeley, et al., 1984). It might be that the recognition memory test did not show decrements in overall memory, but that a recall test would show such effects. However, the design of the current experiment (large numbers of trials, use of visual information) would make it very difficult to test memory using a recall paradigm.

6.2 Theoretical Implications

There is a longstanding debate about whether control is best described as a limited resource, such that increased use of control limits our capability to do other tasks (e.g., Kahneman, 1970), or whether control is best understood as a selection mechanism

(Allport, 1987), which increases our ability to selectively focus on relevant information while ignoring irrelevant information. Throughout this thesis, I have provided evidence that the latter of the two descriptions is more adequate, by demonstrating the beneficial effect of selective processing for both task switching and memory.

In the experiments presented in this thesis, the relationship between control and memory was demonstrated by the findings that switching (associated with a less selective focussing of control) not only led to switch costs during the performance of the task, but also led to less selective encoding of information. This effect was consistently observed across Chapters 2 to 4. In fact, the nature of this interaction was not very much affected by manipulations of top-down control employed in Chapter 3 of this thesis. In this chapter, only the reward condition seemed to directly influence the selectivity of encoding in switch trials, whereas other manipulations increased the selectivity of encoding overall: Performance increased comparably for switch and repeat trials, leaving the modulation of memory for attended and unattended information in switch trials mostly unaffected. The finding that increased top-down control improved task performance and memory at the same time with parallel effects extended the findings of Chapter 2: This result indicates that variations in top-down control can influence task performance and the selectivity of encoding. This finding is in agreement with recent theories about the role of selective attention in memory, which suggest that memory is a direct result of attentional processing (Chun & Johnson, 2011). Moreover, the EEG results provided further support for the role of selective processing for memory, and demonstrated that frontal subsequent memory effects likely reflect selectivity of processing during the encoding phase, consistent with theories that propose a similar neural basis for mechanisms of attention and memory (e.g., Cabeza, et al., 2008; Cabeza et al., 2003).

The modulation of later memory by switching during encoding was replicated even with simplified switch requirements, when only attention was shifted but the classification rule remained the same (Chapter 4). Thus, cognitive control, operationalized here as visual selective attention, affects selectivity of encoding, supporting the interpretations made for earlier chapters. Moreover, the results of the experiments in Chapter 4 indicated that more closely overlapping tasks and stimulus-response mappings still did not lead to an effect of memory selectivity on repeat trials. This result demonstrated the robustness of repeat-trial performance against detrimental effects that lead to a decrease in later memory selectivity, consistent with a suggested shielding function of task sets (cf. Dreisbach & Haider, 2008).

Lastly, a similar effect of reduced selectivity of control was seen in the retrieval phase of Experiment 8: Here, switching again reduced the selectivity of memory ratings to task relevant and irrelevant items. This result indicates that ideas relating to the selectivity of processing also extend to the retrieval phase, where selective attention or other cognitive control processes are required to select between different memory tasks as well as relevant stimuli in memory (e.g., Cabeza et al., 2011; Ciaramelli, Grady, Levine, Ween, & Moscovitch, 2010; Kuhl, Kahn, Dudukovic, & Wagner, 2005).

6.2.1 Implications for Research on Memory

The findings of Chapter 2 have important implications for theories of memory. The results suggest that there is no competition between control processes attributed to the performance of a current task and the simultaneous encoding of memories, in contrast to what has previously been suggested (Otten & Rugg, 2001b; Reynolds, et al., 2004). Instead, the findings from Chapter 2 suggest that, rather than limiting resources when control is exerted to a task during encoding, these control processes serve to select relevant information, resulting in increased task performance and selectivity of memory.

The findings of Experiment 5, in which top-down control was manipulated by introducing reward, extended these results by providing crucial evidence that controlled, focussed task performance increased selectivity of memory even under highly demanding situations. This result implies that detrimental effects of dual-task performance on encoding when participants perform a difficult compared to an easy secondary task (Kensinger, et al., 2003; see also Uncapher & Rugg, 2005), are likely due to the fact that the material of the secondary task was not relevant for the later memory test. Accordingly, encoding seems to be only affected by demanding task conditions when increased control demands are focussed on material that is not relevant for the encoding task, underlining the importance of selective processing for memory encoding.

These findings were further supported by the EEG experiment presented in Chapter 4. The EEG data suggested that frontal subsequent memory effects may reflect selective encoding, rather than overall encoding success. These EEG results are consistent with accounts that emphasize the importance of selective attention for later memory (Chun & Johnson, 2011; Uncapher & Rugg, 2009). The implications of this experiment are therefore that we can obtain a better understanding of the neural correlates of memory by exploring the nature of subsequent memory effects in more detail by including an analysis of unattended information.

The results of Experiment 8 extended the findings of previous experiments by showing that switching during memory retrieval was also associated with both RT and accuracy costs, similar to standard task switching. This finding demonstrated the importance of selective processing during retrieval. The correlation between encoding switch costs and retrieval switch costs (when an outlying participant was excluded) furthermore provided some indication that the similar processes may be underlying switch costs in both contexts.

To successfully incorporate memory sets and task sets into an integrative theory about the control of task-processing and retrieval processing, it seems likely that research in both fields needs to be extended to include questions that they have not traditionally addressed: Research on retrieval orientation needs to incorporate questions regarding the control of retrieval sets to a larger degree. Research on retrieval sets has already started to extend the early research that focussed on differences between different retrieval sets, to include questions of the control and stability of retrieval sets (Herron & Wilding, 2006b; Johnson & Rugg, 2006; Wilckens, et al., 2011; Wilding & Nobre, 2001). In this context, it has for example been investigated how the stability of retrieval sets is affected by frequency of switches (Herron & Wilding, 2006b; Wilding & Nobre, 2001), or how memory tasks of different strength interact (Benoit, et al., 2009). This research suggests that applying research methods and strategies from the task-switching literature to the domain of memory can provide valuable information about successful memory retrieval. Extending this approach, research could investigate the factors that hinder or support the establishment of a memory set, and how memory sets are influenced by other factors that are known to affect task-switching performance, such as preparation time, the build-up of associations between stimuli and responses, or manipulations of bottom-up and top-down attentional processes.

6.2.2 Implications for Research on Cognitive Control

The results of the current thesis also have important implications for the literature on cognitive control. The findings of the second chapter provide valuable insight into the nature of control itself. The discussion between resource-limitations accounts and theories focussing on the selectivity of processing is reflected in a parallel discussion between reconfiguration views (Rubinstein, et al., 2001) and interference accounts (Allport, et al.,

1994) in the task-switching literature. The findings of Chapter 2 suggest that interference might be the more appropriate explanation for the switch costs: increased processing of irrelevant and decreased processing of relevant information in switch trials seems to be more consistent with interference between the tasks than with resource-demanding reconfiguration processes. Moreover, the association between task performance in switch trials and memory selectivity suggests that control processes can stabilize task sets sufficiently to protect them from interfering processes in repeat trials (cf. Dreisbach & Haider, 2008).

These results were extended by the findings of Experiment 3. The results of this experiment, in which CSI was manipulated, suggested that reductions in switch costs usually associated with longer preparation times can depend on the specific characteristics of the design used. Thus, CSI can improve performance overall during task switching, evident in later more selective memory for attended information associated with longer preparation time. Task preparation might therefore be comparably advantageous for switch and repeat trials under some circumstances – somewhat at odds with standard reconfiguration accounts.

Moreover, the results of Experiment 5, in which a reward manipulation was introduced, extended previous findings that suggested that reward increases the stability of cognitive control (versus the flexibility), and improves performance especially in repeat trials (e.g., Mueller, et al., 2007). The reduction of the switch costs showed that reward was particularly effective on switch trials (cf. Kleinsorge & Rinkenauer, 2012). This finding suggests a more complex relationship between reward and cognitive control: One possibility is that, rather than increasing stability as suggested before, reward increases the selectivity of processing. As switch trials were generally associated with less selective processing, evident in the reduction in selectivity of memory in switch trials, reward may have been particularly effective here.

Lastly, the results of the voluntary task-switching experiments have implications for theories of control in addition to what was described above. A debate in the recent task-switching literature has concerned whether the voluntary task-switching paradigm may provide a more direct way to assess control processes during task switching, based on the proposal that the task choice requires top-down processes (Arrington & Logan, 2004, 2005). The research presented in Experiment 4 (comparison of voluntary vs. instructed task switching) suggested that voluntary task switching may be associated with less successful allocation of top-down control and more between-task interference. This conclusion was supported by the findings of the memory test, which suggested less selective processing in the voluntary choice condition. Together, these results question the degree to which voluntary task switching is a more adequate measure of top-down control processes, consistent with suggestions in the recent literature (Demanet, et al., 2010; Mayr & Bell, 2006; Yeung, 2010).

Moreover, Experiment 4 (voluntary vs. instructed switching) provided methodological implications. One of the key challenges for future research on voluntary task switching would be to decrease the ambiguity between conflicting task sets by ensuring that task choice is completed in a sufficiently controlled manner, as to warrant that participants fully decide on a task before they indicate a task choice. If the effects of premature task choices and lack of commitment to the task are controlled for, as well as making sure that timing between conditions remains comparable, the voluntary task-switching paradigm could be modified to study how voluntary choice influences control processes. These restrictions, however, might decrease the validity of the voluntary task-switching design as a measure of voluntary choice, as the resulting rigidity of the design would provide a very restricted environment for voluntary choices.

A further example for the value of studying control and memory processes in a joint paradigm was provided by the EEG data in Experiment 7. The similarity in topographies and timing between switch–specific preparation and memory selectivity effects suggests that switch costs and low memory selectivity may be caused by similar processes: deficits in the preparation phase that lead to a lack of selectivity in processing associated with switching and with low memory selectivity. Lastly, the behavioural results of Experiment 8 suggested strong similarities between retrieval switching and standard task switching, which provided some indication that the same processes may be underlying switch costs in both contexts. Together, the findings indicated the need for the task-switching literature to include the idea of memory task sets. Some concepts, such as the notion of a “response” and of “task”, can be translated fairly easily in the memory domain, and do not have to be changed at all (response) or only slightly extended (e.g., so that task can also refer to “retrieval-orientation task”). Other concepts, such as “stimuli” and “stimulus-response mappings”, may require some rethinking, because in memory research the counterpart to stimuli in task switching are often mental representations of earlier encountered items. Thus, the concept of mental stimulus representations, and associations between these representations and responses, need to be incorporated. Overall, however, the success with which other concepts of the control literate have been applied in the memory domain (e.g., the idea of inhibition, Anderson & Spellman, 1995), indicates that it should be possible to incorporate task sets and memory sets into a joint literature.

There are also implications for research methods used to study task switching. Task-switching research often mainly focuses on the differences between switch and repeat trials while mostly ignoring task- and material-specific differences (but see e.g., Yeung, et al., 2006). By investigating task-specific processes in more detail, task-switching research can likely benefit from a more exhaustive understanding of control processes: Comprehending how control influences task-specific brain activity could help to develop and test questions such as how interference from the irrelevant task can be resolved and how factors such as task strength increase interference. Measuring the strength of activation of competing tasks can likely help to assess different reasons for conflict in task-switching paradigms.

6.2.3 Comparison with Existing Theories

The starting point of this thesis was the observation of similarities discussed in the cognitive control and memory literature. One of the similarities was a parallel discussion about control being an effortful and resource demanding process versus control as a selection mechanism. The current thesis supported the latter idea: that control supports effective task performance and memory by selecting relevant information. This conclusion, and the supporting evidence, relates in important ways to existing theories of the interactions between control, attention, and memory.

One of the similarities highlighted in this thesis was the idea of selective processing in control and memory. The collected results of this thesis are consistently supportive of the hypothesis that selective processing is a critical mechanism in memory encoding. In this context, it has been argued that selective attention biases what information gets encoded, by enhancing the neural processing of this information (Uncapher & Rugg, 2009). The role of control processes in selective encoding described in this thesis fits well with the notion that memory can be described as a result, or by-product, of attentional processing during encoding, such that selective memory is the inevitable result of selective attention (Chun & Johnson, 2011). According to this view, memories are constructed as the result of attentional focussing on external information. Memory and perception are said to engage the same parietal and frontal areas, and the hippocampus binds attended information to stored memory entries. Attention is also needed to select the relevant memories again for remembering. Thus, attention is the mechanism by which memories are built and recovered (Chun, Golomb, & Turk-Browne, 2011; Chun & Johnson, 2011). The idea that attention leads to the building of memories was evident, for example, in the finding that top-down control affected task-performance and memory in a similar way. The comparison of processing of attended and unattended information in the current study extends previous research on the role of selective attention in encoding: It provides some indication of the possible mechanism underlying selective encoding, by demonstrating that the effect of less selective processing of attended stimuli co-occurs with the enhanced processing of unattended stimuli.

The findings of the current thesis also have to be distinguished from other studies of attention and memory. In divided attention accounts and dual-task studies, memory has been shown to be negatively affected by the simultaneous performance of an additional task (e.g., Fernandes & Moscovitch, 2000; Naveh-Benjamin, Craik, Perretta, et al., 2000). The current thesis indicates an important limitation to these findings. Concurrent control demands (e.g., in the current thesis due to switching, or otherwise increased need for control such as the strict criterion applied in the reward condition of Experiment 5) do not necessarily limit encoding when attention is selectively allocated to the to-be-encoded material. This fact that control demands in the current experiments were directed towards memory-relevant information was a crucial difference between current and previous research, where control demands were caused by a secondary task. An interesting question for future research would be how attended and unattended information is processed in such dual-task conditions: Is processing of attended and unattended information reduced compared to a single task condition, or is encoding selectivity reduced, similar to the findings of the current thesis?

The findings described in this thesis also fit well with the suggested role of control processes during the retrieval of memories (Cabeza, et al., 2008; Vilberg & Rugg, 2008; Wagner, et al., 2005): In the neuroimaging literature, it has been suggested that evidence of activity in parietal, attention-related regions during retrieval implies that attention is applied to memory representations during retrieval. It has been argued that attention helps to recover information that is currently relevant by focusing processing from the external world to memory representations (Cabeza, et al., 2008; Vilberg & Rugg, 2008). Alternatively, attention could be used after retrieval, potentially to direct attention towards information that has been retrieved and is currently held in working memory (Wagner, et al., 2005). While the current thesis remains agnostic to the question of the role that parietal regions play in memory, the idea that attention is used to select relevant information during retrieval is consistent with the findings of Chapter 5, which highlight the role of the selectivity of processing during memory retrieval. The finding that switching during retrieval decreases the selectivity of the memory judgments is consistent with accounts that emphasize a role of attention in memory, as switching should decrease attentional focussing.

The need for selective processing has also been discussed in the context of evidence for conflict from recalled irrelevant memories that interfere with the recall of relevant items (Jost, et al., 2012; Kuhl, et al., 2011). Here it has been suggested that selective retrieval becomes more important when increasing numbers of associations compete with each other (Anderson & Bower, 1974). Conflict in the current thesis was caused by conflicts between tasks, rather than items, but similarly led to decreases in memory performance. Accordingly, the current results align well with the previous literature, but importantly extend it by demonstrating possible mechanisms (the increase in selectivity of processing) by which attention and control support in memory. This conclusion is true for research on the role of control during encoding as well as during retrieval.

6.3 Future Directions

The research presented in this thesis has demonstrated that control and memory are intertwined in numerous and complex ways. I have tried to establish across several chapters and experiments that our understanding of both fields benefits from applying ideas from each to the other. The current thesis has used mostly behavioural and some electrophysiological methods to study the relationship between memory and attention. A next question would be whether similarities found on the behavioural level are also reflected in neural measures. The following section will review two key directions for future research in exploring correspondences and differences in the brain mechanisms of control and memory.

6.3.1 Neural correlates of task set and retrieval set

The experiment presented in Chapter 5 was built around the idea that a person has to enter a specific mental state both to perform a task (referred to as “task set”) and to retrieve a memory (referred to as “retrieval set”). Direct comparisons between task sets and retrieval sets remain rare. In particular, there is little convincing evidence for neural overlap of task switching and switching during memory retrieval, that is the similarity in patterns of neural activity between corresponding task sets in task switching and retrieval.

The behavioural research in Chapter 5 is a first step toward contrasting task sets and retrieval orientations within a single study. Moreover, the meta-analysis provided some evidence for neural overlap between the adaptation of a task set or retrieval set. The next logical step would be to contrast both types of mental sets directly using fMRI.

One way to compare brain activity between two conditions would be via the use of pattern classification algorithms such as multi-voxel pattern analysis (MVPA). MVPA has been used successfully over recent years to differentiate between “mental states” associated with the performance of specific tasks (Haynes & Rees, 2006). The underlying idea is that rather than looking at clusters of brain activity, a distributed pattern of neural activity is used to distinguish between different kinds of information currently represented in the brain. Often cross-classification techniques are used to compare neural activity associated with similar mental representations (e.g., of a specific category, such as face stimuli) in different contexts (e.g., during encoding and retrieval). For example, pattern-classification methods have been used to identify neural activity associated with the processing of faces, objects, and words during encoding, to then identify patterns associated with the same categorical information during retrieval (Polyn, Natu, Cohen, & Norman, 2005). In another study, it has been shown that the activation of different categorical information during a working-memory delay period can be identified by using a pattern-classifier trained on brain activity associated with long-term memory processing of this information (Lewis-Peacock & Postle, 2008). A similar approach could also be used to compare task sets and retrieval sets.

MVPA techniques could also be used to compare patterns of brain activity related to switching between task sets with those related to switching between retrieval sets. Specifically, for the example of Experiment 8, it would be possible to investigate similarities of brain activity in the preparation phase during task switching and during retrieval switching. In both phases, participants are presented with a cue frame and prepare either a face task (gender judgment on the face, or faces as target material for the retrieval orientation task) or a name task (gender judgment during the encoding phase, and name as the target material for the retrieval orientation task). The critical question would be whether mental sets of corresponding tasks during encoding and retrieval could be identified via cross-classification methods. Based on the assumption that task sets and retrieval sets are functionally equivalent, it should be possible to use patterns of brain activity in response to the face cue during task switching to identify preparation for the face task in the memory phase. Support for this prediction would extend previous findings of category-specific brain activity during memory encoding and retrieval (Polyn, et al., 2005), by showing that category-specific mental sets (rather than activity associated with individual items) can be identified. Reliable cross-classification performance would suggest that similar mental sets are established when preparing to perform a face task during task switching and during memory retrieval. An interesting extension to previous research that has focussed mostly on category-specific activity in temporal cortex, for example, would be whether category-specific frontal and parietal activity can be identified this way (cf. Yeung, et al., 2006). Such a result would suggest that existence of domain-specific control processes (in addition to general control processes), which have been postulated in the recent control literature (cf. Badre, 2008; Dobbins & Wagner, 2005).

6.3.2 Structure in Task Set and Retrieval Set

The research presented above focuses on control and selectivity of processing in simple laboratory tasks, but both behaviour and memory are more complex outside the laboratory. In particular, whereas laboratory tasks often require a single response or a single memory to be retrieved to each stimulus, in everyday life our actions and our memories appear to be organized according to complex sub-goals (Reed, et al., 1995) or complex associative networks (Atallah, Frank, & O'Reilly, 2004).

Subgoals can be ordered in different hierarchical or sequential structures. In the case of control, an example would be “making breakfast”. Making breakfast in this case is a higher-order goal that consists of several subgoals such as making coffee, spreading butter on bread, and pouring orange juice. Making breakfast itself might be a subgoal of another superordinate goal such as “getting ready to go to work”. These subgoals are often achieved in a specific sequence, for example, you first put a coffee filter into the machine before adding the ground coffee, and you toast your bread before you spread butter on it. Thus, while the overall structure can be flexible (first preparing the bread and then making the coffee vs. making coffee and then preparing the bread) some segments must be organized in a specific structure. A high-order type of control is believed to be needed in these tasks to make sure these segments are completed successfully and in the correct order (Botvinick, 2008; Zacks, Speer, Swallow, Braver, & Reynolds, 2007).

Similar sequential mechanisms are also often required for memory. The vivid remembering of an event is often described as a replay of a sequence of memories, or as mental time travel (Lehn et al., 2009; Tulving, 1993). Similar to successful task performance described above, to remember accurately it is necessary to remember events with their temporal relationships. When investigating the organization of information in memory, the temporal context is of relevance – that is, the order or period of time in which information was encoded (e.g., Polyn, Norman, & Kahana, 2009). While a role of temporal order has long been suggested in theories of memory (e.g., Howard & Kahana, 2002; Tulving, 2002), it is not clear exactly how knowledge of such temporal order supports successful recall.

In parallel to the example of making breakfast described above, the relevance of temporal context in memory can be demonstrated when imagining how you might go about searching for your keys. A usual starting point would be trying to remember when you last had them – for example, when you opened your office door. The temporal organization of your memories would then help you to strategically search your memory for what you did after you opened the door, to reconstruct what happened with the keys. You might remember that your phone rang while you opened the door, and that you put the keys on the table to answer the phone. Thus, the sequential order of your memories helped you recall the relevant target memory.

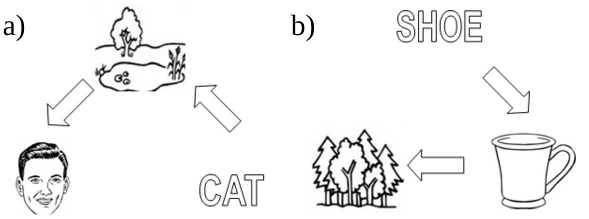


Figure 6.1. Schematic illustration of two exemplary trials, a and b.

Using temporal information to retrieve a memory is in line with models that describe memory as an associative network in which pattern completion mechanisms are used to re-establish information sequentially (Atallah, et al., 2004). One way to remember successfully would be to sequentially recall sub-memories (similar to completing sub-goals) to reconstruct the target memory. A key question regarding control processes in memory would be how sequential structure can guide memory retrieval. In line with the theoretical focus of this thesis, which concerned the relationship and similarities between control and memory, it could thus be investigated how sequential retrieval might relate to theories of hierarchical structure in the cognitive control literature (Badre, 2008; Botvinick, 2008; Koechlin & Jubault, 2006). The following experiment could assess whether the reactivation of information that preceded a target memory is positively associated with the successful retrieval of the target.

Participants would encode a sequence of three stimuli, beginning with a word (see Figure 6.1). In the memory test, the word will cue participants to recall the second or third item of a sequence. If retrieval operates in a sequential manner as postulated, recalling the third item would require retrieval of the second item. That is, as the third item would be retrieved via the second item. Critically, the second and third items of the sequence could be chosen from a set of three categories—faces, scenes, or objects—that are associated with characteristic patterns of brain activity, so that activity of different item types can be distinguished. This design allows to test for neural correlates of remembering item two when the third item is retrieved

MVPA could be used to measure the potential reactivation of items from a specific category during retrieval (e.g., Polyn, et al., 2005). Identifying such reactivation of information would make it possible to obtain evidence for the reactivation of the currently relevant target memory that participants are attempting to retrieve. More importantly, detecting such reactivation would also help to determine whether items that were presented temporally adjacent during the encoding sequence are reactivated.

This study could provide important evidence about a possible mechanisms of higher-order control processes during retrieval: Demonstrating that target memories are retrieved via the systematic recall of temporally preceding information would qualify prior findings that have suggested that reactivation of non-target associations interferes with target retrieval (Jost, et al., 2012; Kuhl, et al., 2011). Using this paradigm, it would be possible to explore the neural mechanisms that underlie the beneficial effect of sequential information on memory retrieval, and would provide information about complex, higher-level control processes during the retrieval of memories. In addition to category-specific activation, it could also be tested whether prefrontal activity is found that resembles the activity found in studies of the sequential nature of cognitive control (cf. Botvinick, 2008), thus extending the parallels between the control of task performance and memory that have been explored in the rest of this thesis.

6.4 Conclusion

The research discussed in this thesis has investigated the complex interactions between control and memory. In this context, the experiments have introduced new paradigms that enable the study of interactions between control and memory during both encoding and retrieval of long-term memories. Across all the experiments reported in this thesis, the key finding was that cognitive control served to increase the selectivity of processing. This finding was evident for the task-switching encoding phase, as well as during later memory retrieval. Critically, the findings reported here suggest that control did not compete for resources with memory encoding. Moreover, in consequence of the closely intertwined relationship of memory and cognitive control, the findings presented here indicated that later memory provides a useful measure of the effectiveness of control during encoding. Accordingly, the work laid out in the current thesis provides novel methods for the further investigation of the rich and varied interactions between cognitive control and long-term memory.

Appendix

Table A1: List of task-switching studies included in the ALE meta-analyses.

Author (year)	Contrast	N	Foci
Brass and von Cramon (2004)	meaning switch vs. cue switch	14	3
	cue switch vs. cue repeat	14	4
	switch vs. repeat (single cue)	14	3
Braver, Reynolds, and Donaldson (2003)	switch vs. repeat (switch x time)	13	5
Cools, Clark, and Robbins (2004)	switch vs. repeat (object or rule switch vs. non-switch)	16	11
DiGirolamo et al. (2001)	switch vs. repeat (young participants)	8	68
Dove, Pollman, Schubert, Wiggins, and von Cramon (2000)	switch vs. repeat	16	13
Gurd et al. (2002)	switch vs. repeat	11	2
Kimberg, Aguirre, and D'Esposito (2000)	switch vs. repeat	9	9
Luks, Simpson, Feiwell, and Miller (2002)	switch vs. repeat (neutrally cued)	11	2
	switch vs. repeat (targets)	11	2
Parris, Thai, Benattayallah, Summers, and Hodgson (2007)	flip vs. hold	22	20
Pollmann, Dove, von Cramon, and Wiggins (2000)	switch vs. repeat	11	7
Rushworth, Paus, and Sipila (2001)	switch vs. repeat (response switch)	20	16
	switch vs. repeat (visual switch)	20	10
Rushworth, Hadland, Paus, and Sipila (2002)	switch vs. repeat (response switch, increases)	10	4
	switch vs. repeat (visual switch, increases)	10	2
Smith, Taylor, Brammer, and Rubia (2004)	switch vs. repeat	20	10
Sohn, Ursu, Anderson, Stenger, and Carter (2000)	transition effects	12	6
Swainson et al. (2003)	switch vs. repeat, go trials	12	2
Sylvester et al. (2003)	event-related counter-switches	14	14
	blocked counter-switching	14	9
Crone, Wendelken, Donohue, and Bunge (2006)	switch vs. repeat (univalent trials)	21	25
De Baene, Kuhn, and Brass (2012)	task switch versus cue repeat	19	5
	adaptation repeat vs. switch	21	5
Ruge, Muller, and Braver (2010)	switch vs. repeat	18	15

Table A1 (continued)

Author (year)	Contrast	N	Foci
Stelzel, Basten, and Fiebach (2011)	switch vs. repeat (response hand switching)	48	13
	switch vs. repeat (abstract rules & response hand switching)	48	3
	switch vs. repeat (abstract task rules switching)	48	2
Derrfuss, Brass, and von Cramon (2004)	switch vs. repeat	20	8
Jamadar, Hughes, Fulham, Michie, and Karayanidis (2010)	switch vs. repeat (informatively cued)	18	18
Li., Sun., Wang, Zhang, Zhang, He, et al. (2004)	switch vs. repeat (attention shifting)	12	10
Liston, Matalon, Hare, Davidson, and Casey (2006)	switch vs. repeat (both colour and motion)	19	8
	switch vs. repeat (colour only)	19	4
Pessoa, Rossi, Japee, Desimone, and Ungerleider (2009)	switch vs. repeat (visual detection task)	20	8
	switch vs. repeat; (colour cue, (pop out task)	20	12
	switch vs. repeat; (colour cue, visual detection task)	20	10
Pollmann, Weidner, Muller, Maertens, and von Cramon (2006)	switch vs. repeat (dimension shift)	21	4
	switch vs. repeat (response shift)	21	16
Ravizza and Carter (2008)	switch vs. repeat (perceptual switching)	20	3
	switch vs. repeat (perceptual switching) (marginal)	20	4
	switch vs. repeat (rule switching)	20	3
Ruge et al. (2005)	switch vs. repeat (in response to cue and target)	18	2
Serences, Schwartzbach, Courtney, Golay, and Yantis (2004)	switch vs. repeat exp. 1(shifting vs. holding attention)	15	5
	switch vs. repeat exp. 2 (shifting vs. holding attention)	8	2
Wylie, Javitt, and Foxe (2006)	switch vs. repeat; (colour switch cues)	14	11
	switch vs. repeat; (colour switch targets)	14	19
	switch vs. repeat (imperative stimuli targets)	14	4
Yeung, Nystrom, Aronson, and Cohen (2006)	switch vs. repeat	15	12
Kim, Johnson, Cilles, and Gold (2011)	switch vs. repeat (stimulus switching)	16	11
	switch vs. repeat (response switching)	16	12
	switch vs. repeat (cognitive set switching)	16	15

N = Number of participant in this study; Foci = Number of foci included.

Table A2: List of studies of retrieval set included in the ALE meta-analyses.

Author (year)	**Contrast**	**N**	**Foci**
Dobbins and Han (2006)	RO source/context vs. item memory (simultaneous and delayed cues)	15	10
	RO source/context vs. item memory	15	22
Dobbins and Wagner (2005)	RO conceptual vs. novelty detection + RO perceptual vs. novelty detection	14	31
	RO perceptual vs. RO conceptual	14	23
Hornberger, et al. (2006)	RO auditory vs. RO picture	18	1
	RO picture vs. RO auditory	18	3
	RO picture vs. RO auditory	18	7
Kompus, et al. (2009)	episodic vs. semantic (1× vs. 6× encoded)	16	6
Woodruff, Uncapher, and Rugg (2006)	RO picture vs. RO word	16	4
	RO word vs. RO picture	16	4
	RO word vs. RO picture (delayed HRF)	16	2
	RO picture vs. RO word (sustained activity)	16	12
Dobbins, et al. (2003)	RO recency vs. RO source	11	43
Phillips, et al. (2009)	switch vs. repeat	12	2
	episodic vs. semantic	12	12
	interaction switch and study history (old/new)	12	2
	interaction switch, task (episodic/semantic) and study history (old/new)	12	1
Ranganath, Johnson, and D'Esposito (2000)	specific vs. general (size vs. old/new judgement)	8	1
Simons, Gilbert, Owen, Fletcher, and Burgess (2005)	context memory (for task or list) > baseline	16	7
Simons, Owen, et al., (2005)	context type (memory for task or position) > baseline	16	14
Simons, Davis, Gilbert, Frith, and Burgess (2006)	recollection of perceived/imagined status > baseline	16	10
	recollection of left/right status > baseline	16	11
Vinogradov, Luks, Schulman, and Simpson (2008)	source memory task > item recognition task	8	5
Vinogradov et al. (2006)	correct self > word reading baseline	8	2
	correct external word reading	8	3
Hayes, Buchler, Stokes, Kragel, and Cabeza (2011)	source > item	16	16
Simons, Henson, et al. (2008)	perceived/imagined status > baseline condition	16	17
	self/experimenter status > baseline condition	16	18

N = Number of participant in this study; Foci = Number of foci included

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