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## *NEURAL CORRELATES OF PROSPECTIVE MEMORY*

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## *Dedication*

*To my family*

*My father, Lidiano*

*My mum, Maura*

*My brother, Andrea*

*They taught me one of the most important value to live this life:  
the humility.*

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# CHAPTER 1

## PROSPECTIVE MEMORY

### 1.1 An Introduction

In recent years, there has been increased interest in experimentally investigating a particular type of cognitive process typically called **prospective memory** (PM). The first experimental study on prospective memory within cognitive psychology was conducted more than 30 years ago (Loftus, 1971) but in the last years there was an explosion of interest in prospective memory research with more than 30 articles publicized on this topic only in 2007 .

“ Prospective memory entails the formation and later realization of intentions that must be delayed for some period of time (Meacham & Leimen, 1982).”*Prospective memory* is an essential precursor of independent living, since the necessity to prospectively remember is highly prevalent in the organization of one’s daily routine and in the challenge of accomplishing occupational and social demands. For instance, remembering to attach a file to an email message before sending it, remembering to take a medication with a meal, or remembering to pick up one’s child from school, are all examples of prospective remembering.

Failures of prospective memory are not uncommon and the resulting errors can have dramatic consequences in workplace settings such as medicine, nuclear power plant operations and aviation. For example, in 1991 a tower controller at Los Angeles airport cleared an airplane to position and hold on runway 24 left (a standard procedure), intending to release the airplane for takeoff as soon as she was able to arrange for another airplane to cross the runway at the far end. The controller was quite busy managing multiple aircraft and making frequent radio transmissions – as is typical at busy airports – and several inadvertent delays occurred. Visibility was poor in the twilight haze, and glare was present from numerous light sources. Forgetting that she had not cleared the holding airplane to depart, the controller cleared an arriving airplane to land on runway 24 left, which it did, crashing into the holding airplane, and killing a number of passengers and crew (National Transportation Safety Board, 1991).

So persistent failures in prospective remembering may impose serious risks on physical well-being (e.g., failing to regularly take medication) or even may impede professional activities (e.g., incessantly forgetting about duties one is supposed to do at work) and endanger the maintenance of intimate social relationships (e.g., chronically forgetting to keep promises to close friends).

The variety of prospective memory situations has been categorized into:

- *event-based* tasks (EBPM), where the appropriate moment for executing an intended action is triggered by an external event (e.g., to deliver a message to a friend upon seeing him) and the successful remembering requires that the target event and the prospective memory task be associated and further that aspects of that association be reinstated at retrieval.
- *time-based* tasks (TBPM), where the intended action has to be executed at a specific point in time or after a particular elapse time (e.g., to visit the dentist's at 10 o'clock);
- less studied- *activity-based* tasks (ABPM), where it is necessary to perform an intended action after the completion of another activity (e.g., to take medication after the meal; Einstein & McDaniel, 1990; Kvavilashvili & Ellis, 1996).

Of the first two types of PM, TBPM is therefore believed to be the most reliant on internal control mechanisms because, assuming no external mnemonic aid is used, TBPM is more dependent on self-initiated mental activities, such as active time monitoring (d'Ydewalle, Bouckaert, & Brunfaut, 2001). However, of the two types of PM, it has been argued that TBPM should be especially sensitive to age-related decline (Einstein et al., 1995; Maylor, 1995). Older adults tend to perform as well or better than their younger counterparts in TBPM tasks that are carried out in naturalistic rather than laboratory settings. These tasks include measures in which the participant is required to phone the experimenter at a specific time over 4 weeks (Devolder, Brigham, & Pressley, 1990), 3 weeks (Poon & Schaffer, 1982), 2 weeks (Moscovitch, 1982), and 5 days (Maylor, 1990); mail postcards to the experimenter (Patton & Meit, 1993); and periodically log the time on an electronic organizer (Rendell & Thomson, 1993, 1999; Sawyer, 1988). In addition, older adults tend to show better TBPM for attending appointments (Martin, 1986). It could be explained considering the motivation of old adults to successfully complete PM tasks outside of the laboratory (Patton & Meit, 1993; Rendell & Craik, 2000) and an other important determinant of the magnitude and direction of age effects on PM tasks is likely to be the presence or absence of external aids to cue the PM event.

In naturalistic tasks, older adults are usually able to set up external cues to act as reminders. The reliance of older adults on external aids is perhaps not surprising as they tend to report more everyday memory failures and more concern about this (Cavanaugh, Grady, & Perlmutter, 1983). Thus, when required to make prearranged phone calls, for instance, older adults use "conjunction cues," such as placing the action to be remembered with another routine event such as having a meal (Maylor, 1990). Naturalistic studies offer little control over the use of such external aids, and when they are prevented, age-related benefits are typically reduced (Maylor, 1990) and in some cases no longer significant (Patton & Meit, 1993), although it is important to note that d'Ydewalle

and Brunfaut (1996) found an age benefit on naturalistic PM tasks even when restrictions on external aids were imposed.

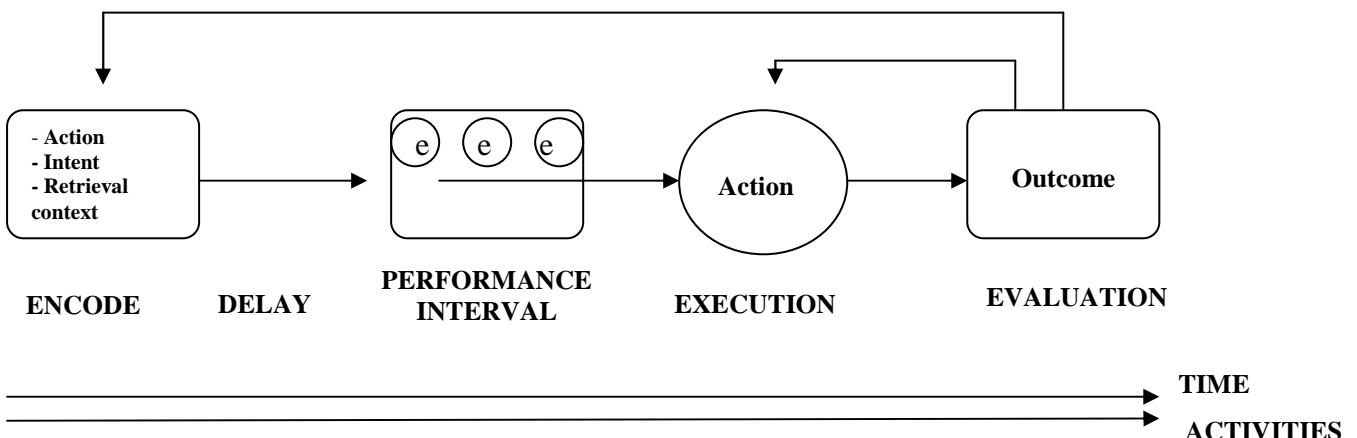
## 1.2 Components of Prospective Memory

Hitch and Ferguson (1991) proposed a theoretical analysis which distinguished three different stages: 1) forming a future intention, 2) remembering the intention during an intervening period and 3) performing the intention on the required occasion. This theoretical analysis is the start point of cast some light on the components of PM (see in Bisiacchi, Sgaramella & Zettin, 1995).

Bisiacchi & Sgaramella (1991) identified four main components necessary to realize a delayed intention and each components require different subcomponents. The first component is the *planification* and it includes the ability of forming and encoding an intention; the second is a *retrospective component* that allow us to remember the content of the intention and the appropriate moment to execute it (what and when); the third is the *execution component* where the intention can be executed on the required occasion and the last component is the *control component* necessary to monitoring each phases and disengage the ongoing activities.

Successively Brandimonte & Passolunghi, (1994), Ellis & Milne (1996) described the realization of a delayed intention of the following phases schematized in figure 1.1.

- A) Formation and Encoding of an intention and action
- B) Retention Interval
- C) Performance Interval
- D) Initiation and Execution of Intended action
- E) Evaluation of Outcome



**Figure1.1** Main phases in the realization of a delayed intention.

Note: e = event



*Phase A* is concerned primarily with the retention of the content of a delayed intention, or, more precisely with the retention of an action (*what* you want to do), an intent (*that* you have decided to do something) and a retrieval context that describes the criteria for recall (*when* you should retrieve the intent and the action and initiate them). For example the different elements of an intention to go to dentist tomorrow evening may be encoded as follows: I should (that-element) “go to the dentist” ( what-element) “tomorrow evening” (when-element). It is highly probable that planning and motivational operations that occurs during this phase will influence the encoding and thus the eventual representation of the delayed intention.

*Phase B* refers to the delay between encoding and the start of a potential performance interval and it could be as brief as a few minutes or as long as several hours, whereas *phase C* refers to the performance interval or period when the intended action should be retrieved. The duration of retention and performance intervals will vary considerably and a delayed intention may be remembered at any point during either of these two phases. The successful realization of the intention however requires that it has to be retrieved on at least one occasion during a performance interval and on the occurrence of the following events.

*Phases D* and *E* are concerned with the initiation and execution of an intended action and the evaluation of the resultant outcome, respectively. Moreover, some form of record of an outcome is necessary either to avoid an unnecessary repetition of a previously satisfied delayed intention or to ensure the future success of a postponed or failed delayed intention.

More recently, Kliegel et al. (2002) resumed the main phases of prospective memory process into four phases:

1. *intention formation*: the point at which an intention to perform a future activity is formed and encoded;
2. *intention retention*: the period during which the intention is retained in memory while performing other ongoing activities;
3. *intention initiation*: the moment at which the execution of the intention should be initiated;
4. *intention execution*: the actual execution of the intended action(s) according to the previously formed plan (Kliegel, Mackinlay, & Jäger, in press; Kliegel, Martin, McDaniel, & Einstein, 2002; cf. also Ellis, 1996, who proposed a fifth phase that is concerned with monitoring the output of an executed intention).

Distinct cognitive processes have been identified as playing the predominant roles during the completion of a particular phase (e.g., Kliegel et al., 2002). During intention formation, *planning skills* are assumed to be the most influential cognitive function, especially when an intention is somewhat complex. Furthermore, an *efficient encoding* of the intention is needed during this first

phase of prospective remembering. Intention retention seems to primarily require storing the content of the intention in *retrospective memory*. Finally, intention initiation and execution seem to rely on processes such as *monitoring*, *cognitive flexibility*, or *inhibition*.

Obviously, the cognitive abilities *retrospective remembering* and *executive functioning* are thought to play the major roles during the prospective memory process. While distinct executive functions are suggested to be intimately involved during intention formation, intention initiation, and intention execution, they seem to play only a negligible role during intention retention (however, executive control may be required during intention retention to some degree to periodically rehearse or check for uncompleted intentions; Carlesimo et al., 2004; Kliegel et al., in press). Hence, the process of becoming aware of the *appropriate moment* that an intended action has to be initiated and executed (the so-called *prospective component* of prospective memory tasks; Einstein & McDaniel, 1996) may strongly rely on executive functions. By contrast, the process of retrieving the *content* of the intention and the specific actions that have to be carried out (the so-called *retrospective component* of a prospective memory task) is mediated by retrospective memory abilities.

### **1.3 Prospective and Retrospective components**

There is typically agreement in the prospective memory literature that the realization of delayed intentions is facilitated by prospective and retrospective processing components (Guynn, McDaniel, & Einstein, 2001; McDaniel & Einstein, 1992; Simons, Scholvinck, Gilbert, Frith, & Burgess, 2006). The prospective component (PM) entails processes that support the detection or recognition of prospective cues and the retrospective component (RM) entails processes that support the retrieval of an intention from memory following the recognition of a prospective cue (Einstein & McDaniel, 1996; Smith & Bayen, 2004).

The main differences between prospective and retrospective components regard the phase of retrieval and encoding of prospective memory. In fact retrieval from retrospective memory is generally instigated as the result of an explicit external (e.g., a student appearing at one's office door) or internal (e.g., thinking "what is her name") agent. In contrast, retrieval from prospective memory, when it is event based, is instigated by the detection of a cue (e.g., finishing the conversation) that does not necessarily prompt realization of the intention (i.e., finishing a conversation could prompt a number of activities; Craik, 1986; Ellis, 1996).

In addition to differences in the conditions under which memory retrieval is prompted in prospective and retrospective memory, there are often differences in encoding between these two forms of memory.

Encoding in retrospective memory can be either intentional (e.g., trying to commit to memory the names of students at the beginning of a semester) or incidental (e.g., encoding the details of a conversation following a class; see Brown & Craik, 2000). However, encoding in prospective memory would by necessity seem to always be intentional (i.e., one has the expectation upon forming an intention that it will be realized in the future).

Behavioural evidence indicates that the prospective component is more sensitive to changes in the perceptual characteristics of the cue than to the semantic relationship between the cue and intention; in contrast, the retrospective component appears to be more sensitive to variation in the semantic relationship between the cue and intention than to variation in the perceptual characteristics of the prospective cue (Cohen, West, & Craik, 2001).

Evidence from studies using a variety of methods has revealed that the prospective component is more sensitive to individual differences in working memory capacity (Smith & Bayen, 2005, Bisiacchi, Tarantino Ciccola, in press) or variation in the working memory demands of the ongoing activity (Marsh & Hicks, 1998; West, Bowry, & Krompinger, 2006) than the retrospective component. Together these data led to the suggestion that in many cases the prospective component is supported by attention demanding processes that serve to monitor the environment for prospective cues (Guynn, 2003; Smith, 2003; although for an alternative view see Guynn et al., 2001). The retrospective component shares many of the processes that support explicit episodic memory in recognition and cued-recall tasks that facilitate the retrieval of contextual information from long-term memory (Einstein & McDaniel, 1996; Guynn et al., 2001; Smith & Bayen, 2004; West & Krompinger, 2005).

Considering the similarities between prospective and retrospective memory, data from several studies have demonstrated that a number of variables influence the efficiency of these two forms of memory in comparable ways. For instance, low frequency words are more often recognized than high frequency words in recognition memory tasks (Hintzman, 1988) and lead to higher levels of prospective responding when used as cues in prospective memory tasks (Einstein & McDaniel, 1990; McDaniel & Einstein, 1993). The efficiency of both prospective and retrospective memory is also modulated by the degree of study test congruity, with recognition accuracy and prospective responding being higher when semantic meaning is congruent from study to test occasions (Marsh, Hicks, & Hancock, 2000; Meier & Graf, 2000; Tulving & Thompson, 1973; Brandimonte, Bisiacchi & Pelizzon, 2000).

Despite studies demonstrating convergence between prospective and retrospective memory, evidence from a growing literature indicates that these two forms of memory can be dissociated. The general division between prospective and retrospective processing components is also supported by evidence from studies examining the neural basis of prospective memory. Patients with damage to the medial temporal lobe can exhibit deficits in both prospective memory tasks and episodic memory tasks (Palmer & McDonald, 2000) and there is some evidence indicating that the regions of the medial temporal lobe are activated by the realization of delayed intentions (Okuda et al., 1998).

These findings are consistent with the idea that there is overlap between the processes underlying the retrospective component of prospective memory and forms of explicit episodic memory including recognition and cued-recall (Einstein & McDaniel, 1996; West & Krompinger, 2005). In contrast to the retrospective component, processes underlying the prospective component may be more heavily dependent on the functional integrity of the prefrontal cortex. Evidence from a number of patient studies indicates that damage to the prefrontal cortex can result in significant impairment in prospective memory in individuals who possess largely intact explicit episodic memory when measured in the form of new learning (Burgess, Veitch, de Lacy Costello, & Shallice, 2000; Cockburn, 1995; Palmer & McDonald, 2000).

Converging with the patient data, studies using functional neuroimaging methods reveal that activation of anterior prefrontal cortex may be associated with strategic monitoring that facilitate the recognition of prospective cues (Burgess, Quayle, & Frith, 2001; Burgess, Scott, & Frith, 2003; Simons et al., 2006).

There are also different self-rating measures used to differentiate prospective and retrospective components. The most prominent example of such measure is the recently developed Prospective and Retrospective Memory Questionnaire (PRMQ; Crawford et al., 2006; Smith et al., 2000; see Figure 1.2). The PRMQ was designed to disentangle self-rated PM and RM performance in everyday life or in clinical settings. Previous self-reports of memory ability, as Rivermead Behavioural Memory Test (RBMT, Wilson, Cockburn & Baddeley, 1991), Cognitive Failures Questionnaire (CFQ, Broadbent, 1982) and Cambridge Prospective Memory Test (CAMPRMPT: Wilson et al., 2005) ignored the distinction between PM and RM tasks and they were designed commonly to assess memory skills related to everyday situations.

Specifically, the PRMQ assesses how often errors in everyday PM or RM tasks occur. Factor analyses revealed that a tripartite structure model best fits the PRMQ scores, that is, a general memory factor and two orthogonal specific factors of PM and RM (Crawford et al., 2003). These

factors are captured using sixteen items that are equally divided between a PM subscale assessing everyday PM errors, and a RM subscale assessing everyday RM errors.

**Proxy-version of the PRMQ Items and their categorizations.**

Item no.	Item	Prospective vs. retrospective	Short- vs. long-term	Self-cued vs. envir.-cued
1	Do they decide to do something in a few minutes time and then forget to do it?	Prospective	Short-term	Self-cued
2	Do they fail to recognize a place they have visited before?	Retrospective	Long-term	Envir.-cued
3	Do they fail to do something they were supposed to do a few minutes later even though it is there in front of them, like take a pill or turn off the kettle?	Prospective	Short-term	Envir.-cued
4	Do they forget something they were told a few minutes before?	Retrospective	Short-term	Self-cued

**Figure 1.2** Items from ‘The Prospective and Retrospective Memory Questionnaire’ (PRMQ). In Crawford *et al.* (2006)

### 1.4 Models of prospective remembering

There are several models that can explain how event-based intentions result in actions.

The Norman and Shallice theory of action control is a very general theory of how action is controlled (Norman & Shallice, 1986). According to the theory, action is controlled by both contention-scheduling and a Supervisory Attentional System. It seems useful also in the context of PM.

The theory proposes that tasks require cognitive resources only when they are new, they do require planning, or are technically difficult. These resources are provided by the Supervisory Attentional System (SAS). In contrast, routine and habitual actions can be controlled by contention scheduling alone, without intervention from the SAS. If deviation from routine is deemed necessary, the SAS influences behaviour by biasing the contention scheduling processes.

The theory states that when a new action has to be carried out and one needs to deviate from normal routine, the SAS is needed. This model zooms in on a required task-switch: you have to stop doing

what you are doing and initiate the required action and people report that they usually make errors when they are distracted or absent-minded (Reason, 1983).

There are also more specific models for how intentions result in actions. Some of these focus on the storage of intentions in memory and potential dynamic properties of their memory representations, whereas other models put more emphasis on how such a representation is activated by environmental cues and how they ultimately result in action.

On the other side, in the *memory-based prospective memory models* when an intention is formulated, it is stored in memory as declarative knowledge and plays a causal role in action. Because an intention is merely a memory content, the probability that it will be retrieved depends on the level of activation of the representation and the presence of adequate retrieval cues. A fully activated intention representation is accompanied by recall of the intention and subsequent action. There is usually no further deliberation on alternative courses of action.

In contrast, Goschke and Kuhl (1993, 1996) argue that mental representations of intended actions have a special dynamic status in memory, and they discuss evidence that supports this claim. The *intention-superiority effect* is the observation that words denoting an intended action are recognised faster and more accurately than neutral words. This effect suggests that an intention is represented at a higher level of activation.

Goschke and Kuhl (1993, 1996) report experiments that provide evidence that the effect reflects an unwitting enhancement of the activation level of intention related concepts. They also provide some evidence that the activation level is high after intention formation, then diminishes, but rises again prior to the appropriate time of action. As soon as the intended action is carried out, the dynamic properties disappear (see also Marsh, Hicks, & Bink, 1998).

One of the first models who underlined the distinction between the prospective and retrospective memory components was the *Noticing+Search model*, proposed by Einstein and McDaniel (1996). This model identified two separate stages in prospective remembering. First of all, an event should be noticed: it should not only be perceived but it should also create some internal response. This can be a general feeling of familiarity, for example; such a feeling of familiarity is more likely when the actual event was used specifically during intention formation, instead of described only in categorical terms. For example, when there is a new play on, it is more likely to remember the intention to buy tickets if you had intended to see this particular play than if you had intended to see *any* play; this is true because the name of this play can cause an internal response when it is displayed in the local newspaper.

After an event is noticed, a memory search for the meaning of the event is instigated. It is like seeing somebody jogging in the park. At first you do not recognise her/him, but somehow she/he

looks familiar. Then, after searching your mind, you recognise her/him as the woman/man who cleans your desk at the office twice a week. It is argued that this search in memory also applies to the retrieval of an intention. It is assumed that the noticing stage is relatively automatic, but the memory search is controlled and requires cognitive resources.

In contrast, *the associative memory system model* (McDaniel, Robinson-Riegler, & Einstein, 1998), states that no controlled memory search is necessary.

According to Moscovitch (1994), prospective memory is supported by the medial-temporal/hippocampal module – a reflexive associative memory system. Moscovitch (1994) assumed that an “automatic-associative” memory system accepts externally encountered cues that are consciously attended and that the cues interact with memory traces previously associated with the cues. If a cue produces enough interaction with a memory trace, then the system delivers to awareness the information associated with the cue. Critical for purposes of prospective memory, this information is retrieved rapidly, obligatorily, and with few cognitive resources. This mechanism could thus mediate prospective memory retrieval if the target event interacts sufficiently with the representation of the intended action so that the intended action is delivered to awareness. Note that in contrast to the cue-focused views, the target event is not necessarily recognized as a cue—there is no necessary prior identification of the target event’s significance that then prompts memory search. The target event simply stimulates (or fails to stimulate) a reflexive associative process that brings the intended action to awareness.

Three lines of evidence provide preliminary support for this model.

1. First, Guynn, McDaniel, and Einstein (1998) reported that reminders that required participants to focus on the association between the target event and intended action produced better prospective memory than did reminders that required participant to focus on the target event alone.
2. Second, in a small pilot study, Guynn et al. (2001) reported that target events paired with associated intended actions (based on pre experimental experience) produced better prospective memory than did the identical target events paired with unassociated intended actions
3. Third, there are conditions under which older adults perform as well as younger adults in event-based prospective memory (Cherry & LeCompte, 1999; Einstein et al., 1992; Einstein & McDaniel, 1990; Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995), which is consistent with a reflexive-associative process that requires few cognitive resources.

This model supports the retrieval of an intended action when a target event is attended to, by automatically producing interactions between the cues and memory traces previously associated with these cues. Only if there is sufficient interaction between the target event and the memory trace of the intended action will the intention spring to mind: rapidly, obligatorily, and with few cognitive

resources. Whether there is sufficient interaction depends on the number of associations the cue has and on the strength of the associative link.

Successful prospective memory is also dependent on the degree of processing of the cue, and whether or not the retrieved intention is put into action, which is the responsibility of other processes (see Guynn, McDaniel, & Einstein, 2001).

All of the above models of prospective memory make different predictions regarding the need for and the role of cognitive resources. A prominent question within the literature related to event-based prospective memory is the degree to which the engagement of strategic processing is required for a prospective cue to be recognized as such when it is encountered in the environment.

One school of thought proposes that relatively automatic or spontaneous processes support the detection of prospective cues (Einstein and McDaniel, 1996; McDaniel et al., 2004). For example, the automatic associative memory system model predicts that once a cue is processed well enough, no resources are needed for memory retrieval given a strong association.

A second school of thought lead to the proposal that individual must engage in resources demanding preparatory processes (Smith, 2003; Smith & Bayen, 2004) or strategic monitoring (Guynn, 2003) in order for a prospective cue to be detected. Guynn (2003) claimed that successful completion of the prospective component may be due to explicit monitoring for the opportunity to realize the intention in which case the cue and associated action would be actively maintained in awareness. She described two strategic processes that work in concert to facilitate the realization of delayed intentions (i.e., prospective retrieval mode and item checking). Prospective retrieval mode is thought to reflect a tonic “cognitive or neurocognitive task set to treat stimuli as cues to retrieve stored episodes” (Guynn, 2003, p. 247); in contrast, item checking is thought to represent a process that serves to evaluate whether or not a candidate stimulus is a prospective cue in contexts where a cue is anticipated.

Alternatively, the prospective component may involve more subtle attentional processing that requires capacity but may be outside of awareness. The primary approach that sustained this theory followed that of Smith’s (2003; see also Guynn, 2003, and Marsh, Hicks, & Watson, 2002). The Smith’s theory assumes that the preparatory attentional processes consume limited cognitive resources, and consequently, successful performance on the prospective task will come at some cost to the ongoing task. The costs of performing a PM task regard the speed and accuracy of performing the non-target ongoing task items. If performing a PM task produces substantial increases in the time (or decreases in the accuracy) to perform the ongoing task (for non-target items), then this would be evidence that participants were relying on monitoring. Moreover, to the extent that a monitoring process is needed for PM performance, monitoring levels should be



indicative of PM performance. In contrast, finding minimal or no effects of performing a PM task on the efficiency of processing the non-target items would suggest that participants were relying on a spontaneous retrieval process. Further, according to this view, high levels of PM performance can occur under conditions of no monitoring.

Smith argues that cognitive resources are necessary to monitor for cues that indicate that the intended task has to be carried out. Smith (2003) presented a strong version of the monitoring view affirming that:

*“ retrieval of an intention will never be automatic, because nonautomatic preparatory processes must be engaged during the performance interval, or the time in which the opportunity to carry out the action is likely to occur, but before the occurrence of the target event (p.349). ”*

In the Smith’s model ‘Preparatory attentional processes and memory processes (PAM) postulates that the prospective component always involve resource-demanding processes and prospective memory performance is never automatic. Preparatory attentional processes and memory processes involves preparatory attentional processes and retrospective memory processes:

➤ **Preparatory attention processes** may involve explicit monitoring of the environment for the occurrence of prospective memory target events or more subtle processes needed for maintaining the intention. The Preparatory attention processes are resource-demanding and must be engaged on a given prospective memory target trial to recognize the target as an opportunity to perform the intended action. Because the Preparatory attention processes must precede recognition of the target event, they will be engaged in nontarget trials as well. Thus indirect evidence of the Preparatory attention processes comes in the form of a cost to ongoing activities in nontarget trials. Therefore, embedding a PM task in an ongoing task will reduce the resources available to the ongoing task, even when the target is not present. Better prospective memory performance should be accompanied by increased monitoring, which will occur at a greater cost to the ongoing activity.

➤ **Retrospective memory processes** involve both recognition of the target event and retrospective retrieval of the intended action.

Smith (2003) presented clear evidence of a dissociation between PM and retrospective memory. Although slower response times on the ongoing task (indicating a greater cost, interpreted as more preparatory attentional processing) was associated with better PM performance, no such relationship existed in the identical situation with an embedded retrospective recognition task.

Smith and Bayen (2004, 2005, 2006) provided further evidence for this dissociation of preparatory attentional and retrospective memory processes in their formal model of PAM.

The multinomial model successfully accounts for PM data by assuming distinct concepts for preparatory attentional processes and for retrospective memory. With respect to the resource demands of PM, it is possible that nonautomatic processes are required for the retrospective component of the PM task, as well as for execution of the task and for the retrieval of the intention. It is the requirement of resource-demanding processes for retrieval of the intention that distinguishes the PAM theory.

Moreover, in an evaluation of the influence of working memory resource availability on PM performance, Smith and Bayen (2005) found that the preparatory attentional processes were significantly influenced by increased working memory capacity. The evidence indicates that preparatory attentional processes are resource demanding.

Additional support for attributing the cost on the ongoing task to preparatory attentional processes comes from a recent study by West et al. (2005). West and colleagues examined response times on an ongoing task on trials that preceded the occurrence of PM target trials. Of importance, they contrasted trials that preceded correct PM responses with targets that preceded PM misses.

Response times were longer on trials that preceded PM hits than on trials that preceded PM misses. West et al. (2005) interpreted their results as indicating that disruptions in preparatory attentional processing lead to PM failure. Thus, the existing evidence is completely consistent with the proposal that the cost seen in these experiments is likely to be due at least in part to preparatory attentional processes.

McDaniel and Einstein (2000) proposed *the multiprocess view*, which takes into account evidence for both monitoring and spontaneous retrieval processes. This theory assumes that whether one relies on a monitoring or spontaneous retrieval process depends on the characteristics of the PM.

Given the prevalence of prospective demands in everyday life, McDaniel and Einstein argued that it is adaptive to have a flexible system that can accomplish PM retrieval through several mechanisms. According to the multiprocess view, there is a general bias to rely on spontaneous retrieval. It would be maladaptive to depend exclusively on a monitoring process that heavily taxes working memory resources because (a) people often have multiple, simultaneous PM demands and (b) the delays before they can perform intended actions are often substantial. Further, the particular method that people use to help them remember to perform actions in the future depends on a variety of factors including the importance of the PM task, the characteristics of the target event and their relation to the target actions, the nature of the ongoing task, and individual differences (see McDaniel & Einstein, 2000, for explanations of how these variables are expected to affect PM strategies that people use). Particularly, in their article, McDaniel & Einstein (2005) investigated the cost on

ongoing task when the importance of the PM task is emphasized, when focal processing of the target is not encouraged by the ongoing task and when there are multiple target events.

Results support the multiprocess prediction that the nature of target event and the instructional emphasis on the PM task affect participants' strategies. Participant relied on spontaneous retrieval processes with a focal target event and moderate-emphasis instructions while participant relied on strategic monitoring with a nonfocal target or high-emphasis instructions or both. Performance of a PM task with a single target does not produce significant costs on the accuracy and speed of performing the ongoing task while six target events produce a cost of performing a PM task thereby, suggesting a more controlled approach to prospective remembering. Concluding results showed that whether performing a PM task produces costs to the ongoing task depends on a variety of factors. So, both monitoring and spontaneous retrieval alone can produce prospective remembering.

The PAM theory and the multiprocess framework make similar prediction regarding the cost associated with a PM task in some circumstances but not in others. A critical assumption of the multiprocess framework is that under some circumstances, retrieval of the intention (the prospective component) requires no resources or capacity prior to the occurrence of the target event.

According to the multiprocess framework, the circumstances promoting automatic retrieval include (a) the intended action is simple, (b) the target and action are sufficiently associated at encoding, (c) the background task requires processing of the relevant dimension of the target, and (d) the target is salient (Kliegel et al., 2001; McDaniel & Einstein, 2000). When these conditions are met, successful performance of an intended action should occur without cost to any ongoing activities.

The PAM theory differs from the multiprocess view by assuming that successful retrieval of a delayed intention can only occur in the context of resource-demanding.

Successively, Smith et al., (2007) examined in detail one of the criteria for automatic retrieval of intentions according to the multiprocess view of PM: the target salience. Salience is consider not a property of events but rather is a psychological reaction of the perception of difference in a prevailing context of similarity. In fact, the experiments presented in this study, demonstrated a cost to ongoing activities when an event-based task is embedded in the ongoing task. In the first experiments they found a cost to ongoing task using a perceptual salient target (*a word displayed in red on a black screen during a lexical decision task when all other strings were displayed white on a black screen*). In the second experiment, the same cost was found using a semantic salient target (the PM target was the participant's name). At the end in Experiments 3 and 4, the cost was found despite meeting all of the criteria for a task to be automatic as specified by the multiprocess

framework. The results, which were predicted by the PAM theory (Smith, 2003), suggest that resource demanding processes are required for successful performance of a delayed intention.

The evidence regarding the need for cognitive resources is mixed. This is probably due to the fact that experimental procedures vary widely regarding the nature of the ongoing tasks, the way that cognitive load is manipulated, and the kind of prospective memory task.

For example other experiments, in agree with the monitoring view, showed that dividing attention leads to worse prospective remembering: if participants, in addition to some ongoing task and a prospective memory task, are given a third task, prospective memory suffers (McDaniel et al., 1998; Stone, Dismukes, & Remington, 2001). Prospective memory also suffers if the difficulty of an ongoing task is increased (Kidder, Park, Hertzog, & Morrell, 1997; Stone et al., 2001; Marsh & Hicks, 1998). Even if the total number of tasks and the difficulty level of the ongoing task(s) remain unchanged, but participants are required to switch between different ongoing tasks at unpredictable times, prospective memory is worse than when no switches are required (Marsh, Hancock, & Hicks, 2000).

On the other side, in agree with spontaneous retrieval, manipulating the availability of cognitive resources does not always affect prospective memory. D'Ydewalle, Luwel, and Brunfaut (1999) found that the addition of an extra ongoing task did not affect prospective memory performance or Otani et al., (1997) varied the cognitive demands of some ongoing activity but found no effect.

## CHAPTER 2

### NEUROPSYCHOLOGICAL AND NEUROIMAGING STUDIES OF PROSPECTIVE MEMORY

#### 2.1 Theoretical approaches to Prospective Memory and implications for brain activation

As discussed in the previous chapter, a prospective memory task recruits several cognitive processes such as forming and holding an intention in memory, dividing attention between the ongoing task and the PM task, monitoring for the appearance of prospective cues, retrieving the retrospective memory of the task and planning/executing the response at the appearance of the prospective cue.

There is evidence from recent behavioural studies consistent with multicomponent models of prospective memory but the neurocognitive mechanisms supporting prospective memory are still poorly understood (Bisiacchi, 1996; Kliegel, Mackinlay, & Jäger, in press; Kliegel, Martin, McDaniel, & Einstein, 2002).

Based on the analysis of cognitive processes involved in prospective memory tasks, a putative neuroanatomical basis of prospective memory has been postulated (e.g., Burgess et al., 2000; Cohen & O'Reilly, 1996; McDaniel, Glisky, Rubin, Guynn & Routhieaux, 1999; Vogels, Dekker, Brouwer, & de Jong, 2002). On the one hand, it is assumed that the *prefrontal cortex* mostly mediates those processes involved in prospective remembering that are thought to be 'executive', such as the planning of an intention or the executive control mechanisms required to successfully initiate and execute an intention.

As we have previously seen in Chapter 1, one model of prospective memory suggests that supervisory executive processes are demanded throughout the PM task (Burgess and Shallice, 1997; Shallice and Burgess, 1991). These processes recruit and maintain attentional resources during monitoring for an environmental marker (environmental event) that signals the appropriateness of performing the PM task (Burgess and Shallice, 1997; Guynn, 2003; Smith, 2003) and participate in the initiation of PM task performance (cf. Guynn et al., 2001; McDaniel et al., 1998). We will label this model the supervisory model.

Since frontal areas are explicitly assumed to be involved in supervisory executive functions (e.g., Fuster, 1999; Shallice and Burgess, 1991), the supervisory model implies that frontal areas are

involved in PM. Some support for this idea comes from neuroimaging and neuropsychological studies (e.g., Burgess et al., 2000; Martin et al., 2003; McDaniel et al., 1999).

On the other hand, the memory system of the *medial temporal lobes* is assumed to be essential for the retrospective component of prospective memory tasks, i.e. to retrieve the content of an intention (e.g., Guynn, McDaniel, & Einstein, 2001). For example, the preparatory attention and memory process (PAM) model proposes that monitoring of the environment initiates a recognition decision about whether the stimulus is a PM target or a nontarget (Smith and Bayen, 2004). Additionally, more extensive retrieval activity for the intended action might be initiated following a positive recognition decision (Smith, 2003).

Attempted recognition of the target would occur on every trial. In terms of brain activity, this process implies that structures supporting recognition processes should be activated on every trial, perhaps followed by a recall process reflecting episodic retrieval of the intended action. The hippocampal formation appears to be a good candidate for this process as it is implicated in neuropsychological and evoked potential investigations of recognition (Smith and Halgren, 1989) and has been implicated in PM by Okuda et al. (1998) using PET (see in the following section). The noticing plus search view suggests that associative retrieval processes similar to those involved in cued recall are engaged to retrieve the intended action, and these also would appear to be supported by the hippocampal formation (Isaac and Mayes, 1999; Moscovitch, 1994). Thus, PM retrieval activities and retrospective memory may involve similar neuronal dynamics in the hippocampal formation. Animal studies have supported distinct contributions of hippocampus and other brain structures, including the parietal lobes, in PM tasks (Kametani and Kesner, 1989).

In summary, it has been postulated that specific subprocesses of prospective memory strongly rely on the prefrontal cortex, the medial temporal lobes, or on interactions between these structures (Cohen & O'Reilly, 1996).

The main empirical evidence for the above position derives from: 1) single-case studies of patients who show failures in the realisation of delayed intentions, 2) studying clinical populations (Kliegel et al., 2008) and 3) from functional imaging studies (see next paragraphs) .

Cockburn (1995) reported a patient with bilateral frontal lobe damage and impaired executive functions (specifically deficits in planning, initiating and inhibiting ongoing behaviour; distractibility in some situations and perseverations in others; lack of inhibitory control), whose most marked deficit was a failure to perform a series of PM tests in which she had to actively interrupt an ongoing activity to perform an intended action. Palmer and McDonald (2000) demonstrated that patients who had undergone temporal lobe resection as a treatment for epilepsy were impaired on tests of both prospective memory and episodic memory leading to the suggestion

that retrieval processes supported by the medial temporal lobe underlie both forms of memory. Together the findings of the above experiments as well as work examining the effects of damage to the medial temporal lobe and the functional neuroanatomy of prospective memory indicate that this region is an important component of a neural network that supports retrieval processes common to prospective memory and episodic memory.

West, McNerney & Krauss (2007) examined the locus of a prospective memory deficit in an individual with multiple sclerosis. The individual demonstrated above average to superior general intelligence, retrospective and autobiographical memory, short-term/working memory and executive functions, but poor prospective memory on a variety of measures incorporating naturalistic, self-report- and laboratory methods. This deficit appeared to arise from a disruption of processes underlying strategic monitoring. This data clearly demonstrates that impaired prospective memory can exist in the presence of an otherwise intact neuropsychological profile.

Kliegel et al. (2008) reviewed studies that had investigated prospective memory performance in a number of clinical populations, such as patient populations suffering from brain damage, Alzheimer's disease, Parkinson's disease, Multiple Sclerosis, schizophrenia, affective disorders, developmental disorders etc.. The findings of some studies are consistent with the hypothesis that damage to the prefrontal cortex invariably results in poor prospective remembering (Burgess, 2000; Cockburn, 1995; Fortin et al., 2002, 2003). For example, some investigators found that patients with circumscribed lesions of the prefrontal cortex (i.e. lesions to frontopolar BA10) exhibit substantial difficulties in performing real-life multitask situations that involve prospective remembering, such as planning and preparing a meal (Burgess, 2000; Burgess et al., 2000; Fortin et al., 2002, 2003; Shallice & Burgess, 1991). By applying laboratory-based prospective memory tasks to TBI patients and normal controls, several studies have strongly suggested that TBI results in a diminished ability to carry out time-, event-, or activity-based intentions (Carlesimo et al., 2004; Hannon et al., 1995; Henry et al., in press; Kinch & McDonald, 2001; Kinsella et al., 1996; Kliegel, Eschen, & Thöne-Otto, 2004; Knight et al., 2005, 2006; Mathias & Mansfield, 2005; Maujean et al., 2003; McCauley & Levin, 2004; Schmitter-Edgecombe & Wright, 2004; Shum et al., 1999, 2002; for a partial quantitative review see Henry et al., in press).

## **2.2 Neuroimaging studies of Prospective Memory: Position Emission Tomography technique (PET)**

There is a current consensus amongst investigators that at least some of the processes which are critical to realising delayed intentions are supported by brain structures located in the frontal lobes and related structures (Bisiacchi, 1996; Bisiacchi and Sgaramella, 1993; Cockburn, 1995; Cohen & O'Reilly, 1996; Shallice & Burgess, 1991). Taken together, the previous PET studies indicated the involvement of the lateral and the medial rostral prefrontal cortices in event-based prospective memory. Burgess et al. (2000) tested the link between rostral PFC and prospective memory using PET. They reviewed the lesion loci of five neurological cases, whose everyday life impairments included failure to create and carry out intentions, taken from the case studies of Eslinger and Damasio (1985), Shallice and Burgess (1991) and Goldstein et al. (1993) using the Damasio and Damasio (1989) method of CT scan analysis. Burgess et al. (2000) found that all the cases had sustained damage to at least one of the following frontal areas: left frontal pole and surrounding regions (Damasio and Damasio region LF04, which encompasses parts of Brodmann's areas (BAs) 8–10), left anterior cingulate (Damasio and Damasio region LF01) and right dorsolateral prefrontal cortex (RDLPFC; Damasio and Damasio region RF07). Burgess et al. (2000) also report these regions, in addition to the left posterior cingulate and forceps major region, as implicated in performance of a multitasking test requiring PM in 60 neurological patients with circumscribed cerebral lesions. They proposed that the anterior and posterior cingulates are involved in the basic retrospective memory components of PM, that the RDLPFC is involved in planning and creation of intentions (Goel & Grafman, 2000), and that BA 10 is critical to the maintenance of intentions.

This finding was in agreement with that of Okuda et al (1998) who also found increases in the left frontal pole in prospective memory conditions relative to the ongoing task alone. In this study subjects were taught a set of 10 nouns ("targets") before the scanning began. There were two scanning phases: "experimental" and "control". During the experimental scanning phase participants were required to repeat verbally a series of 10 sets of five nouns that were presented to them auditorily. Occasionally, one of the stimuli they heard was a target word that they had learnt before scanning, and subjects were instructed to tap with their left hand when they heard these. The control scanning phase consisted merely of the word string repetition task alone. The subjects repeated both tasks in random order. Okuda et al. (1998) found regional cerebral blood flow (rCBF) increases in the experimental (i.e. the PM) condition compared with the control task in the following regions: left hemisphere: anterior cingulate gyrus (BA 24), superior frontal gyrus (BA 10) and parahippocampal gyrus (BA 28); right hemisphere: inferior and middle frontal gyri (BA 8, 9

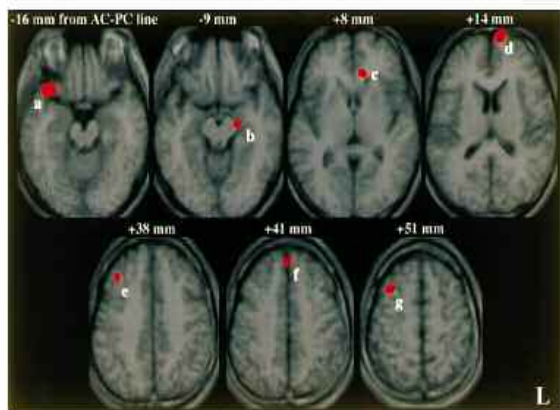


and 47). In addition, there was involvement of the frontal lobe medially (BA 8). However, Okuda et al (1998) were unable to determine whether this activation was associated with intention maintenance, target detection or the requirement for “dividing attention between the planned action and the routine activity”.

These two studies, despite using different methods, show a number of areas of agreement, and together

provide some hypotheses both regarding the regions of the brain involved in PM, and the roles that they play. Thus both studies suggest involvement of the anterior cingulate gyrus plus BA 8–10, especially on the left, plus some involvement more dorsolaterally in the right frontal lobe. However, there is less agreement between them as to the roles these regions play in the realisation of delayed intentions. Thus Okuda et al. (1998) suggest that the right middle frontal activation reflects the extra load upon memory in a PM task, with the left BA 10 and right BA 47 regions “related to the process of holding intention of future behaviour”, while the left parahippocampal activation reflects the novelty detection requirements of the task. However, in the Burgess et al. lesion study (2000), the suggested role of the right frontal lobe is in the creation of intentions (as a function of planning), with an area which includes left hemisphere region BA 10 involved in the prospective components of RDI such as the maintenance or triggering of an intention. More promising, both investigations agree in the involvement of parts of BA 8 (especially the left) in these prospective components.

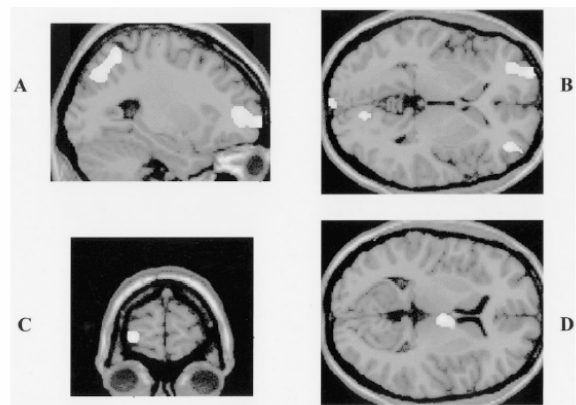
Okuda et al. (1998) were unable to determine whether this activation was associated with intention maintenance, target detection or the requirement for “dividing attention between the planned action and the routine activity”. The Burgess et al., (2000) study helped in this respect, by including a condition where subjects were told that intention cues/targets might appear, but none actually did. Critically, rCBF increases in lateral area 10 were also found in this condition, i.e. where there is only the *expectation* of intention cues, and such cues are never witnessed or responded to. Thus lateral BA 10 is more involved with the maintenance of an intention rather than cue recognition or intention execution (Figure 2.1 and 2.2).



Red areas activated regions during the prospective memory task compared with the control task.

- (a) The right inferior frontal gyrus
- (b) the left parahippocampal gyrus
- (c) the left anterior cingulate gyrus
- (d) the left superior frontal gyrus

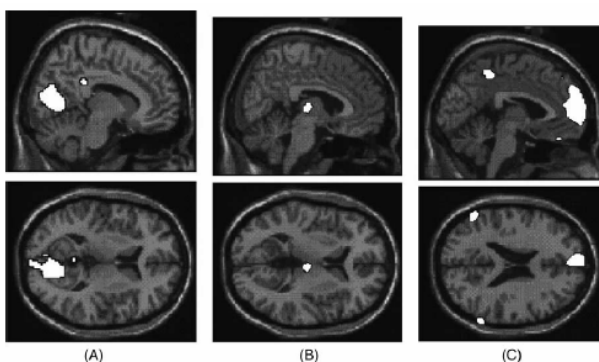
**Figure 2.1** In Okuda et al., (1998)



Plates A, B and C show the right parietal, bilateral orbitofrontal, right lateral prefrontal and regions associated with intention maintenance. Plate D shows the thalamic region associated with intention execution.

**Figure 2.2** In Burgess et al. (2001)

A second PET study confirmed the role of lateral BA 10 in PM conditions, but also showed that the *medial* BA 10 is more active in ongoing conditions than PM ones (Burgess et al, 2003). Furthermore, the medial BA 10 was also more active (compared with PM conditions) in a simple attentional baseline condition where subjects just responded as fast as possible to any change on the display (see Figure 2.3).



Representation of selected significant rCBF changes.

**Column A** shows occipital region where blood flow increase occurred in the ongoing relative to the baseline task.

**Column B** shows thalamic rCBF increase in the prospective memory conditions relative to the ongoing task condition.

**Column C** shows the BA 10 decrease in the prospective memory conditions relative to the ongoing task condition.

**Figure 2.3** In Burgess et al. (2003)

The two Burgess et al PET studies had used a “conjunction” experimental design. This is where one investigates haemodynamic changes common to tasks which putatively stress the process of interest

(Shallice, 1988) but where the other characteristics of the tasks are made quite different, for example by using spatial material for one, and verbal material for the other task.

Accordingly, Burgess et al (2003) interpreted their results as suggesting that the functions supported by area 10 in prospective memory are “central” in the respect that they are material-inspecific, and unrelated to precise intention retrieval or cue recognition demands. Instead, Burgess et al. favoured an explanation in terms of one of the possibilities raised by Okuda et al (1998), that the rostral PFC rCBF changes were related to the attentional demands made by having to “bear in mind” an intention whilst

performing an ongoing task.

Further evidence for the specificity of some regions of area 10 comes from a recent paper by Okuda et al (2007). In two positron emission tomography (PET) studies brain activity associated with time- vs. event-based prospective memory tasks was examined. In the time-based condition of the first study young healthy volunteers were asked to make a response based on their self-estimation of the passage of time while engaged in an attention-demanding ongoing activity. In the time-based condition of the second study, participants had a clock available. Both studies showed activation differences in rostral PFC (principally BA 10) according to whether the task was time- or event-based.

In study one, subjects performed two prospective memory tasks (one time- and one event-based) and a baseline task required the ongoing activity alone. The ongoing activity was a serial addition task. A digit, randomly selected from one to nine, was presented binaurally every 3 seconds and the subjects were required to add up the digits one by one and report the sum immediately after the presentation of each digit. The prospective response was to clench both hands. In the time-based task, the subjects were asked to make the prospective response once during the first 30 seconds, twice during the next 30 seconds, once during the third 30 seconds, and once during the last 30 seconds after the task started. In the event-based task, they were asked to make the prospective memory response when a cue stimulus (the number "7") was presented during the ongoing activity. The cue stimulus was presented once during the first 30 seconds, twice during the next 30 seconds, once during the third 30 seconds, and once during the last 30 seconds. Okuda et al (2007) found in this experiment that an area of left lateral superior rostral PFC (BA 9/10) was more active during the time-based PM condition than during either the event-based PM condition or the ongoing task alone.

Okuda et al's (2007) second experiment used a conjunction design, looking at the activations common to two different PM tasks: “verbal” or “non-verbal”, each presented in three conditions (Time PM; Event PM; Ongoing Task only). In the verbal tasks, the ongoing task required the

participants, when presented with pairs of words, to make a same-different judgment based on the number of syllables in each word. For the ongoing task of the non-verbal conditions, participants were presented with a pair of

rectangles and had to judge if the shapes were identical, regardless of their orientation.

In the time-based PM conditions of each task, a clock was always presented at the center of the screen, which was updated every second to indicate current time from the start of the task. Subjects were asked to press a button at every minute after starting the task, and were told that they could use the the clock to help them. In the event-based PM conditions, subjects were asked to press a button whenever they encountered a cue stimulus, which was the word ‘guitar’ in the verbal tasks, or exact squares in the non-verbal tasks.

In contrast to the first study, a region of increased rCBF was found in left lateral rostral prefrontal cortex during the event-based PM conditions compared with the time-based conditions. This region was somewhat inferior within area 10 to that found in experiment 1. Across both studies, rCBF in the rostro-medial prefrontal cortical regions increased during the time-based task and the ongoing-alone task as compared to the event-based task. These regions were more rostral, superior and closer to the midline than the medial BA 10 regions identified in experiment 1. (The aspect of exactly *where* within area 10 the activations occurred will become important in the discussion of the functions of area 10 below.) With our current limited understanding of both of the dynamics of prospective memory tasks and of the functional architecture of area 10 it is yet too early to reach a full explanation of these results. However, they do seem to suggest that brain activity in the rostral prefrontal cortex shows different patterns during the performance of time- and event-based prospective memory tasks.

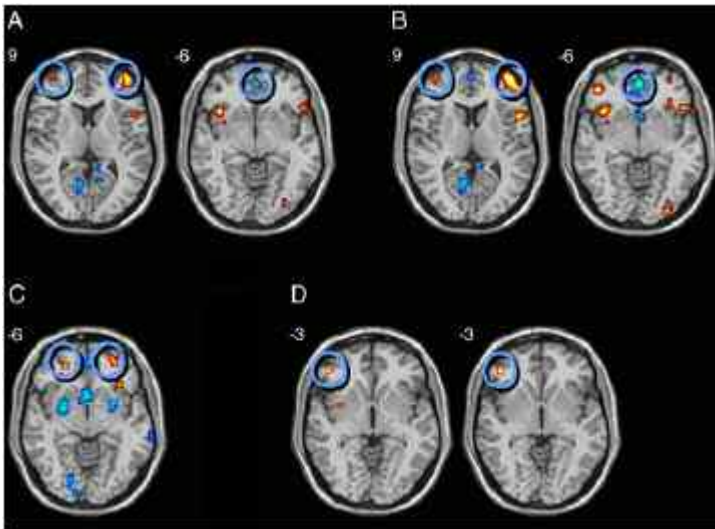
Furthermore, they seem to suggest that subregions of area 10 are differentially involved in time-based tasks according to whether or not a clock is present as an aid to notice the passage of time. One possibility to explain this latter phenomenon, and which relates to the explanation of the Simons et al.’s (2006) findings above, is that having a clock available increases the degree to which the participant attends to environmental stimuli rather than maintaining a continually updated, self-generated representation of the passage of time. In other words, it changes the relative amount of *stimulus-oriented* and *stimulus-independent* attending).

## **2.3 Neuroimaging studies of Prospective Memory: Functional Magnetic Resonance**

### **Imaging technique (fMRI)**

Simons et al. (2006) examined these issues by scanning participants using fMRI while they were undertaking a task in which PM trials were embedded in an ongoing task in such a way as to prevent participants from actively rehearsing the intentions. Two PM conditions were used, one with a high cue identification demand and a low intention retrieval demand (the 'cue identification PM condition'), and one with a low cue identification demand and a high intention retrieval demand (the 'intention retrieval PM condition'). Cue identification was manipulated by altering the perceptual salience of the PM cues. In the low cue identification demand condition, the cues were perceptually distinct from the ongoing trials, while in the high demand condition, the cues were perceptually similar but conceptually distinct. Intention retrieval demand was manipulated by varying the number of actions participants needed to perform in order to determine the appropriate response. If, as predicted by previous neuroimaging studies (Okuda et al., 1998; Burgess et al., 2001, 2003; den Ouden et al., 2005), an anterior prefrontal cortex network supports PM functions regardless of the demands on cue identification and intention retrieval, then a substantial overlap can be expected between the patterns of activation associated with each PM condition.

Simons et al. (2006) explicitly tested this hypothesis by measuring brain activity (using a conjunction of two different PM tasks: "Words" and "Shapes") whilst manipulating the demands on either recognizing the appropriate context to act on ("cue identification") or remembering the action to be performed ("intention retrieval"). In the "word task", each trial consisted of two nouns presented next to each other in the middle of the screen, one of which was written in upper case and the other in lower case letters. A consistent pattern of hemodynamic changes was found in anterior prefrontal cortex (BA 10) across both types of tasks and across both PM conditions (compared with the ongoing task): there was activation in the bilateral BA 10, which was accompanied by deactivation in the medial BA 10. These regions were located somewhat more medially than those that showed common activation in both conditions (see Figure 2.4). Simons et al. (2006) argue that the regions that were activated in both PM conditions may reflect the requirement in PM tasks for the biasing of attention between external events (e.g. identifying the distractor stimuli) and internal thought processes (i.e. maintaining the intention and remembering the intended actions). However, it also seems from the comparison of the two PM conditions that there are some sub-regions of area 10 which are more sensitive to particular PM task characteristics.



(A) Contrasting cue identification PM trials with ongoing trials, bilateral BA 10 activation and medial BA 10 deactivation was observed.

(B) A highly similar pattern is shown in the intention retrieval PM vs. ongoing contrast.

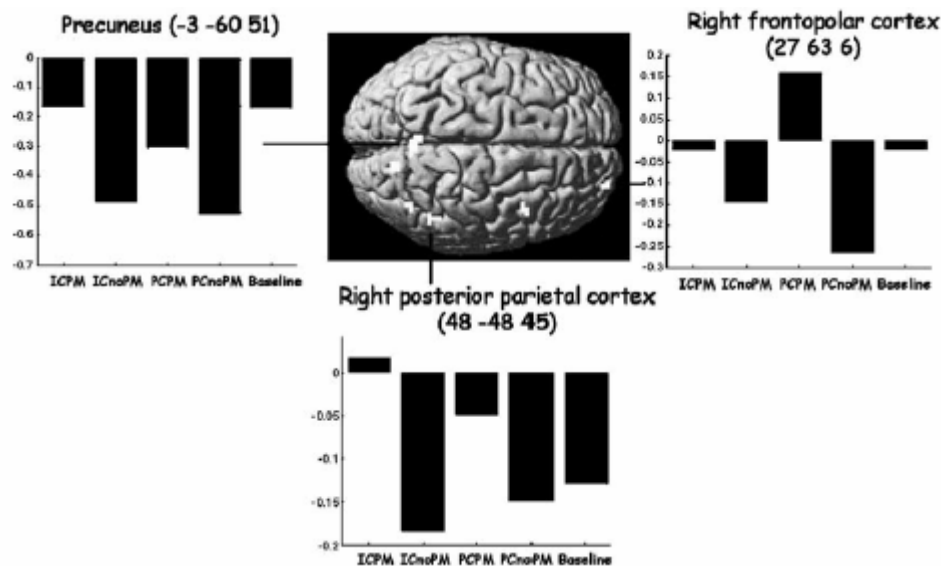
(C) Differences between conditions the direct intention retrieval PM > cue identification PM contrast, with significantly greater activation in anterior prefrontal cortex bilaterally in the intention retrieval PM condition, and evidence of deactivation in medial anterior BA 10.

(D) Left lateral BA 10 activation was found in the contaminated ongoing > uncontaminated ongoing condition

**Figure 2.4** In Simons, Schölvinck, Gilbert, Frith, and Burgess (2006)

Even den Ouden et al. (2005) suggested that different regions of the medial prefrontal cortex (mPFC) play a different role in thinking about intentions.

They reported activation in the lateral BA 10, the lateral parietal cortex and the precuneus associated with keeping an intention in mind (to press a key on seeing a red stimulus background) while performing an ongoing Casuality task responding to questions about intentions and actions (Figure 2.5). The lateral part of the frontopolar cortex (BA 10) activated during PM tasks appears to be involved in maintaining an intention whilst performing an ongoing task (Burgess et al., 2001, 2003). The right parietal lobe has been suggested to play a role in sustained attention or vigilance and the precuneus a special role in processing intentions related to the self (Gusnard and Raichle, 2001; Johnson et al., 2002; Kajer et al., 2002; Kelley et al., 2002).



**Figure 2.5** Greater activations in the frontal pole (BA10), the precuneus/PCC and the right parietal cortex in the prospective memory condition compared with blocks in which subject did not execute the prospective memory task.

*In den Ouden et al (2005)*

Motor brain regions seem to play an important role in the encoding of delayed intentions. Eschen et al., (2007) demonstrated that motor brain regions are differentially activated during the verbal encoding of simple actions intended for later enactment in contrast to the verbal encoding of similar actions for later verbal report. They found that during the verbal encoding of actions intended for later enactment with the right arm in comparison to the verbal encoding of actions for later verbal report following regions in the left hemisphere were more activated: the postcentral gyrus (BA 2), the left precuneus (BA 7), the posterior superior frontal gyrus (BA 6), the posterior middle temporal gyrus (BA 39/37), the posterior middle frontal gyrus (BA 6) and the inferior parietal lobule (BA 40).

Results indicate the presence of preparatory motor operations during the encoding of delayed intentions requiring a future motor response, which cannot be attributed to semantic information inherent to action verbs.

## **2.4 Neuroimaging studies on Prospective Memory: Magnetoencephalography technique (MEG)**

Magnetoencephalography (MEG) is a noninvasive technique for investigating neuronal activity in the living human brain. The time resolution of the method is better than 1 ms and the spatial discrimination is, under favorable circumstances, 2-3 mm for sources in the cerebral cortex (Hämäläinen et al., 1993). Importantly, MEG can be used to investigate activity in medial temporal and subcortical areas, including hippocampus (Tesche et al., 1996), thalamus (Tesche, 1996) and cerebellum (Tesche and Karhu, 1997).

Martin et al. (2006) measured brain activity using magnetoencephalography in five participants during tasks that included prospective memory, retrospective memory, and oddball trials. Participants were asked to respond to a particular infrequent shape (termed the PM target) when they saw it. Another infrequent shape (the oddball) did not require a response, allowing to assess differences between prospective remembering and perceiving a rare event. Finally, two additional shapes were associated with a RM task. These shapes (termed the RM targets) were preceded by a retrospective memory cue in the form of the word “Memory” flashed on the screen, which alerted participants that the following stimulus would be a test of RM for the response associated with the stimulus.

The addition of source modeling of neurophysiological (MEG/EEG) data may provide information on brain dynamics that is useful in teasing apart different stages of PM. There are many measures of brain activity that can be derived from MEG measurements. In the present study, spectro-temporal features in the MEG data were characterized using onset and duration of features in evoked-response waveforms and also a wavelet analysis of oscillatory activity. Frequencies of particular interest in the wavelet analysis included theta, upper alpha, and lower alpha. Both theta and alpha frequency bands have been associated with memory processes (Gevins et al., 1997; Jensen and Tesche, 2002; Klimesch, 1999; Klimesch et al., 2005; Raghavachari et al., 2001; Sarnthein et al., 1998; Tesche and Karhu, 2000).

Sources were identified in the hippocampal formation, the posterior parietal and frontal lobes.

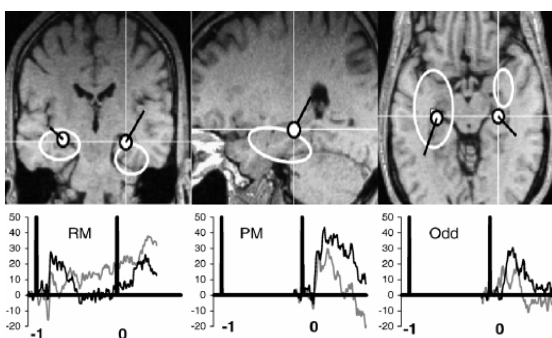
Activation of the hippocampal sources occurred earlier in the RM and PM conditions than the oddball condition, and appears to have a similar duration in the PM and RM conditions, both longer than the oddball condition. This is the first study to report hippocampal activation for a PM task using MEG and, this considered together with the results for the parietal cortex, provides strong support for the noticing plus search model introduced at the outset (Einstein and McDaniel, 1996; McDaniel, 1995).



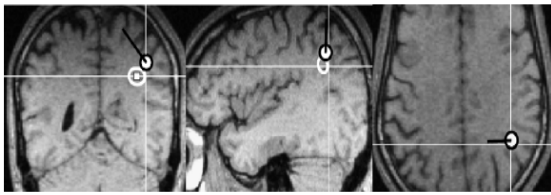
The timing of the hippocampal activation is consistent with the model's assumption that noticing, which should take place in the PM but not the oddball condition, is followed by a search that retrieves the intended action associated with the PM target.

Then, the results showed a very early activation in the parietal source in the PM condition (a mean onset time of 87.2 ms, compared to 158.8 ms for the RM condition and 187.2 ms in the oddball condition). This very early response suggests involvement of the parietal cortex in PM trials before elaboration of higher-order visual processing in the occipital association cortex. Interestingly, the early parietal response in PM trials may be similar to activation observed in go-nogo tasks. VanRullen and Thorpe (2001) measured visual ERPs in a go-nogo visual categorization task and found perceptual category effects beginning at 75–80 ms at parietal locations, which they contrasted with frontal locations showing differences around 150 ms post onset that depended on the task. Taken with the current results, this suggests that noticing that the appropriate conditions for a PM response have occurred may be mediated through perceptual categorization at very short latencies. Activation of frontal sources during PM trials is consistent with results reported by Burgess et al. (2001), who found greater activation when participants expected PM targets, regardless of whether such targets were actually shown. The frontal sources detected in the present study were active in all conditions for all participants, and there was no observable dependence of activation on condition. According to the supervisory model, activation associated with monitoring for a PM target should be similar to activity elicited by the oddball.

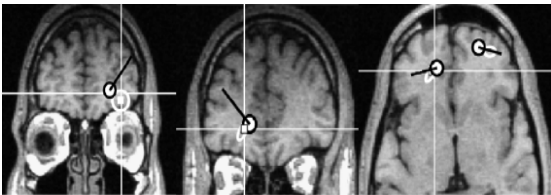
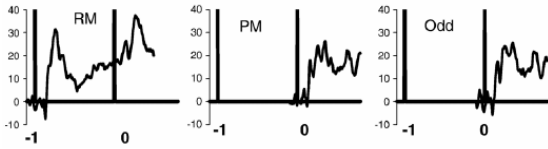
However, because onset of the RM target stimuli was cued by an explicit prompt, participants would not have expected PM targets on the RM trials, and therefore the supervisory model might expect that monitoring (supervisory processes activated to detect PM targets) should have subsided on RM trials. Thus, the present pattern of similar frontal activation extending to RM trials is not necessarily consistent with the supervisory model or previous patterns supporting it. However, the authors emphasize that their results do not allow us to draw firm conclusions about the supervisory model because there was inadequate power to detect differences in frontal area activations (Figure 2.6).



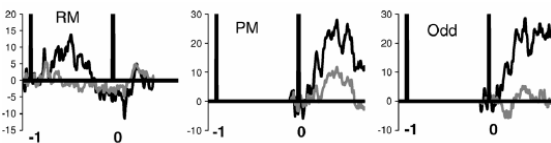
*The hippocampal sources*



*The parietal sources*



*The frontal sources*



**Figure 2.6** In Martin et al. (2006)

## 2.5 Conclusion and discussion about Brodmann Area 10

The main neuroimaging findings on prospective memory reveal a strikingly similar pattern of hemodynamic changes, involving the anterior prefrontal cortex (BA 10), confirming the view from previous neuroimaging studies that this region is likely to be of central importance for prospective memory (Okuda et al., 1998; Burgess et al., 2001, 2003; den Ouden et al., 2005).

To sum up, Okuda et al. (1998) reported activation in the left frontal pole (BA 10) as well as in the right dorsolateral and ventrolateral prefrontal cortices (BA 8/9/47) and anterior cingulate (BA 24), when participants remembered and acted upon a list of target words relative to performing an ongoing routine activity (word repetition). Activation in the frontal pole (BA 10, bilaterally) was also found by Burgess et al. (2001) across several cognitive tasks. Burgess et al. (2003) extended these results by showing that the bilateral activation of the lateral BA 10 associated with retrieving a delayed intention was accompanied by deactivation in the medial BA 10. Recently, den Ouden et al. (2005) reported activation in the lateral BA 10, the lateral parietal cortex and the precuneus when participants kept an intention in mind while performing the ongoing task of responding to questions about intentions and actions.

The greater *lateral BA 10* activation associated with intention retrieval can be conceived of in terms of differential attention towards external events and internally generated thought processes: area 10 seems to be sensitive to differences in the source of the representations that are currently active in one's mind (Burgess, Simons, Dumoutheil, & Gilbert, 2005; Gilbert, Frith, & Burgess, 2005; Gilbert, Simons, Frith, & Burgess, in press; Simons, Owen, Fletcher, & Burgess, 2005; Simons, Gilbert, Owen, Fletcher, & Burgess, 2005; see also Christoff & Gabrieli, 2000; Gusnard, Akbudak, Shulman, & Raichle, 2001).

By this account, when one's primary aim is to detect a cue, attention must be turned towards the external world; once the cue has been detected, however, one must disengage from the external stimuli and attend to internal representations so that the relevant intention can be retrieved from memory. Thus, placing higher demands on cue identification implies biasing attention more towards external stimuli, whereas a higher load on intention retrieval implies an increase of attentional focus upon internally generated thought.

A number of previous studies have shown that the lateral BA 10 plays an important role in the recollection of details about the context in which previous events occurred (Ranganath, Johnson, & D'Esposito, 2000; Rugg, Fletcher, Chua, & Dolan, 1999; Simons, Gilbert, et al., 2005; Simons, Owen, et al., 2005), an ability that requires retrieval of internally represented mnemonic information (Simons, Gilbert, et al., 2005; Simons, Owen, et al., 2005).

In contrast, the medial BA 10 has been associated with performance of tasks that emphasize the processing of externally presented stimuli (Gilbert et al., 2005; Janata et al., 2002; Small et al., 2003). Thus, Burgess et al. (2005) have suggested that the lateral areas of BA 10 may play a role in maintaining attention towards internal cognition and the more medial areas in maintaining attention towards external stimuli. The results from the PM versus ongoing contrasts in the present experiment can be interpreted along these lines, with the medial BA 10 deactivation reflecting disengagement from the external ongoing task stimuli and the lateral BA 10 activation being associated with the directing of attention towards the internally represented PM intention (see Burgess et al., 2003, for a similar suggestion). Consistent with this view, lateral BA 10 activation was greater when the demands on intention retrieval were higher, and there was evidence of greater medial BA 10 activation associated with the cue identification PM condition, in which external cue processing demands were greater. Taken as a whole, these results are in agreement with the hypothesis that BA 10 acts as a "gateway", biasing attention between externally derived perceptual information used to detect the occurrence of a PM cue and internal thought processes relating to the stored PM intention (Burgess et al., 2005; Gilbert et al., 2005; Simons, Gilbert, et al., 2005).

The first experiment to test this hypothesis was presented by Gilbert, Frith and Burgess (2005). They contrasted, using fMRI, the neural activation that occurs when people are performing tasks using stimuli presented on a display, with that which occurs when they are performing the same tasks “in their heads”. The medial Area 10 was found to be activated in the condition where people are using externally displayed stimuli (i.e. “stimulus-oriented attending”, SO) compared with when they are doing the same task in the absence of relevant stimuli (“stimulus-independent cognition”, SI). It also showed lateral BA 10 activation at the points where subjects switched between either condition, regardless of the direction of the switch (i.e. SO -> SI; SI -> SO). Thus the existence of a neural mechanism which arbitrates between stimulus-independent and –oriented thought received support, and a link between this mechanism and rostral PFC seemed a promising line of enquiry. A further fMRI study (Gilbert, Simons, Frith and Burgess, 2006) demonstrated *performance-related* activation (i.e. increased activation was associated with faster RTs) in the medial Area 10 in simple reaction time conditions which did not require substantial stimulus processing. Thus the characterisation of the medial rostral PFC as most active when an unusual degree of attention to external stimuli is required was supported.

These results indicate that there might be a general principle for the functional organisation of at least some parts of human brain area 10. This view received further support from a meta-analysis conducted by Gilbert, Spengler et al. (2006a). They analysed the reaction times (RTs) to paradigms from 104 PET/fMRI studies, yielding 133 independent contrasts. The tasks that had provoked these activations came from a wide range of functions, e.g. memory, mentalizing, perception, as well as prospective memory. A fascinating general principle emerged. Gilbert, Spengler et al. (2006a) found that RTs in tasks which had provoked lateral area 10 activations tended to be slower than RTs in whatever control task had been used. The pattern occurred regardless of the type of task under study, and thus seems to be a general principle of area 10 neuroimaging findings. If the lateral area 10 plays some part in effecting tasks which require the various forms of stimulus-independent cognition as argued here, then this pattern would be expected.

This is because reaction times to tasks which require attending to stimuli *plus* some form of stimulus independent thought (e.g. performing an ongoing task whilst maintaining an intention, checking for PM cues etc.) will be longer, typically, than to tasks which only require the stimulus attending component (e.g. the ongoing task alone).

This result also accounts for the consistent findings of rostral PFC activation in paradigms where there may be expected to be a novel degree of juxtaposition between stimulus-oriented and – independent thought, either induced intentionally by the task or because of spontaneous task-irrelevant thoughts (e.g. prospective memory and other multitask and switching paradigms, e.g.

Braver and Bongiolatti, 2002; Burgess et al., 2001, 2003; Dreher et al., 2002; Koechlin et al., 1999, 2000; Okuda et al., 1998; Pollmann et al., 2001, 2004; or memory control processing, e.g. Fletcher and Henson, 2001; Herron et al., 2004; see Gilbert et al., 2006b for review).

However while there might be general principles for the organization of area 10 functions, this does not mean that there is not specialization within these parameters. Thus Gilbert et al. (2006b) investigated, using the neuroimaging database described above, the location of activations within Area 10 according to the type of task being used. They found evidence for specialization of function within Area 10, with mentalizing tasks tending to provoke activations within the caudal medial parts of the BA 10, episodic memory tasks (i.e. retrospective memory) being associated with lateral area 10 activations, and paradigms that required the co-ordination of two or more activities (including prospective memory) being associated with very rostral activations within area 10.

## CHAPTER 3

### NEURAL CORRELATES OF PROSPECTIVE MEMORY: ELECTROPHYSIOLOGICAL EVIDENCE

#### 3.1 Studies on event related potentials (ERPs)

The methodology often used to study the neural processes involved in cognitive tasks is the ERPs methodology. Event-related potentials (ERPs) are voltage fluctuations that are associated in time with some physical or mental occurrence. These potentials can be recorded from the human scalp and extracted from the ongoing electroencephalogram EEG by means of filtering and signal averaging. Because the temporal resolution of these measurements is on the order of milliseconds, ERPs can accurately measure when processing activities take place in the human brain.

The spatial resolution of ERP measurements is limited both by theory and by our present technology, but multichannel recordings can allow us to estimate the intracerebral locations of these cerebral processes. According to multicomponent models of prospective memory ( see Hitch & Ferguson, 1991 in Chapter 1), event-related brain potentials (ERPs) studies that examined the neural correlates of prospective memory, have revealed two modulations of the ERPs associated with detection of prospective cues and the retrieval of intentions from memory: the N300 and prospective positivity (West et al., 2001; West & Ross-Munroe, 2002).

The first component, *N300*, reflects greater negativity for prospective cues than for ongoing activity trials that is maximal in amplitude over the occipital–parietal region of the scalp between 300 and 400 ms after stimulus onset (West & Covell, 2001) and it is was mainly elicited when cues are defined by letter case (West et al., 2001), color (West & Ross-Munroe, 2002) or word identity (West, Herndon, & Ross-Munroe, 2000). The N300 is greater in amplitude for prospective hits than for prospective misses leading to the suggestion that it is associated with processes underlying the detection of prospective cues (West, Herndon, & Covell, 2003a; West & Ross-Munroe, 2002) or the prospective component of prospective memory.

The amplitude of the N300 is reduced in older adults (West & Covell, 2001; West et al., 2003), and this reduction appears to result from the failure of older adults to recruit controlled attentional processes that facilitate cue detection (West & Bowry, 2005). This proposal is consistent with behavioural evidence indicating that age-related declines in prospective memory in later adulthood

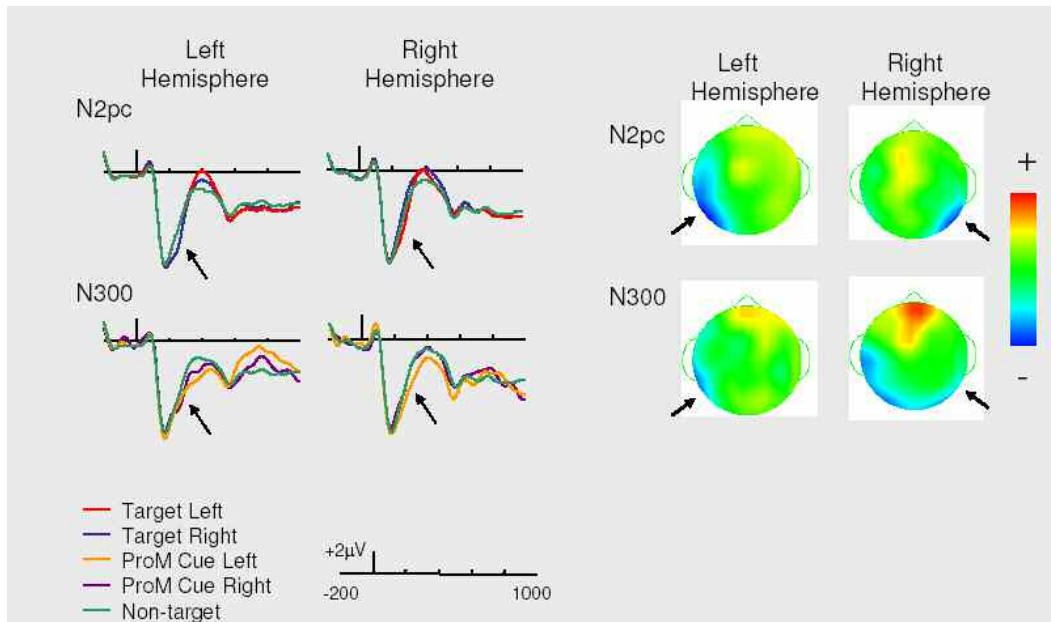
result from a reduction in the likelihood that older adults recruit preparatory attentional processes (Smith & Bayen, 2006).

West et al. (2004) compared the functional characteristics of the neural generators of the N300 with those of the N2pc when prospective memory cues were embedded in a target discrimination task similar to that used by Eimer (1996). If a common neural mechanism contributes to the detection of prospective memory cues and target selection, the functional characteristics of the N300 and N2pc should be similar. Specifically, the amplitude of these modulations of the ERPs should be greater over the hemisphere that is contralateral to the visual field in which the prospective cue or target appears. In contrast, if distinct processes contribute to the detection of prospective memory cues and target selection, the N300 and N2pc should demonstrate different functional characteristics. West also sought to replicate the finding that the prospective positivity can be dissociated from the target P3 (West et al., 2003).

The ERP correlates of target selection for information represented in visual working memory task showed the presence of one component, the N2pc. This component is associated with target selection in visual search tasks (Luck & Hillyard, 1994) and visual discrimination tasks (Eimer, 1996): enhancement of N2 component 200-300 msec after stimulus onset over the occipital-parietal region of the scalp that is contralateral to the visual field in which the target is presented. Luck & Hillyard (1994) argued that N2pc was associated with distractor suppression during visual search while Eimer (1996) the N2pc was related to target selection rather than to component was embedded in a target discrimination.

The *N300* associated with the detection of a prospective memory cue and the N2pc are similar because their amplitude is maximal over the occipital-parietal region of the scalp (Eimer, 1996; West et al., 2001) and appear to reflect subcomponents of the N2, which is generally elicited by the presentation of a task-relevant stimulus. Like the N300, the N2pc is elicited by targets that are defined by a single feature or a conjunction of features (e.g., orientation, color, or size; Luck, Fan, & Hillyard, 1993; Luck & Hillyard, 1994) and by those that are defined by letter and word identity (Eimer, 1996). Together, these similarities lead one to wonder whether a common neural mechanism that supports the selection of task-relevant information contributes to generation of the N300 and the N2pc. Targets and prospective memory cues elicited an N2pc, revealing that a common neural mechanism contributes to the selection of task-relevant stimuli in prospective memory and working memory. In contrast, the N300 was elicited only by prospective memory cue trials and appears to reflect the activity of distinct subcomponents that are differentially sensitive to the influence of attention (Figure 3.1).

These findings are consistent with those of a growing body of literature indicating that an attentional mechanism possibly supported by the right hemisphere serves to facilitate the detection of prospective memory cues when they are encountered, thereby enhancing the efficiency of prospective memory (Burgess et al., 2001; Smith, 2003).



**Figure 3.1** The N300 and N2pc: ERPs data. *In West et al. (2004)*

West et al. (2001) investigated the influence of attention on the N300 in a study in which individuals were told to ignore highly salient prospective cues for half of the blocks and to make a prospective response when the prospective cues were detected in the remaining blocks. In that study, the amplitudes of the N300 in the attend and ignore conditions were similar over the left hemisphere, indicating that this modulation probably reflected the N2 component, which is elicited by perceptually salient stimuli (Mangun & Hillyard, 1995). In contrast, the amplitude of the N300 over the right hemisphere was greater in the attend condition than in the ignore condition, presumably reflecting the influence of attention on prospective remembering.

In agreement with predictions derived from the automatic associative and PAM models and in contrast to the idea that noticing is a relatively automatic process, West et al. (2001) observed that the amplitude of the N300 is modulated by the allocation of attention in prospective memory tasks. Further evidence that attentional processes contribute to generation of the N300 comes from a study that revealed that the amplitude of this modulation is sensitive to the working-memory demands of the ongoing activity (West, Bowry, & Krompinger, 2004). In that study, the amplitude of the N300 was attenuated when prospective memory cues were embedded in a 3-back working memory task



relative to when cues were embedded in a 1-back working memory task, while the amplitude of prospective positivity was not sensitive to variation in N-back load supporting the proposal that preparatory attentional processes (Smith & Bayen, 2005) that consume working memory capacity underlie successful prospective remembering.

These two findings have led to the proposal that noticing may be achieved through the attentional modulation of those neural systems that support processing of the defining features of the prospective memory cue (West et al., 2001; for a review of the ERP and attention literature see Hillyard et al., 1995), and that attentional processes associated with the detection of PM cues are sensitive to working memory demands of the ongoing activity and that different processes may support prospective memory depending on the working memory demands of the ongoing activity.

Even in the preparatory attention and memory (PAM) processes theory of prospective memory, Smith (2003) proposes that the allocation of preparatory attentional processes, which are thought to consume working memory capacity, is required for a stimulus to be recognized as a prospective memory cue. In agreement with this proposal, an index of preparatory attentional processes was found to correlate with the accuracy of prospective memory and individual differences in working memory capacity (Smith, 2003).

A second component associated with the retrieval of the intention from memory is the *prospective positivity*. This component is typically observed between 400 and 1200 ms after stimulus onset and is broadly distributed over the central, parietal, and occipital regions of the scalp (West & Covell, 2001). Like the N300, the prospective positivity distinguishes prospective hits from prospective misses indicating that it is associated with successful prospective memory (West & Ross-Munroe, 2002).

The exact nature of prospective positivity is not well understood. It can reflect the activity of neural mechanism that supports post-retrieval monitoring processes that are engaged following the detection of a PM cue and the recovery of an intention from memory that serves to determine whether a prospective response is warranted similar to directed search of Einstein and Mc Daniel (1996) or support the ability to disengage from the ongoing activity once the prospective cue is detected or to coordinate the ongoing and prospective components of the task following the detection of a PM cue (West et al. 2005).

Sometimes it is difficult to distinguish ERP correlates of retrieval processes in prospective and retrospective memory (i.e. recognition and cued-recall). Modulations of the ERPs elicited during recognition memory have been associated with the contribution of familiarity to recognition of a

previously studied item, the recollection of a previous item, and monitoring the produce of a memory search (Allan et al., 1998; Rugg, 1995); likewise, modulations of the ERPs elicited during cued-recall have been related to the retrieval of an associate from memory and the recovery of contextual information related to a studied pair (Allan & Rugg, 1998).

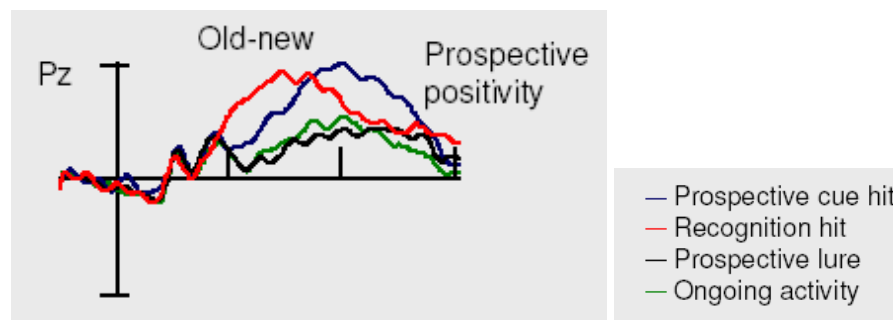
The recognition of a previously studied item in retrospective memory tasks is consistently associated with a series of modulations that arise as early as 200 ms after stimulus onset and are distributed over the parietal and frontal regions of the scalp (i.e., old–new effect, FN400, frontal slow wave).

The parietal old–new effect reflects greater positivity for old items than new items between 300 and 800 ms after stimulus onset that is greater in amplitude over the left than right hemisphere (Paller & Kutas, 1992; Rugg & Nagy, 1989). Between 300 and 600 ms the parietal old–new effect is greater in amplitude for hits and misses than new items (Rugg et al., 1998a) and is similar in amplitude for items that were encoded at deep and shallow levels during encoding (Rugg et al., 1998a, 1998b). Together these findings have led to the suggestion that the early old–new effect is associated with the contribution of item familiarity or implicit memory to recognition. Between 600 and 800 ms the parietal old–new effect is greater in amplitude for deeply encoded items than shallowly encoding items (Rugg et al., 1998a) and for old items that are presented in the same format at study and test relative to old items that are transformed between study and test (Curran, 2000; Donaldson & Rugg, 1998). These findings have led to the proposal that the later portion of the parietal old–new effect is associated with recollection (Rugg et al., 1998a). In addition to the early portion of the parietal old–new effect, a second positivity has also been observed over the frontal region of the scalp between 300 and 500 ms after stimulus onset that has been associated with familiarity (FN400, Curran, 2000; Curran & Dien, 2003). The frontal slow wave can emerge as early as 300–500 ms after stimulus onset and is typically greater in amplitude over the right than left hemisphere (Rugg & Doyle, 1992). The frontal slow wave is greater in amplitude for hits than misses (Rugg et al., 1998a) and when contextual information related to the item is recovered from memory relative to when individuals fail to retrieve contextual information (Donaldson & Rugg, 1998; Wilding & Rugg, 1996, 1997). The frontal slow wave is thought to be associated with the activity of post-retrieval processes that support the utilization of recollected information to guide task performance (Allan et al., 1998).

The ERP correlates of cued-recall have not been as extensively studied as those of recognition. The successful retrieval of a prior associate during cued-recall consistently elicits a slow wave that emerges between 300 and 500 ms after stimulus onset, persist for several hundred milliseconds, and

is broadly distributed over the frontal, central and parietal regions of the scalp (Allan & Rugg, 1998). The recovery of contextual information from memory is known to contribute to the slow wave elicited during cued-recall, as the amplitude of this modulation is greater when both associative and contextual information are recalled than when only associative information is recalled (Allan & Rugg, 1998). Further evidence that the retrieval of contextual information contributes to the amplitude of the slow wave is reflected in the similarity between the ERPs elicited during associative recognition (Donaldson & Rugg, 1998) and cued-recall (Allan & Rugg, 1997).

West & Krompinger (2005) investigating the event-related brain potential (ERP) correlates of retrieval processes in prospective and retrospective memory found that prospective positivity reflects two distinct components. The first is associated with the retrieval of a prior episode from memory and is common to prospective memory and explicit episodic memory (e.g., recognition or cued-recall,). The second appears to be more unique to prospective memory and may be related to post-retrieval processes that serve to coordinate the prospective and ongoing components of the task after a cue is detected and an intention is retrieved from memory (West & Krompinger, 2005; Figure 3.2)



**Figure 3.2** *In West & Krompinger (2005)*

There is evidence that the P3b component contributes to the prospective positivity in some task conditions. For instance, the amplitude of the prospective positivity between 400 and 600 ms after stimulus onset is greater for perceptually salient prospective cues relative to non-salient prospective cues (West, Wymbs, Jakubek, & Herndon, 2003b), consistent with evidence that the amplitude of

the P3b is modulated by target distinctiveness (Donchin & Coles, 1988). In contrast, the amplitude of the prospective positivity is not sensitive to the salience of the prospective cues between 600 and 800 ms, leading to the suggestion that the P3b does not contribute to the prospective positivity during this interval. The later portion of the prospective positivity (between 600 and 800 ms) is also greater in amplitude when there are multiple cue-intention associations relative to when there is a single cue-intention association (West et al., 2003b), leading to the proposal that the prospective positivity is associated with the activity of a neural mechanism that supports the retrieval of an intention from memory (West & Ross-Munroe, 2002).

Distinct processes are known to contribute to the Late Positive Complex including the P3a, P3b and slow wave. P3a frontal elicited by the presentation of a deviant or novel stimulus regardless of whether the event represents an attention-demanding stimulus (Squires, 75). P3b parietal positivity, is only elicited by attention-demanding stimuli (Donchin, 88) or the activity of process related to stimulus categorization (Kok, 2001) or working memory or context updating (Donchin, 88).

There are similarities between the P3b revealed in oddball task and parietal positivity. PM tasks typically require probability target stimuli that are embedded in a more or less engaging ongoing activity such as a short-term encoding and recall identifying pictures of famous individuals, or performing semantic judgements. Oddball task individuals are typically require to monitor a relatively continuous series of stimuli for the occurrence of a low-probability target and to make either an overt (button press) or covert (count) response following the detection of a target.

The main difference regards the allocation of attention: in fact in the PM task it is of critical importance to have participants perform an ongoing activity that engages their attention so that realization of the intention requires active disengage from the ongoing activity in order to make a PM response. This need to detect PM cues while concurrently absorbed in ongoing activity may be somewhat unique to PM and may be what differentiates PM tasks from vigilance tasks like the oddball where an individual's attention is focused upon the detection of target stimuli.

The effects of aging on the prospective positivity have been somewhat mixed in previous research with one study revealing little effect of aging on the prospective positivity (West et al., 2003) and two studies revealing a clear decrease in the amplitude of the prospective positivity in older adults (West & Bowry, 2005; West & Covell, 2001).

This findings indicate that similar neural processes contribute to the retrieval of item and associative information when that information is encountered within the context of a prospective memory or retrospective memory task. The finding that similar neural processes contribute to prospective and retrospective memory is consistent with the automatic associative model of prospective memory

(Guynn et al., 2001) that reflects an extension of Moscovitch's (1994) working-with-memory model of episodic memory to the area of prospective memory.

In the automatic associative model, Guynn et al. propose that prospective remembering occurs when a focally attended prospective memory cue interacts with a memory trace that represents the cue–intention association, resulting in delivery of the intention to conscious awareness. In agreement with this proposal, data from a number of studies have demonstrated that prospective memory is less efficient when individuals are engaged in processing that is incongruous with that required for the detection of a prospective memory cue (Marsh, Hicks, & Hancock, 2000; Meier & Graf, 2000), presumably resulting from the allocation of focal attention to attributes of the stimulus that are unrelated to its role as a prospective memory cue.

On the other side, these findings indicate that neural processes that are statistically independent from those supporting recognition and cued-recall facilitate the realization of intentions when the prospective memory cue is encountered within the context of an ongoing activity and self-initiated processing is required ( Craik, 1986; Graf & Uttl, 2001).

The observation of a latent variable that differentiates the ERPs elicited by prospective hits from the ERPs elicited by the other trial types that reflected the N300 and prospective positivity is consistent with evidence from a number of neuropsychological studies demonstrating that neural mechanisms distinct from those supporting episodic memory or general intelligence underlie successful prospective memory.

## CHAPTER 4

### PROSPECTIVE MEMORY AND ONGOING TASKS

#### 4.1 Review of the typical paradigms used in prospective memory research

Experimental paradigms of prospective memory typically involve busily engaging participants in an ongoing task while at the same time asking them to perform an action upon seeing a particular target item (Einstein & McDaniel 1990; 2004). For example, participants might be asked to rate words for pleasantness (the ongoing task) and also to perform the prospective memory task of remembering to press a designated key on the keyboard when they see a particular target word. A characteristic of these experiments is that participants are asked to perform the action immediately upon seeing the target word.

To sum up, in a typical situation involving prospective memory:

- there is an intention or are multiple intentions to act on;
- the intentions cannot be executed immediately;
- an intention consists of performing an action in a particular circumstance (the ‘retrieval context’). In event-based studies the retrieval context is signalled by a cue (the “intention cue”);
- the delay period between creating an intention and the occurrence of the appropriate time to act (“the retention interval”) is filled with an activity known as the “ongoing task”;
- performance of the ongoing task prevents continuous, conscious rehearsal of the intentions over the entire delay period. Typically this is achieved by choosing an activity demanding a high degree of attentional resources or by a long delay period;
- the intention cues (or retrieval context) does not interfere with, or directly interrupt, performance of the ongoing task. Intention enactment is therefore self-initiated;
- and mostly no immediate feedback is given to the participants regarding errors.

The dual-task nature of prospective memory paradigms is analogous to research on divided attention (e.g., Craik, Govoni, Naveh- Benjamin, & Anderson, 1996). Divided attention studies begin with the assumption that humans have a limited source of attentional or conscious capacity. If the primary task relies in some way on this limited resource, then the addition of an attention demanding secondary task should have a negative impact on performance on the primary task. Thus, a key feature of any divided attention study is that performance in the divided attention

condition is compared with performance in a full attention condition. Despite the dual-task nature of prospective memory paradigms, the parallel comparison has generally been neglected in this area of research.

Although divided attention paradigms and prospective memory paradigms share some similarities, the tasks also differ in important ways. As noted by Kvavilashvili et al. (2001), participants in prospective memory studies must interrupt their ongoing activity in response to an intermittently occurring event, whereas participants in divided attention studies respond, often in a fairly continuous fashion, to a frequently occurring stimulus source. The idea behind divided attention tasks is that both tasks should make continuous demands on the limited resources available for performing the two tasks simultaneously. This distinction between divided attention and prospective memory tasks may have contributed to the inattention to ongoing task performance.

Brandimonte et al. (2004) proposed some differences between the paradigms commonly used to study prospective memory and those used to investigate vigilance. In a typical laboratory –based prospective memory, the participant is required to perform an ongoing task while at the same time he/she has to remember to perform an action at the appropriate moment. Therefore, the paradigm usually takes the form of a dual task with a primary, ongoing task that serves as a covering task for the prospective background task (e.g. Einstein & McDaniel, 1996). In contrast, in a typical vigilance task, participants are required to monitor an information source for the occurrence of a specified target-event (e.g listen actively and detect infrequent target tones); in doing so they attend to only one source for a prolonged, unbroken period of time (see Parasuraman, 1985). Another important difference is that failure to detect a target in a vigilance task is regarded as attentional in its nature whereas a failure in prospective memory task is commonly considered a memory lapse (Maylor, 1996).

On the other side, it is widely accepted that there is an element of vigilance in every prospective memory task (Dobbs & Reeves, 1996; Maylor, 1996). That is, once the intention to perform an action in the future has been formed, it must be checked occasionally and monitoring for the target must occur. But the important difference between prospective and vigilance processes may be that while the former requires retrieval the latter does not (see Logan, 1998).

In the literature it is not clear and sometimes not specified which type of paradigm is usually adopted in a PM task. We analysed the PM task paradigms reported in articles with the following criteria (see Table 4.1):

- published since 2000;
- concerning event-based prospective memory and
- examining younger adults.

From the twenty-eight papers considered, twelve used a task-switching paradigm in which subjects were required to interrupt the execution of the ongoing task in response to an intermittently occurring event. For example, Burgess, Scott and Frith (2003) used as ongoing task number/letter/picture processing tasks requiring to press two different keys and the PM conditions were identical to those of the ongoing task”except participants were told to press both response buttons together if two even numbers appeared, or if both letters on the same trial were vowels or if both circles were in the middle two rows of the grid, regardless of their orientation”. West and Krompinger (2005) used as ongoing task a semantic related judgements task and asked participants in the PM task to: “press one of two keys indicating whether the cue was in the upper (C key) or lower (M key) position.”

The remaining thirteen papers used a variety of dual-task paradigm requiring to complete the execution of the ongoing task before the execution of the prospective task. Hicks, Marsh and Cook (2005) used a lexical-decision task as ongoing task and following event-based PM task: “participants were asked to press the ‘ / ‘ key whenever they encountered a word denoting an animal... Participants were told to press the ‘ / ‘ key during the blank interval after making their word response (after Marsh et al., 2002)”. *Smith* used a lexical decision task (2003) as ongoing task and following event-based PM task: “They were told that they should try to remember to press the F1 key when they saw any of these words during the experiment and in the embedded condition, participants had to remember to press the F1 key while performing the lexical decision task (2003)”. Three articles were excluded from our classification: two of them because the instructions were ambiguous. For example, in Smith et al. (2005; 2007) authors do make explicit instructions for the PM task: “Participants were not explicitly instructed to press the tilde key before the *Y* or *N* key. If participants inquired about whether to make both responses, they were told that they could press the tilde key only or they could press the tilde key after having pressed the *Y* or *N* key. All responses were recorded, regardless of whether they pressed the tilde key when the string was displayed or when the focus point for the next trial was displayed. All participants in the PM group who remembered to perform the PM task pressed the tilde key instead of the *Y* or *N* on the target trial.” So participants interrupted the ongoing task to execute the prospective response (task-switching).

In one article (Okuda et al., 2007) it was difficult to understand the type of paradigm used because it is not well specified: the ongoing task was a serial addition task where “a digit, randomly selected from one to nine, was presented binaurally every 3 s and the participants were required to add up the digits one by one and report the sum immediately after the presentation of each digit”. In the event-based PM task:“ they were asked to make the prospective response (clench both hands) when a cue stimulus (the number ‘7’) when was presented during the ongoing activity”. It is not clear



whether the participants performed only the PM task or also the ongoing task when the prospective target appeared.

STUDIES	PARADIGM	DUAL-TASK or TASK SWITCH?
Smith (2003)	Ongoing: lexical decision task PM: press F1 if they saw one target words during Ongoing	Dual-task
Smith & Bayen (2004)	Ongoing: sentence verification task PM: press F1 if they saw one of four target words during ongoing	Dual Task or Task Switch
Smith & Bayen (2005)	Ongoing: sentence verification task PM: press F1 if they saw one of four target words during ongoing	Dual-task
Smith, Bayen, & Martin (2007)	Ongoing: lexical decision task. PM: One of the PM groups to press the tilde key when they saw a letter string in red during the ongoing lexical decision task. The other PM group was instructed to press the tilde key if a particular word appeared in the lexical decision task. Participants were not explicitly instructed to press the tilde key before the Y or Nkey (they could press the tilde key only or they could press the tilde key after having pressed the Y or Nkey)	Dual Task or Task Switch
West , Wymbs, Jakubek, And Herndon (2003)	Ongoing: semantic related task PM: when both words were green/yellow press a key other than the keys used for ongoing	Task-switch
West and Kropminger (2005)	Ongoing: semantic related judgements task PM: press two keys (upper or lower position) when they saw target	Task-switch
West, McNerney and Travers (2006)	Ongoing: semantic related judgements task PM: press two keys (upper or lower position) when they saw target	Task-switch
West, Bowry and Kropminger (2005)	Ongoing: 1-back and 3-back, press N-key if letter matched and M-key if was not a N-back match; PM: when a letter was presented in the prospective color they should respond by pressing the V-key.	Task-switch
McDaniel, Guynn, Einstein and Breneiser (2004)	Ongoing: word-rating task PM: press a key if they saw one of two target words during ongoing	Dual-task
McDaniel , Einstein, Graham and Rall (2004)	Ongoing: digit monitoring task PM: press a key if a red screen appear on the computer but not until they finished the current task	Task-switch
Einstein, McDaniel, Thomas, Mayfield, Shank and Morrissette (2005)	Ongoing: word-categorization ongoing task. PM: press a key whenever the target item occurred.	Not Clear
Finstad, Bink, McDaniel and Einstein (2006)	Ongoing: judgements task PM: press a key if they saw one of four target during ongoing	Task-Switch
Marsh, Hicks & Hancock (2000)	Ongoing: lexical-decision task PM: press a key if they saw the target animal word 'dog'	Dual-task

STUDIES	PARADIGM	DUAL-TASK or TASK SWITCH?
Marsh, Hicks, Cook, Hansen, & Pallos (2003)	Ongoing: lexical decision task PM: press a key if they saw the target animal word 'dog' ..clearly specified that the word response to the ongoing lexical decision task should be made first	Dual-Task
Taylor, Marsh, (2004)	Ongoing: pleasantness rating PM: if they encountered an animal beginning with letter L they should press the key before making their pleasantness rating	Dual Task
Hicks, Marsh and Cook (2005)	Ongoing: lexical-decision task PM : press a key if they saw the target animal word 'dog' (after making their word response)	Dual-task
Burgess, Quayle and Frith (2001)	Ongoing: different Four tasks. PM :press a key with the third finger if they saw the target	Task-switch
Burgess, Scott and Frith (2003)	Ongoing: number/letter/picture processing tasks pressing two different keys PM : press both keys together if two even number appear together	Task-switch
Simons, Scholvinck, Gilbert, Frith and Burgess (2006)	Ongoing: indicate if the left or right of two words contained more letters PM : press a different key if the words belonged to the same semantic category	Task-switch
Schmitter-Edgecombe and Wright (2004)	Ongoing (WM test) : to continuously monitor the words presented on the computer screen and to keep in mind at all times the last three words that appeared on the screen. PM: In the focal-cue condition, participants were instructed that, in addition to completing the verbal working memory test, they were to press the semicolon key on the keyboard whenever the target word <i>stone</i> appeared.	Dual task
Cohen, Meiran & Kessler (2006)	Ongoing: concreteness judgment task (concrete vs. abstract) with their right hand PM: They were then asked to also press the yellow key (the "1" key on the upper left corner of the keyboard), using the index finger of their left hand, whenever the PM cue word, the Hebrew word SEFEL (cup) was presented.	Dual task
Okuda, Fujii, Ohtake, Sukiura, Yamadori, Frith & Burgess (2007)	Ongoing: serial addition task PM : clench both hands when the number 7 was presented during the ongoing activities	Dual-task
Kliegel, Martin, McDaniel and Einstein (2002)	Ongoing: word-rating task PM: press a third key whenever one of two appeared	Task-switch
Kliegel, Guynn and Zimmer (2007)	Ongoing: computerized word-rating task PM: press a third key whenever one of three targets appeared they had to refrain from ongoing and press the third key.	Task-switch
Zollig, West, Martin, Mareike, Lemke, & Kliegel (2007)	Ongoing task : semantic relatedness judgement task. PM: represented the second time a word pair appeared in the prospective colour (key 'v')	Task switch

STUDIES	PARADIGM	DUAL-TASK or TASK SWITCH?
Cohen, Jaudas & GoLLwitzer (2008)	Ongoing: lexical decision task PM: Participants were instructed to press the F1 key on the computer keyboard (after first making their lexical decision) if they saw any one of the prospective memory targets during the experiment.	Dual Task
Loft, Kearney & Remington (2008)	Ongoing: lexical decision task PM: Participants were instructed that whenever a PM cue was detected, they should respond first to the lexical decision task and make their PM response during the subsequent waiting message between trials	Dual Task
Bisiacchi, Tarantino & Ciccola (in press)	Ongoing: naming picture task PM: participants were also instructed to press the spacebar key on the keyboard as quickly as possible after naming, whenever the picture "bread" appeared	Dual Task

Table 4.1. Paradigms used in a PM task.

## 4.2 Dual task and task switch paradigms in attention literature

After analysing the main paradigms used in a PM task, it would be interesting to discover in what a PM task really differs from an attentional task.

In the next two paragraphs, we report neuroimaging and electrophysiological studies (ERPs) with typical dual task or task switch paradigms used in attention literature until now and in the last paragraph we report the first study that compared dual task and task switch performance. We expected that the areas activated in a PM task (with dual task and task switch paradigms) are similar to the areas activated respectively in dual task and task switch paradigms in the attention literature.

### 4.2.1 Dual task paradigm

One of the most common manifestations of control over attention is the ability to divide attention between two tasks, and one of the most common methods to study divided attention is the dual task paradigm. Performing dual tasks usually results in performance decrements as compared to single-task performance (for a review, see e.g. Pashler, 1994). Such decrements, evidenced as prolonged reaction times and/or higher error rates, are indicative of additional cognitive demands in the dual task situation as compared to the isolated performance of the single tasks (Braun, 1998; DeJong, 1995; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997).

Current theories of adult dual task performance have modelled limitations in terms of resources or capacities, outcome or competition conflicts, and structural bottleneck. According to resource theories (e.g. Khaneman, 1973; Navon & Gopher, 1979, 1980; Norman & Bobrow, 1975; Wickens,

1991) limitations emerge when task demands must compete for processing capacities. Outcome conflict theorists (e.g. Hirst & Kalmar, 1987; Navon, 1985; Navon and Miller, 1987, 2002) propose that limitations are due to confusion or 'cross-talk' of parallel processing in response to task demands. Bottleneck models (e.g. Broadbent, 1958,1971; Meyer and Kieras, 1997; Pashler, 1994) assume that limitations are structural and occur at one or more stages which necessitate serial processing of information. Following the response selection bottleneck theory, if a person is engaged in selecting the response to a stimulus for one task, then selecting another response to a different stimulus for a second task cannot proceed until the first response-selection process has finished (e.g., Pashler, 1994). In contrast, models of adaptive executive control consider that declarative set of rules for performing individuals tasks are acquired through practice and are converted to procedural knowledge.

Although these approaches to modelling mental resources are seemingly in competition with one another, several researches have suggested that they may not be exclusive and that each model provides insight into differences aspects of limitations in dual task performance (see Fracker & Wickens, 1989; Meyer et al.1995).

The basic rationale of the dual-task approach is that the volume of resources and the way resources are allocated can only be properly investigated by overloading the processing system and by examining patterns of interference.

This interference has been studied for several decades with the psychological refractory period paradigm (Telford, 1931) in which two targets that require independent responses are presented on each trial, separated by a variable delay period; interference typically takes the form of increased response times for the second target at short interstimulus delays. In this paradigm, two stimuli, S1 and S2 (the stimuli for the first and second tasks, respectively) are presented in rapid succession, each receiving a separate response (R1 and R2), resulting in two response times: RT1 and RT2. The interval between the presentations of S1 and S2 (the stimulus onset asynchrony, SOA) is manipulated, and the basic finding is that RT1 is not affected by SOA, whereas RT2 decreases as SOA increases (the so-called PRP effect).

The ability to coordinate concurrent cognitive processes is a crucial executive function (Baddeley, 1996). Such paradigms have demonstrated that the simultaneous performance of two tasks leads to increased response times and more errors. A failure to simultaneously perform two tasks is a characteristic feature of the dysexecutive syndrome exhibited by some patients with frontal lesions (Baddeley et al., 1997 ).

#### *4.2.1.1. Neuroimaging studies*

In recent years, a number of imaging studies aimed at identifying the neuroanatomical correlates of the additional cognitive demands in dual-task performance. The first study to explore cerebral areas associated to dual-task performance was that of D'Esposito, Detre, Alsop, Shin, Atlas, & Grossman (1995). These authors compared cerebral activity when two tasks were performed in isolation or simultaneously. Tasks used were a semantic judgment task and a spatial-rotation task, which were considered as activating predominantly posterior brain regions (Haxby et al., 1991). The simultaneous execution of both tasks involved significant increases of activity bilaterally in the dorsolateral prefrontal cortex (BA 9 and 46) and the anterior cingulate region. These data support the hypothesis that the dorsolateral prefrontal cortex is involved in the allocation and coordination of attentional resource (see also Goldberg et al., 1998; Schubert & Szameitat, 2003; but see Jiang, Saxe, & Kanwisher, 2004).

The finding of an overadditive activation in prefrontal regions was interpreted as being related to additional cognitive demands present in the dual task, as compared to the summed demands of both single tasks. However, while these studies are highly valuable for the localisation of the neuroanatomical correlates of dual-task performance, they do not allow specifying which specific processes are in particular associated with the dual-task related LPFC activation. This is, because the results of a gross comparison between dual-task and single-task blocks reflect the influence of numerous dual-task related demands.

Note, for example, that the amount of the working memory load, the need to divide attention, as well as the need to coordinate task processing may differ between dual-task and single-task blocks and, accordingly, may be responsible for the observed activation difference (cf. Jiang et al., 2004).

So, with regard to functional neuroimaging data, two potential mechanisms have been proposed to explain this deterioration in performance on dual-task paradigms relative to separate performance of each task:

- (1) dual-task paradigms may require additional cognitive operations and activation of specific brain regions in addition to those activated by the performance of single tasks alone;
- (2) the two tasks may interfere (and thus increase reaction times) if they recruit the same population of neurons at the same time or if they activate distinct neural populations (within the same brain region) that mutually inhibit each other when recruited simultaneously (Klingberg, 1998).

Herath et al. (2001) also demonstrated that performance of dual-reaction-time tasks activates cortical regions in addition to those activated by the performance of single tasks (in this case visual

and somatosensory detection tasks). These brain activations were located bilaterally in the superior frontal cortex, but also in the intraparietal sulcus and the supramarginal gyrus.

Schubert et al. (2003) affirmed that the main focus of the dual-task-related activation was located in regions surrounding the left inferior frontal sulcus. Based on findings of other recent neuroimaging studies, they argued that activation of the left inferior frontal sulcus reflects increased synaptic activity related to the need to manage interfering information in order to determine the appropriate action.

Collette et al. (2005) explored the neural substrate of both dual-task management and integration task with PET. The main distinction between dual tasks and integration task is that dual task requires subjects to combine two tasks that are unrelated to each other and coordination or integration tasks requires the integration of information coming from different sources (e.g., Yee et al., 1991; see, however, Emerson et al., 1999). Unlike dual task management processes, few studies have explored the neural substrates of the integration process. Prabhakaran et al. (2000) used fMRI to identify the brain regions preferentially involved in maintaining integrated versus unintegrated spatial and verbal information in working memory. Their results indicate that the right middle and superior frontal gyri (BA 9, 10, 46) were more involved in maintaining integrated information, while the maintenance of unintegrated information required greater involvement by the posterior cerebral areas. In another study, Mitchell et al. (2000) confirmed the involvement of the right medial prefrontal cortex (BA 10) and also demonstrated greater activation in the left anterior hippocampus when participants had to remember objects together with their location than on trials in which participants were told to remember either object or location information but not both. Moreover, both the anterior cingulate (BA 24/32) and left precentral gyrus/ premotor cortex (BA 6) were also more activated in the integration condition.

In the study of Collette et al. (2005) the paradigm included two simple (visual and auditory) discrimination tasks, a dual task and an integration task (requiring simultaneous visual and auditory discrimination), and baseline tasks (passive viewing and hearing). The comparison of the dual task to the single tasks demonstrated left-sided foci of activity in the frontal gyrus (BA 9/46, BA 10/47 and BA 6), inferior parietal gyrus (BA 40), and cerebellum. By reference to previous neuroimaging studies, BA 9/46 was associated with the coordinated manipulation of simultaneously presented information, BA 10/47 with selection processes, BA 6 with articulatory rehearsal, and BA 40 with attentional shifting. Globally similar regions were found for the integration task, except that the inferior parietal gyrus was not recruited. These results confirm the hypothesis that the left prefrontal cortex is implicated in dual-task performance. Moreover, the involvement of a parietal area in the

dual task is in keeping with the hypothesis that a parieto-frontal network sustains executive functioning.

However, other studies did not demonstrate additional prefrontal activity during dual-task performance. Klingberg et al. (2001) showed that that increased activity of the right inferior frontal gyrus (RIFG) correlated with the interference effect is very likely to be a specific outcome of situations where two concurrent tasks interfere with each other. The brain appears to recruit the RIFG for a subsequent (delayed) response when there is interference between dual tasks.

Finally, Just et al. (2001) have demonstrated that cerebral activity during the simultaneous realization of two tasks was substantially less than the sum of the activation when each task was performed alone. This was observed not only in primary and secondary sensory areas but also in association areas (primarily parietal and temporal cortex). These results indicate that the dual-task condition induces some mutual constraints among cortical areas. The authors interpreted these data as suggesting the existence of biological mechanisms that place an upper limit on the amount of cortical tissue which can be activated at any given time, thereby resulting in a limit on how much attention is available to distribute over concurrent tasks.

Szameitat (2006) showed that cortical areas of the posterior LPFC along the inferior frontal sulcus (IFS) and in the middle frontal gyrus (MFG) are involved in the co-ordination and re-organisation of the processing of two concurrent tasks, which interfere with each other due to a limited processing mechanism. These findings allow a much more detailed description of the functionality of the LPFC for dual-task performance as compared to previous studies.

Previous research about the function of lateral prefrontal cortices suggests that the currently observed activation foci located along the posterior IFS and in the posterior MFG might subservise different functions for task control (e.g. D'Esposito et al., 1998; Owen, 2000; Smith & Jonides, 1999). In more detail, the IFS might be related to the retrieval, implementation, and maintenance of the task set, i.e. the set of stimulus response associations (Brass & von Cramon, 2004; Bunge, Kahn, Wallis, Miller, & Wagner, 2003). Opposed to this, the posterior MFG might be related to monitoring (Petrides, Alivisatos, Meyer, & Evans, 1993), interference resolution (Bunge, Ochsner, Desmond, Glover, & Gabrieli, 2001), and the selection of the appropriate task (Rowe, Toni, Josephs, Frackowiak, & Passingham, 2000). For this, the MFG might operate on and/or modulate the contents stored in the IFS (Owen, Evans, & Petrides, 1996; Petrides, 1996). Thus, in different-order trials, the MFG might re-arrange, e.g. by activating and/or inhibiting, representations stored in the IFS. Alternatively, the MFG might monitor the presentation order of the tasks and initiate an updating of the task representations performed by the IFS. Further studies are clearly needed to dissociate the functionality of these two areas for dual-task processing.

The manipulation of task-scheduling demands results not only in LPFC activation but also in activation of parietal areas, e.g. along the IPS. This observation is in line with a number of studies showing that the demand to coordinate task processing is associated with a network of areas consisting mainly of prefrontal and parietal cortices. Several authors have suggested a functional dissociation between prefrontal and parietal areas for the coordination of task processing. In more detail, it has been proposed that the prefrontal cortex is associated with the initiation and coordination of attentional processes while the parietal cortex is implementing these processes (Clark, Egan, McFarlane, Morris, Weber, Sonkilla, et al., 2000; Corbetta & Shulman, 2002; Hopfinger, Buonocore, & Mangun, 2000; Norman & Shallice, 1986). In other words, it has been proposed that the top-down control of the prefrontal cortex influences the information processing in parietal association cortices (Cohen, Braver, & O'Reilly, 1996; Desimone, 1996; Miller, 2000; Smith & Jonides, 1999). Thus, the task scheduling organized by the prefrontal cortex might be realised by or rely on its interaction with superior parietal areas (cf. Bunge, Hazeltine, Scanlon, Rosen, & Gabrieli, 2002).

Resuming we can conclude that the DLPFC is essential for the organisation of complex human behaviour especially in situations where contradictory or interfering information has to be processed in order to execute goal oriented behaviour.

#### *4.2.1.2 Electrophysiological correlates*

Considering electrophysiological correlates of dual task, in literature there are few studies which investigated ERPs in dual task. Most of the studies revealed the sensitivity of the P3 component in processing resources in dual-task paradigms.

Two different types of manipulations have been carried out in dual-task P3 studies, namely difficulty and priority manipulations (Kok, 1997). Both types of manipulations have proven to be highly effective in demonstrating trade-offs in performance by using the POC technique (Wickens, 1984). Approximately linear trade-off (POC) functions have been found between tasks as a function of the degree of attention allocation of each task, which implies that a single limited resource was shared between the tasks. The rationale underlying this approach is that an increase in difficulty or priority of the primary task will lead to a decrease of resources available for processing of stimuli in the secondary task. The same rationale underlies the irrelevant probe technique, that will be discussed first.

1) Several studies have investigated changes in middle-latency ERP components like PI and NI to auditory and visual 'probes'. The probe technique involves the recording of ERP components to



task-irrelevant stimuli that are presented while the subject performs a primary task. It is assumed that ERPs to the probes will absorb the 'spare capacity' that is not invested in the primary task. An increase in difficulty of the primary task will result in a concomitant decrease of resources available for the probe stimuli, and thus lead to an amplitude reduction of probe ERP components (Defayolle et al., 1971; Papanicolaou & Johnstone, 1984).

In conclusion, the general impression from these studies is that the probe ERP results are too variable to provide a reliable basis for assessment of higher processing demands of the primary task. The relative low sensitivity of the middle-latency ERP components (P1, N1) to the cognitive demands of the primary task could indicate that these components mainly reflect capacity allocated to early perceptual processes that are involved in selection (or inhibition) of physical stimulus characteristics. In this respect, irrelevant probe ERPs seem to be functionally related to the early negativities that have been described in focused attention studies.

2) Studies that have varied *the difficulty* of the primary task have used a variety of visual tasks such as simulated flight control, compensatory and pursuit tracking, as well as both visual and auditory discrimination tasks as secondary tasks. The primary purpose of most of these studies was to investigate the utility of ERP measures in order to monitor changes in mental workload in complex real-world tasks.

In a series of investigations a number of investigators have found that the amplitude of P3 can serve as a secondary task measure of the resource demands of a primary task. An interesting dissociation was found by Wickens and Isreal who studied P3 in an auditory oddball task and varied the difficulty of a visual tracking task as primary task. In Wickens' study (Wickens et al., 1977) the tracking task required the subjects to manipulate a control stick so as to keep a randomly moving cursor on the display centred with a circular target. Difficulty was manipulated by varying the number of dimensions in which the subject was required to track. In the easy (one dimensional) condition the cursor moved only to the left and right on a horizontal axis. In the difficult (two dimensional) condition the cursor could move in any direction on the screen. Subjects were further instructed to count the deviant stimuli in the auditory oddball task. P3 amplitude in the secondary task decreased from the single- to dual-task conditions. However, when the number of tracked dimensions increased from one to two, P3 amplitude in the secondary task did not show a further decrease. The fact that in these studies P3 showed a reduction in amplitude from single- to dual-task conditions indicates that some perceptual-central resources were shared by these tasks.

Wickens et al. (1983) and Sirevaag et al. (1998) found the increase in P3 amplitude with an increase of the difficulty of the primary task. These results appear to contradict the results of single-task task studies reviewed in the previous section that clearly indicated that P3 amplitude is reduced with an

increase of the processing demands of the task. However, these findings alone cannot be used to support the resource allocation view, because reduction in P3 amplitude could have resulted from other factors than scarcity of resources, such as ‘costs of concurrence’ (Gopher & Donchin, 1986). More important is the requirement that P3 amplitude in the secondary task shows a further reduction in amplitude as a function of primary task difficulty.

3) Other demonstrations of the P3 reciprocity effect in dual-tasks have been provided in paradigms in which *task priority* rather than difficulty was manipulated. These experiments may be seen as further refinements of early P3 studies showing that task relevance is one of the major determinants of P3 amplitude. For instance, a classic finding has been that the amplitude of P3 is strongly reduced when a subject’s attention is directed away from the task in which the eliciting stimuli were embedded (Duncan-Johnson and Donchin, 1977; Squires et al., 1977; Johnson, 1988). A central question in subsequent dual-task studies was whether P3 amplitude would also reflect more graded changes in attention as a function of task priority.

#### **4.2.2. Task switch paradigm**

The task-switching paradigm has become popular during the last few years. Originally launched 70 years ago by Jersild (1927), Allport, Styles, and Hsieh (1994) adopted this paradigm to study cognitive control and now paradigms that require task-switching may be considered an ‘operational measures of executive control’ (Kimberg, Aguirre, & D’Esposito, 2000). The standard procedure used to study task switching is as follows: Participants are given lists of simple cognitive tasks (e.g., judgment whether a number is odd or even or larger or smaller than a reference number) to work through. A comparison between the response latencies for “pure” lists (i.e., lists with only one task type included, such as AAA) and mixed lists (e.g., ABAB) yields significantly longer response latencies for mixed lists, or so-called switch costs.

The specific components involved and their interplay are yet to be resolved (see Monsell, 2003), but switching costs probably include processes of task-set reconfiguration (Meiran, 1996; Rogers & Monsell, 1995), transient interference from previous stimulus–response mappings (Allport, Styles, & Hsieh, 1994; Allport & Wylie, 1999), and long-term task interference effects (Mayr, 2002; Mayr & Keele, 2000). A prospective process of “task-set reconfiguration” (Rogers & Monsell, 1995), prior to task performance, has been invoked because the cost of switching, as measured by RT increase, is lower when subjects have greater opportunity for advanced preparation. An alternative account, however, proposes switching costs are the consequence of the persisting activation of

processes related to the first task (Wylie & Allport, 2000; Allport et al., 1994; Allport & Wylie, 1999).

According to this theory, advance preparation reduces switching costs because it allows time for interfering “task set inertia” from the previous task to dissipate. By altering the time when an instructional cue was presented within a preparation interval, Meiran et al. (2000) provided evidence that both passive dissipation of the old task set and active reconfiguration for the new task set occur. Notwithstanding this debate, most authorities agree that “residual” RT costs can be observed despite advance preparation. The nature of the residual component of task switching, however, is not clear (Meiran et al., 2000). It may be a consequence of a second executive control process that only occurs after onset of the first stimulus in the new task or it may be a reflection of interference from the old task (Meiran et al., 2000; Monsell et al., 2000; Wylie & Allport, 2000).

Research with modern neuroimaging and electrophysiological methods offers the promise of clarifying the neural mechanisms that underlie such control processes.

#### *4.2.2.1 Neuroimaging studies*

In recent years a number of neuroimaging studies have investigated the neural mechanisms involved in cognitive control processes (Banich et al., 2000; Dove, Pollmann, Schubert, Wiggins & von Cramon, 2000; MacDonald et al., 2000). Most of these studies provided evidence that both the prefrontal cortex but also areas in the intraparietal cortex play a crucial role for the control of our behaviour (Brass et al., 2004).

Most event-related fMRI studies of task switching reported no specific brain region for switch trials, but simply an increased activation of a bilateral DLPFC–parietal network for switch relative to repeat trials (Dove *et al.*, 2000; Rushworth *et al.*, 2001).

Research on the neural substrates of rule representation has thus far focused primarily on lateral prefrontal cortex (LatPFC), a region that includes mid-dorsolateral PFC (DLPFC; Brodmann areas [BAs] 9, 46) and ventrolateral PFC (VLPFC; BA 44, 45, 47). Lateral PFC is thought to be responsible for the ability to keep a goal in mind with no external cues present, and to use that goal to guide behavior in spite of previous reinforcement to act otherwise (Diamond & Goldman-Rakic, 1989). Several lines of evidence support this claim. First, on the basis of what we know about its functional connectivity, it is argued that LatPFC is the part of the brain in which perception interfaces with action planning (Fuster, 1997). Second, patients with damage to Lat PFC have trouble implementing or flexibly switching between rules on a variety of laboratory tasks, most

famously in the Wisconsin Card-Sorting Task (WCST; see, e.g., Milner, 1963). Deficits in rule implementation are often observed when a strongly prepotent response tendency must be overridden in favor of a recently learned rule, as in the Stroop task (Miller & Cohen, 2001). Third, monkeys with lesions to VLPFC have difficulty learning and using both simple S–R associations and more complex rules (Murray, Bussey, & Wise, 2000; Passingham, Toni, & Rushworth, 2000). Fourth, as will be described briefly below, the pivotal electrophysiological studies carried out by Patricia Goldman-Rakic, Joaquín Fuster, and others focused a spotlight on Lat PFC by investigating its role in working memory.

Block design studies that compared task switching with performing each task individually also reported activation of a bilateral prefronto-parietal network (DiGirolamo *et al.*, 2001; Smith *et al.*, 2001; Dreher *et al.*, 2002; Braver *et al.*, 2003). Dreher and colleagues (2002) found that predictable task order in switching was associated with activations in the right hippocampus, anterior medial prefrontal cortex (BA 10), and posterior cingulate (BA 30), whereas unpredictable task order and timing were associated with increased activation in lateral prefrontal cortex (BA 45 and 9), in addition to other posterior areas. Under the most demanding endogenous control conditions, i.e., predictable order and timing, additional activation was observed in left frontopolar cortex, further suggesting an anterior shift in prefrontal activity as cognitive demands increase.

The only discrepant result with those findings comes from one fMRI task-switching study that reported a superior parietal cortex activation during switching that was not part of task-related regions (Kimberg *et al.*, 2000).

In conclusion, brain imaging experiments have begun to reveal the network of brain areas that participate in task switching. Of particular interest has been the identification of brain areas involved in controlling the reconfiguration of task sets (e.g., Brass & von Cramon, 2002; Kimberg, Aguirre, & D'Esposito, 2000; MacDonald, Cohen, Stenger, & Carter, 2000; Sohn, Ursu, Anderson, Stenger, & Carter, 2000). Overall, the studies highlight medial and lateral regions of prefrontal cortex and parietal cortex as brain areas of potential relevance to task-switching operations. The specific contribution of participating regions is also beginning to be investigated (Brass & von Cramon, 2002; Luks, Simpson, Feiwell, & Miller, 2002). A study combining functional magnetic resonance imaging (fMRI) and transcranial magnetic stimulation (TMS) has shown that the neural mechanisms of task-set reconfiguration may depend on what aspect of task performance task-switching emphasises (Rushworth, Hadland, Paus, & Sipila, 2002). The pre-supplementary area was critically involved in reconfiguring an intentional set, in which different stimulus–response mappings were required between tasks; but was not critical in reconfiguring an attentional set, in which different stimulus dimensions were relevant to drive responses between tasks.

#### 4.2.2.2 *Electrophysiological correlates*

Because control processes involved in task set preparation and execution may be distinguished by their time course, neurophysiological measures with adequate temporal resolution may be particularly helpful in separating them. Event-related brain potentials (ERPs) in task-switching experiments can help elucidate the cognitive processes that lead up to behavioural differences between switch and repeat trials in general, as well as those processes more specifically involved in task-set reconfiguration. Most ERP task-switching studies have focused on differences between ERPs to switch and repeat stimuli occurring after stimulus onset (e.g., Barcelo et al., 2000, Barcelo et al., 2002, Gehring et al., 2003, Hsieh and Yu, 2003, Poulsen et al., 2005 and Swainson et al., 2003). ERP differences between switch and repeat trials occurring after stimulus onset may reflect processing differences occurring as a result of differential levels of proactive interference for switch compared to repeat stimuli, differential level of activation of the relevant task-set at stimulus onset, as well as differential stimulus-response interference elicited by the stimulus itself. Therefore, although anticipatory task-set reconfiguration may indirectly affect stimulus-locked ERPs (e.g., Barcelo et al., 2000), it is difficult to isolate this effect from that of other passive interference or stimulus-elicited processes.

Event-related brain potentials (ERPs) may also provide an index of the process of task set reconfiguration in task-switching paradigms. Using Rogers and Monsell's (1995) alternating runs paradigm, Karayanidis et al. (2003) identified an increased positivity in anticipation of switch relative to repeat trials that was time locked to the onset of the response to the preceding stimulus, thus emerging within the response–stimulus interval. This switch-related differential positivity peaked approximately 400 ms after the response to the preceding trial and was maximal parietally. Wylie et al. (2003) also found that trials preceding a predictable switch in task were associated with a larger sustained posterior positivity compared to trials preceding a repeat in task. ERP studies using cued task-switching paradigms have also reported a parietal switch-related positivity emerging around 400–500 ms after cue presentation (Miniussi et al., 2005; Nicholson et al., 2005; Nicholson et al., 2006; Rushworth et al., 2002, 2005).

Nicholson et al. (2005) found that, at long cue–stimulus intervals (600 ms), RT switch cost was smallest and the switch-related positivity resolved before stimulus onset. In contrast, at short cue–stimulus intervals (150 ms) that provided little or no opportunity for anticipatory task set reconfiguration processes, RT switch cost was larger and, although the switch-related positivity emerged immediately following cue presentation, it did not resolve until after stimulus onset. This suggests that the differential positivity for switch relative to repeat trials reflects processes involved

in task set reconfiguration, such as inhibiting the currently irrelevant task set and activating the currently active task set.

Nicholson et al. (2006) manipulated the amount of information conveyed by the task switch cue. Partially informative (switch-away) cues indicated that the impending trial would require a switch to one of two alternative tasks, but the specific task to be performed was only defined by the position of the stimulus itself.

Switch-away cues elicited a differential positivity relative to repeat trials, similar to that elicited by fully informative cues but of smaller duration. A second switch-related positivity was then elicited upon stimulus onset, when the new task set was defined and could be activated. Thus, the differential switch positivity obtained to fully informative cues appears to be associated with the process of task set reconfiguration, and this process, in turn, appears to consist of multiple components that may include processes such as suppression of activation of the now irrelevant task set and activation of the currently relevant task set. In cued task-switching paradigms, changes in RT switch cost and switch-related positivity with increasing cue–stimulus interval appear to provide a useful measure of cognitive control processes involved in task set reconfiguration.

In summary, anticipatory task-set reconfiguration is associated with increased positivity in anticipation of switch relative to repeat trials, particularly over parietal electrodes. At longer preparation intervals, this differential activity for switch trials can be completed prior to stimulus presentation and is associated with reduced RT switch cost. With short preparation intervals, which provide little or no opportunity for anticipatory task-set reconfiguration, these processes occur after stimulus onset and are associated with larger RT switch cost.

#### **4.2.3 Performing Two Tasks Simultaneously or Successively’: Dreher et al. (2003).**

In literature is evident that studies about attention have investigated cognitive processes of dual task and task switch separately and the only study which compared task switching and dual task performance is of Dreher et al. (2003). Dreher et al. (2003) designed a functional magnetic resonance imaging (fMRI) study to investigate the nature of cognitive control is whether performing two tasks successively or simultaneously activates distinct brain regions comparing task-switching and dual-task performance.

In this new dual task, subjects had to discriminate simultaneously whether a stimulus letter was a vowel or in upper case (or both) by pressing a right response button, and a left button otherwise. In the task-switching condition, subjects had to switch between two letter-discrimination tasks depending upon the color of the letter. If the letter was red, subjects performed a vowel–consonant

discrimination task (vowel, right; consonant, left). If the letter was green, subjects performed a case discrimination task (upper case, right; lower case, left). This allowed us to directly compare dual-task situations to task switching, by equating for stimulus presentation and the number of motor responses.

In two conditions used for baseline, subjects performed each of these two vowel/consonant and upper/lower case discrimination tasks in separate blocks of trials. The baseline was the average of these two simple discrimination tasks.

The results showed that performing two tasks successively or simultaneously activated a common prefronto-parietal neural network relative to performing each task separately.

More importantly, they found that the anterior cingulate and the lateral prefrontal cortices were differently activated in dual-task and task-switching situations.

When performing two tasks simultaneously, as compared to performing them in succession, activation was found in the rostral anterior cingulate cortex. The ACC activation is unlikely to reflect novelty detection (Clark *et al.*, 2000), error detection (Kiehl *et al.*, 2000), or an increase in motivation (Gehring and Willoughby, 2002).

In contrast, switching between two tasks, relative to performing them simultaneously, activated the left lateral prefrontal cortex and the bilateral intra-parietal sulcus region.

The authors interpret these results as indicating that the rostral anterior cingulate cortex serves to resolve conflicts between stimulus–response associations when performing two tasks simultaneously, while the lateral prefrontal cortex dynamically selects the neural pathways needed to perform a given task during task switching.

This contrast mainly activated the rostral part of the anterior cingulate gyrus (BA 24/32; Fig. 4.3.2.1). Activation was also found in the posterior cingulate gyrus, the left middle and superior temporal gyrus (BA 21/22), the precuneus and the lateral cerebellar hemisphere bilaterally.

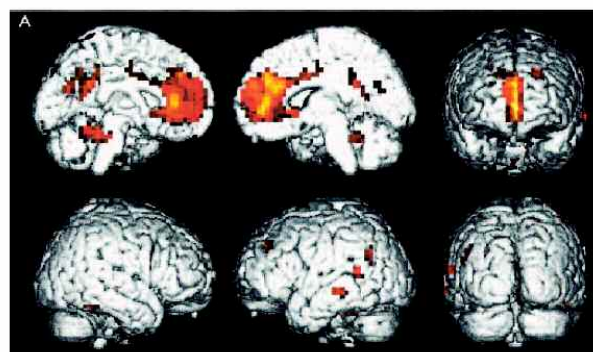
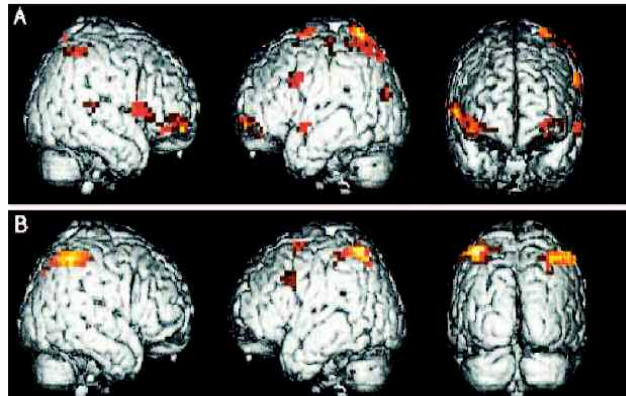


Figure 4.2.3.1 Brain Regions Activated by Dual-task Performance Relative to Task Switching

Activation was found in the left medial frontal gyrus, the right inferior frontal gyrus, the fronto-polar cortex bilaterally (BA 10), the left superior parietal cortex, the intra-parietal cortex (BA 7/40) bilaterally, the left superior temporal gyrus (BA 22) and the left medial occipital gyrus (BA 18/19; Fig. 4.3.2.2).



*Figure 4.2.3.2 Brain Regions Activated by Task Switching Relative to the Dual-task Condition*

The results of this study showed that performing two tasks successively or simultaneously activated a common prefronto-parietal neural network relative to a baseline consisting of the average of two discrimination tasks performed separately. This shows that this network is not specific for task-switching or dual-task performance, but is more generally recruited for executive processes.

When directly comparing simultaneous and successive performance of two tasks, we found that the rostral ACC and the lateral PFC were distinctively activated by simultaneous and sequential task performance. Performing two tasks simultaneously activated the rostral anterior cingulate relative to successive performance of the two tasks. Conversely, performing two tasks successively activated the left lateral PFC and the bilateral IPS region relative to performing the two tasks simultaneously.



## CHAPTER 5

### THE RESEARCH

#### 5.1. Research rationale

According to the data presented in chapter 4, there is evidence that it may not be an arbitrary choice whether to introduce the PM task as a dual-task or a task-switch procedure.

While both dual-task and task-switch paradigms are known to require executive resources (e.g., Baddeley, 2001), a hand full of studies on the development of PM have indicated that PM tasks that require the active interruption of the ongoing activity appear to be of particular difficulty to relatively young or relatively old participants, presumably because inhibitory processes are involved (Kliegel et al., 2000).

There is evidence that suggests that PM tasks that explicitly require active ongoing task interruption in order to switch to PM execution may be more demanding than tasks that allow for parallel processing of both tasks. However, so far, both paradigms are largely used interchangeably in the literature and a direct comparison of both task versions has not been reported.

The first aim of the present study is to directly compare event-based PM performance in a task-switch and a dual-task setting within the same overall procedure and examine potential differences in behavioural and neurophysiological processes associated with either task version (Experiment 1).

When analyzing the literature on neuroimaging attentional studies and comparing areas activated by dual task and task switch paradigms with areas activated by PM tasks (with dual task and task switch paradigms respectively), it was very interesting to find the activation of common areas. Particularly, considering the dual task paradigm in prospective remembering and attention the activation of a specific rostral part of the anterior cingulate gyrus (Okuda et al., 1998; Dreher et al., 2003; D'Esposito et al., 1995) and of the right inferior frontal gyrus is evident (Okuda et al., 1998; Okuda et al., 2006; Herath et al., 2001; Schubert et al., 2003; Szameitat et al., 2006).

Considering the task switch paradigm in prospective remembering and attention the activation of a neural network involving parietal and frontal areas; in particular 'the fronto-polar cortex bilaterally (BA 10)' (Burgess et al., 2003; Simons et al., 2006; den Ouden 2005; Dreher et al., 2003); the parietal cortex (Burgess et al., 2001; Dreher et al., 2003; Dove et al., 2000; Rushworth et al., 2001; DiGirolamo et al., 2001; Kimberg et al., 2000) and the precuneus (den Ouden et al., 2005; Burgess et al., 2001; Dreher et al., 2003), is evident.

We expect to find potential differences in behavioural and neurophysiological processes associated with each task. The second aim of this research was to compare a PM task with an attentional task

(with a dual task paradigm and task switch paradigm respectively in Experiments 2A and 2B) in order to investigate whether the processes underlying a PM and an attentional task are the same (Experiment 2A and 2B).

In both experiments we used the PLS analysis to identify spatiotemporal relationships between the neural activity and the experimental design (Lobaugh et al., 2001; McIntosh et al., 1996) and the Low-resolution electromagnetic tomography (LORETA) to estimate the three-dimensional intracerebral current density distribution in order to localize differential neural recruitment between tasks (Pascual-Marqui, 1999, 2002).

These techniques are described in Appendix 1.

## **5.2 Experiment 1**

Across the empirical literature it has largely been just a matter of preferential choice as to whether participants were instructed to stop working on the ongoing task whenever they encountered a prospective memory cue or whether they were encouraged to first respond to the ongoing task demands of the cue and then execute the prospective memory action. It is the aim of the present experiment to directly compare event-based PM performance in a task-switch and a dual-task setting within the same overall procedure and examine potential differences in behavioural and neurophysiological processes associated with either task versions.

## **5.3 Methods**

### *5.3.1 Participants and design*

Seventeen participants, aged between 18 and 29 years ( $M = 24.05$ ,  $SD = 2.19$ ; 9 female), were enrolled in the study. All participants were right-handed according to their score on the Edinburgh-Handedness-Test (Oldfield, 1971) and they were students at the University of Padua. All were in good health, none reported brain injuries, psycho-affective medication, drug consumption or other diseases affecting brain functioning and they had normal or corrected-to-normal vision. All participants were paid 20 Euro for their participation in the experiment and were provided with descriptions of the study before informed consent was obtained. The experiment was conducted in agreement with the declaration of Helsinki.

The design of the study was a one factorial study design with the within-person factor of PM task type (dual-task and task-switch), the administration order of which was counterbalanced.

### 5.3.2 Material

*Ongoing task.* For the ongoing task, participants were asked to evaluate five-letter strings (e.g., DFDFD) as to whether the second and the fourth letter were identical or not (which in the given example would constitute a Yes-response; an example for a No-response is DFDGD). Stimuli were centrally presented on the computer screen in white on a black background. The first, third and fifth letters were always identical. Responses were to be given with the right hand using the ‘K’ and ‘L’ keys of a computer keyboard. The key-response-mapping was counterbalanced across participants (i.e., for half of the participants the ‘K’-key was the Yes-key and for half of the participants the ‘L’-key was the Yes-key).

*PM task.* The PM task consisted of remembering to press the spacebar whenever the letter ‘B’ was presented in one or both of the ongoing task target positions (i.e., second or/and fourth position; e.g. SBSBS, SBSDS). For the *dual-task* version, participants were instructed that whenever they detected a PM cue they should firstly proceed in the ongoing task routine (i.e., decide whether or not the second and fourth letter are the same) and then press the PM response key (i.e., the spacebar). For the *task-switch* version, participants were instructed that when a prospective cue was presented they should remember to directly press the spacebar of the keyboard *without* performing the ongoing task. Besides pure ongoing task items (containing no B’s) and proper PM cues (containing a B on the second and/or fourth position) distracter items were also presented (containing the letter B on the first, third and fifth position). For these items, all participants were instructed to respond according to the ongoing task rules (i.e., evaluate the second and the fourth letter).

Each of the two task versions consisted of ten blocks of 36 trials each that were run in a single session of about 30 minutes. Each block included two prospective stimuli (one representing an ongoing task Yes-response-item and one representing an ongoing task No-response-item; i.e., one containing one and one containing two B’s), ten distracter stimuli (five representing an ongoing task Yes-response-item and five representing an ongoing task No-response-item; i.e., five with identical and five with different letters at positions two and four) and 24 ongoing task stimuli (twelve representing an ongoing task Yes-response-item and 12 representing an ongoing task No-response-item).

Each trial started with the presentation of a fixation cross displayed for 800 ms. After a blank screen for 100 ms, the five-letter-string was displayed for 1600 ms or until the participant’s response, followed by a fixed blank screen of 1000 ms. Stimuli were selected in each trial in a pseudo-random order. At the end of each block a feedback on the accuracy of correct response appeared on the screen.

### 5.3.3 Procedure

After providing informed consent and the set-up of the EEG-electrodes (see below), participants were seated in a dimly-lit and sound-attenuated room with their head fixated on a head-and-chin rest at a distance of 57 cm from a 19-inch computer screen. Then, the ongoing task was introduced. Next, the PM task was introduced, either as dual-task or task-switch procedure. Participants were asked to repeat the instructions in their own words and any errors or omissions were corrected. Then, a practice block of ten ongoing task items followed. After completing the first PM version and a short break, the remaining PM task version was introduced. Again, participants were asked to repeat the instructions in their own words and any errors or omissions were corrected. At the end of the session, participants were debriefed.

### 5.3.4 ERP Recordings.

The electroencephalogram (EEG) was continually recorded while participants performed the task. The EEG was recorded from an array of 20 Ag/AgCl scalp electrodes mounted on an elastic cap (ElectroCap International, Inc.) and positioned according to the 10-20 International System (AEEGS, 1991). According to previous studies on neural correlates of PM (West et al., 2003; West & Krompinger, 2005; West & Ross-Munroe, 2002), the montage included the following scalp positions: Fp1, Fp2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T3, T4, P7, P3, Pz, P4, T6, O1, O2.

Two electrodes placed on the external *canthi* of the left and right eyes were placed to monitor horizontal eye movements; and two electrodes placed above and below the left eye were used to monitor vertical eye movements and blinks. The vertical and horizontal EOG was recorded bipolarly. The ground electrode was placed along the midline behind Fz. All the electrodes were referenced to the right mastoid and re-referenced offline to the right and left mastoids. Data were recorded with a band-pass filtered setted to DC-50 Hz and digitized at a sampling rate of 500 Hz. Electrode impedance was maintained below 5 k $\Omega$ .

Event-related potentials (ERPs) were averaged offline according to the stimulus type. ERP analysis epochs included 200 ms of pre-stimulus baseline and 1000 ms post-stimulus activity. Epochs with excessive drift or containing eye movement or blink were manually rejected and only epochs with correct responses were averaged. In this way, approximately 25% on average of trials were discarded. Artefacts rejection was performed with a cut-off of  $\pm 75$   $\mu$ V. All ERPs were band-passed filtered between 0.1 and 30 Hz.

### 5.3.5 Data analysis

Accuracy, reaction times (RTs), and event related potentials (ERPs) were analysed. For analytical purposes, regarding the EEG data, performance was grouped according to a general two within-person factor design with one factor representing the *PM task version* (2 levels: dual-task and task-switch version) and the other factor representing *item condition* (3 levels: ongoing task item, prospective cue item and distracter item; see Zöllig et al., 2007 for a similar procedure).

*Analysis of mean amplitude.* Differences between task versions and item conditions were examined in two epochs where the N300 and positivity complex are typically observed (West et al., 2003; West & Kropfing, 2005; West & Ross-Munroe, 2002; Zöllig et al., 2007). The N300 represented the maximum negative voltage between 200 and 300 ms, the prospective positivity represented the maximum positive voltage between 400 and 1000 ms divided in two intervals (400-700 ms and 700-1000ms). The selection of electrodes characterizing the N300 and the prospective positivity was based on findings from previous studies (West et al., 2003; Zöllig et al., 2007). Specifically, the amplitude of the N300 was quantified at occipital and parietal electrodes. The amplitude of the prospective positivity was quantified as mean amplitude between 400 and 1000 ms at frontal and parietal sites.

*Partial least squares analysis.* In addition to traditional ERP analyses, partial least squares (PLS) analysis (Kovacevic & McIntosh, 2007; Lobaugh, West & McIntosh, 2001) was used to further explore potential differences between the two task versions (see, e.g., Zöllig et al., 2007, for a similar approach). PLS operates on a ERP data matrix containing the conditions (Ongoing task (vs) PM task with dual task paradigm and Ongoing task (vs) PM task with task switch paradigm) in the row and the amplitude for all time points and electrodes in the column (i.e., 0-1000 ms, at each electrode).

The input data matrix for the analyses was obtained by mean-centering the columns of the ERP data matrix with respect to the grand mean. The averages within task were thus expressed as deviations around zero. Singular value decomposition (SVD) was then performed on these matrices to identify the structure of the latent variables. Three outputs were derived from the SVD that were used to interpret the relationships between ERP amplitude and task design. The first was a vector of singular values, which represents the unweighted magnitude of each latent variable and can be used to calculate the proportion of the cross-block covariance matrix (i.e., the percentage of task-related variance) attributable to each latent variable. The second and third outputs contain the structure of the latent variables and are orthogonal pairs of vectors (saliencies).

One vector defines the design scores representing contrasts between tasks across the latent variables. The other vector (ERP saliences) identifies where, in time and space, the effects in the design scores are expressed for the LV.

The significance of the latent variables singular values was determined using a permutation test that provided an exact probability of observing the singular value by chance (e.g.,  $p < .001$ ).

The significance of the LVs singular values was determined using a permutation test (500 replications) that provides an exact probability of observing the singular value by chance (e.g.,  $P=.001$ ). The stability of the ERP saliences at each time point and location in space was established through bootstrap resampling (200 replications) that provides a standard error for each of the saliences. The ratio of the salience to its bootstrapped standard error is approximately equal to a z-score; therefore, bootstrap ratios greater than 2.5 can be taken to indicate stable saliences or points that differ from zero (Matlab code to perform the PLS analyses can be obtained at [www.rotman-baycrest.on.ca](http://www.rotman-baycrest.on.ca)).

## 5.4 Results

### 5.4.1 Behavioural results

*Ongoing task performance.* In a first step, ongoing task performance was analyzed across the two factors PM *task version* (dual-task versus task-switch) and *item condition* (ongoing task item versus distracter item), both with respect to response times (RT) and accuracy. Mean central tendencies are summarized in Table 5.1. The data for distracter item were separated into ‘correct responses’ and confusion errors (see this distinction in Zollig et al., 2007) when the wrong prospective response was made.

		Item Condition	
		Ongoing	Distracter
Task version		<i>M</i> ( <i>SD</i> )	<i>M</i> ( <i>SD</i> )
Dual Task	RT (ms)	745 (122)	804 (147)
	Accuracy (%)	95 (7)	94 (7)
Task Switch	RT (ms)	761 (118)	813 (119)
	Accuracy (%)	97 (3)	94 (4)

Table 5.1 Behavioural results (response times and accuracy) of ongoing task performance across PM task version and item condition.

A 2 (task version) x 2(item condition) repeated measures analysis of variance (ANOVA) on RT data averaged across correct trials revealed a main effect of item condition,  $F(1,16) = 34.13$ ,  $p < .001$ ,  $\eta^2 = .681$ , indicating faster RTs in ongoing task items compared to distracter items. Neither a main effect of PM task version, nor an interaction was revealed, both  $F$ 's  $< 1$ .

A 2 x 2 repeated measures analysis of variance (ANOVA) on accuracy data revealed a main effect of item condition,  $F(1,16) = 6.12$ ,  $p < .05$ ,  $\eta^2 = .277$ , indicating reduced overall performance accuracy in distracter items. However, an interaction was also revealed,  $F(1,16) = 7.74$ ,  $p < .05$ ,  $\eta^2 = .326$ . This interaction suggested that reduced accuracy for distracters was only observed in the task switch version,  $t(17) = 3.55$ ,  $p < .01$ , but not in the dual-task version,  $t < 1$ . Subjects made more confusion errors when they encountered a stimulus encode as intention but in the wrong position, so they had to inhibit the prospective response in order to continue in executing the ongoing task. No main effect of PM task version was obtained,  $F < 1$ .

Because only the dual-task version also required an immediate ongoing task response to the PM cue items, only in the dual-task version it was also possible to compare RT ( $M = 973.28$  ms;  $SD = 191.92$ ) and accuracy ( $M = .94$ ;  $SD = .10$ ) of the ongoing task responses to the PM cue items with RT and accuracy of the ongoing task items proper and the distracter items. Separate  $t$ -tests revealed increased RTs in the PM cue items compared to both ongoing task items proper,  $t(17) = -6.92$ ,  $p < .001$ , and distracter items,  $t(17) = 5.47$ ,  $p < .001$ , but no differences in accuracy, both  $t$ 's  $< 1$ .

*PM performance.* In a second step, PM task accuracy<sup>1</sup> was compared between the two task versions. A  $t$ -test for dependent variables revealed reduced PM performance in the task switch version,  $t(17) = 1.765$ ,  $p < .05$  (one-tailed, directional hypothesis; see Figure 5.2).

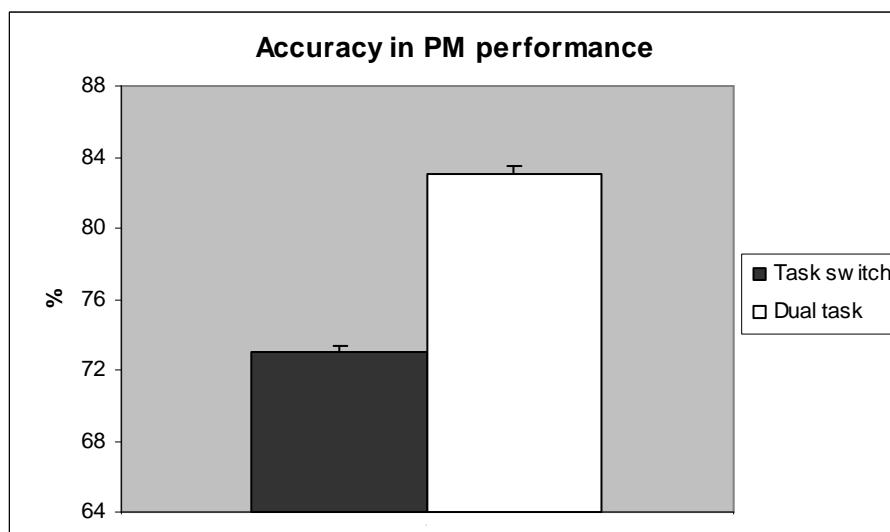


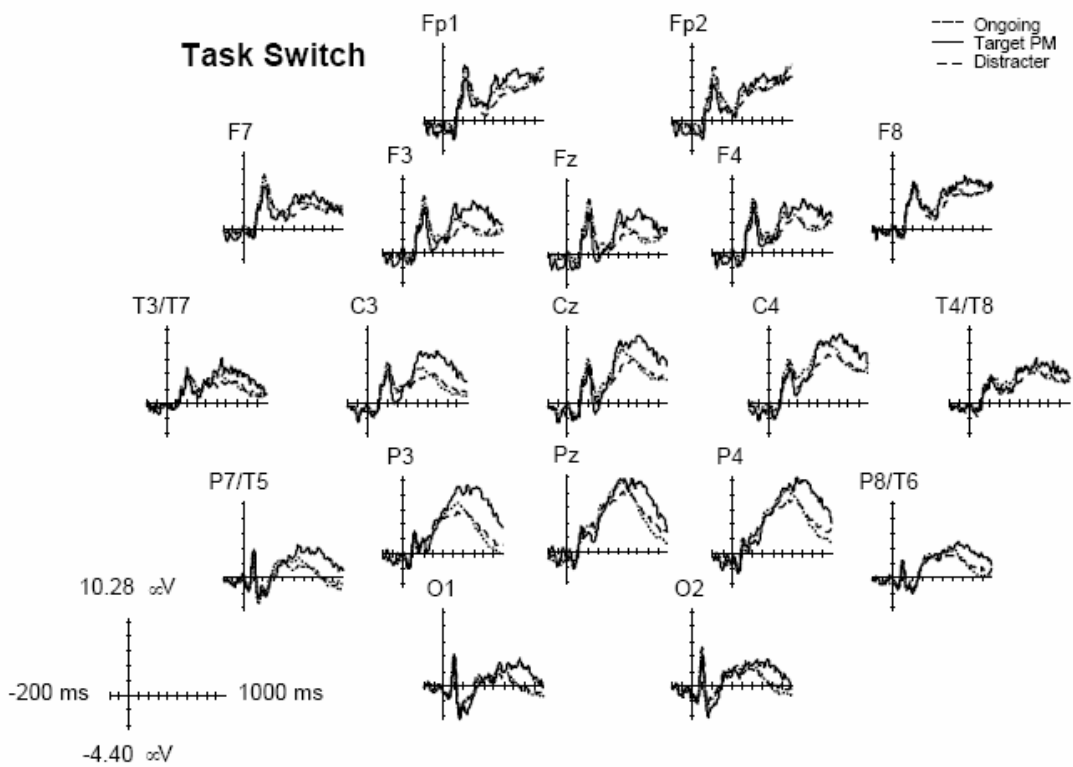
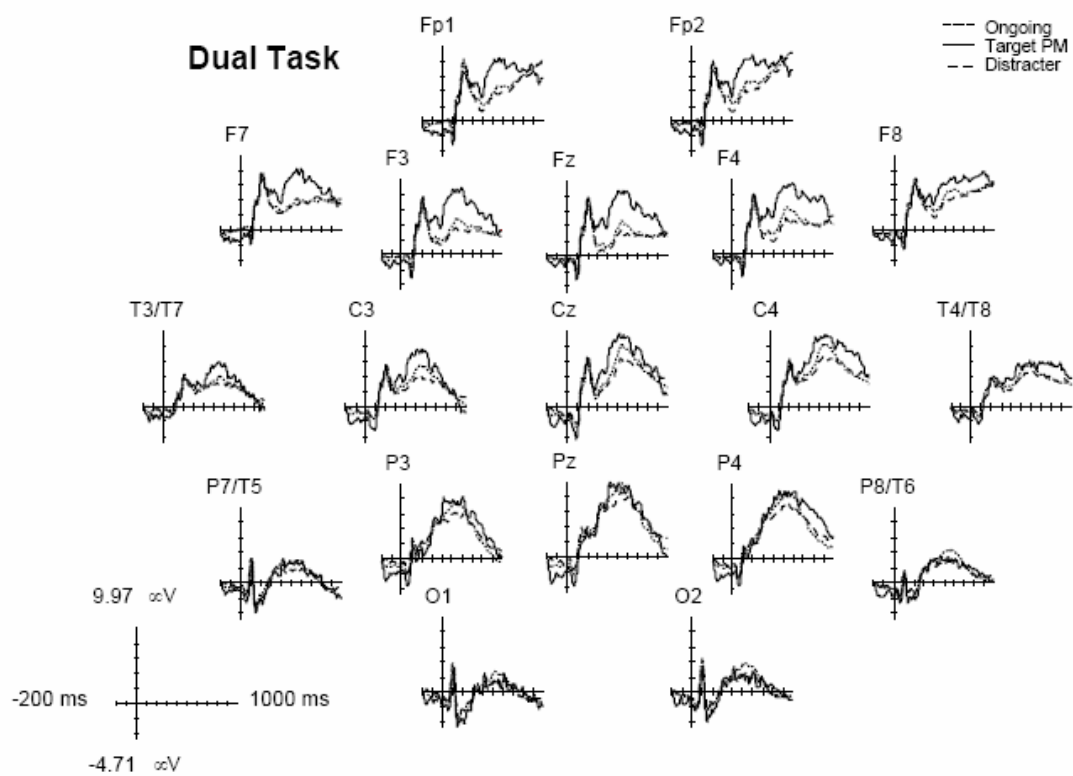
Figure 5.2. Mean PM accuracy for dual task versus task switch version.

Note. TS = task switch version; DT = dual task version. Error bars represent the standard error of the mean.

#### 5.4.2 Electrophysiological data

*ERP components.* The grandaveraged ERPs portraying the N300 and the prospective positivity are displayed in Figure 5.3 and Figure 5.4. The topography of these modulations is portrayed in Figure 5.5.





Figures 5.3 and 5.4 Grandaverage event related potentials (ERPs) at electrodes demonstrating the N300 and prospective positivity in dual task version and in task switch version.

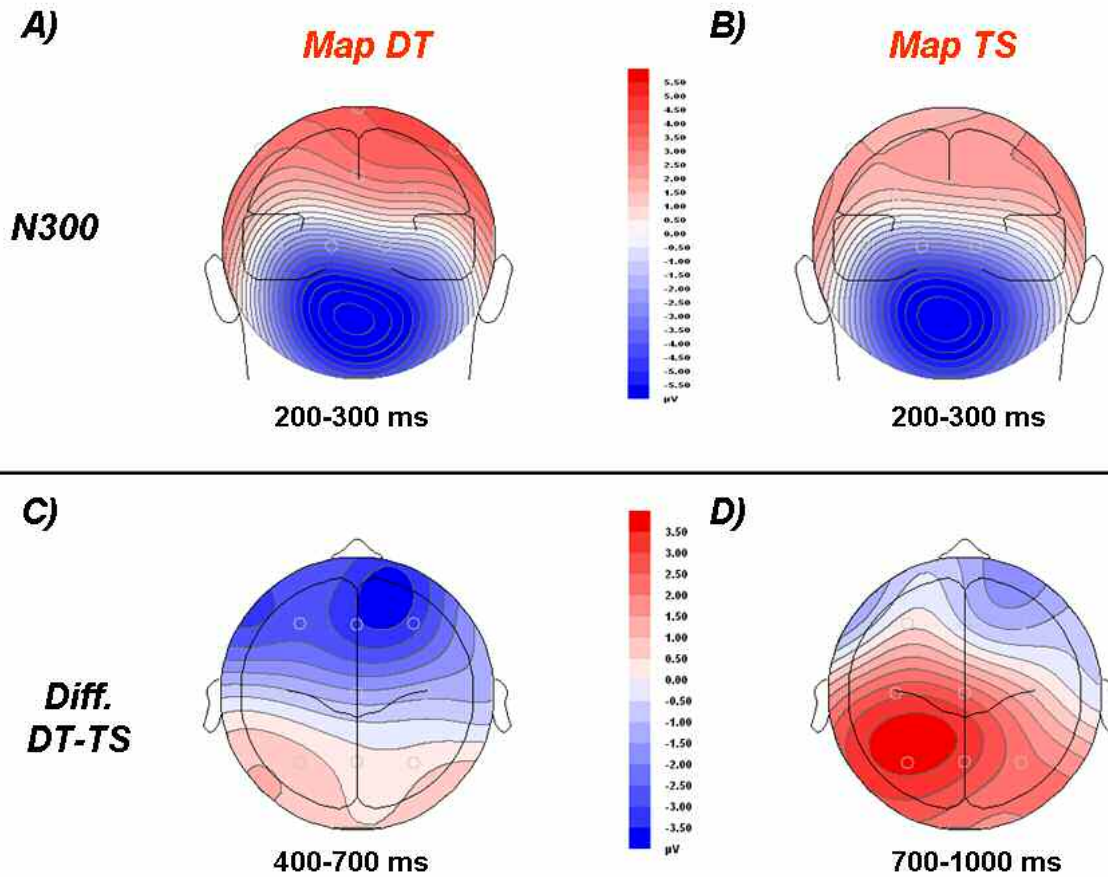


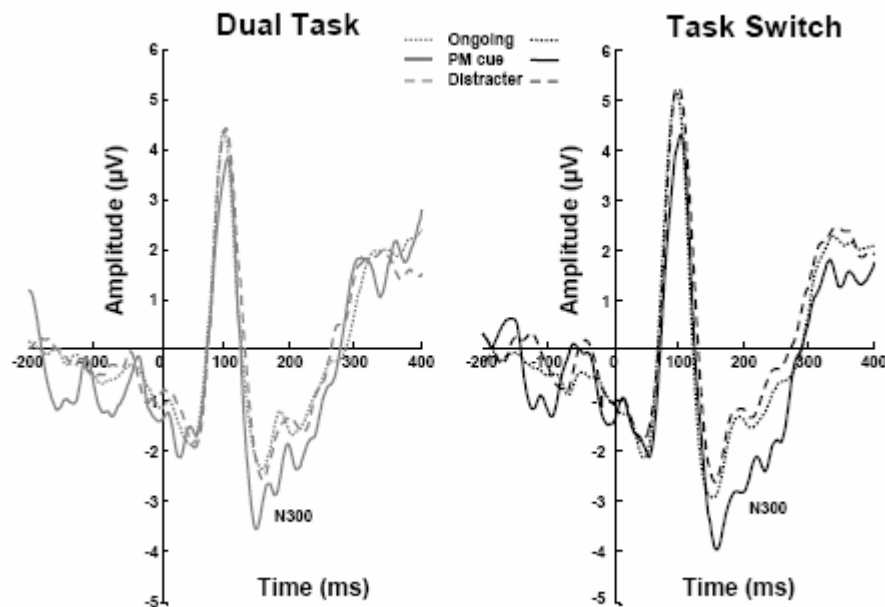
Figure 5.5.

Maps representing difference subtraction in current density between dual task and task switch version in the prospective condition. Figures A and B represent subtraction between correct prospective trials and ongoing activity trails during the time windows between 150 and 300 ms respectively in dual task (DT) and task switch (TS) version. Figures C and D represent the subtraction in prospective condition between task switch and dual task version in the time window between 400 and 700 ms and 700-1000 ms.

*Differences in mean amplitude.* The *N300* was quantified as mean amplitude between 100 and 400 ms and analysed according to four factors: PM task version (dual task versus task switch), item condition (ongoing task item, prospective item versus distracter item), time window (100-200ms, 200-300 ms versus 300-400ms) and electrode sites (occipital versus parietal sites) (Figure 5.6).

A 2 x 3 x 3 x 2 repeated measure analysis of variance (ANOVA) was conducted. In this analysis the main effect of item condition was significant,  $F(2,32) = 3.32, p < .05, \eta^2 = .190$ , reflecting a greater negativity for the prospective items respect to the ongoing task items and to the distracter items in both tasks. There were no differences between the distracter items and the ongoing task items,  $F < 1$  (see Figure 5.5). The only other relevant effect to be significant was the Item Condition x Time x

Electrode interaction,  $F(2,32) = 4.65$ ,  $p < .001$ ,  $\eta^2 = .210$ . Post hoc analyses of this interaction revealed that the amplitude of the N300 was greater especially for prospective items between 200 and 300 ms and over occipital electrodes (Dockree et al., 2005).



*Figure 5.6.* Grandaverage event related potentials (ERPs) at occipital electrodes demonstrating the N300 in the item condition (ongoing, prospective and distracter) respectively for dual task (a) and task switch (b) version.

The amplitude of the prospective positivity was analysed according to 4 factors: PM task version (task switch versus dual task version), item condition (ongoing task item, prospective item versus distracter item), time window (400-700ms and 700-1000ms), Hemisphere site (left: P3-C3-F3; central PZ-CZ-FZ and right P4-C4-F4) and an anterior-posterior site (parietal P3-PZ-P4, central C3-CZ-C4 and frontal F3-FZ-F4) (see Figure 5.7).

A 2 x 3 x 2 x 3 x 3 repeated measure analysis of variance (ANOVA) on ERPs averaged across correct trials revealed a main effect of condition,  $F(2,32) = 6.86$ ,  $p < .003$ ,  $\eta^2 = .300$ , with the amplitude of the prospective positivity being greater for prospective items than distracter and ongoing task items. The significant interaction Task x Condition x Time,  $F(2,64) = 4.34$ ,  $p < .017$ ,  $\eta^2 = .225$ , indicated a difference in the amplitude of the prospective positivity between the two tasks. Post hoc analyses revealed that in dual task the amplitude of this component was greater in the time-window between 400 and 700ms respect the time between 700 and 1000ms. Moreover, in both time windows, the amplitude resulted greater for prospective items respect the ongoing task and distracter items. On the contrary, post hoc analyses in task switch version revealed that the amplitude of this component was greater in the time-window between 700 and 1000ms respect the

time between 400 and 700ms; as in dual task version, the amplitude of this positivity resulted greater for prospective items than for ongoing task and distracter items in both two time windows. Interestingly, the interaction Task x Condition x Hemisphere site,  $F(4,64) = 2.95$ ,  $p < .03$ ,  $\eta^2 = .155$ , and the interaction Task x Condition x Time x Hemisphere site,  $F(4,64) = 8.62$ ,  $p < .001$ ,  $\eta^2 = .351$ , were also significant revealing the amplitude of the prospective positivity differed between two tasks. Post hoc analyses revealed that in task switch the prospective positivity elicited by prospective items had greater amplitude over left and central electrodes in the time window between 700 and 1000ms respect dual task paradigm. In dual task the prospective positivity elicited by prospective items didn't show differences over hemisphere. At last Task x Item Condition x Anterior/posterior site interaction,  $F(4,64) = 4.34$ ,  $p < .003$ ,  $\eta^2 = .213$ , was reliable indicating that in dual task version the amplitude of this positivity was greater in anterior site respect posterior site and in task switch version it was greater in posterior sites.

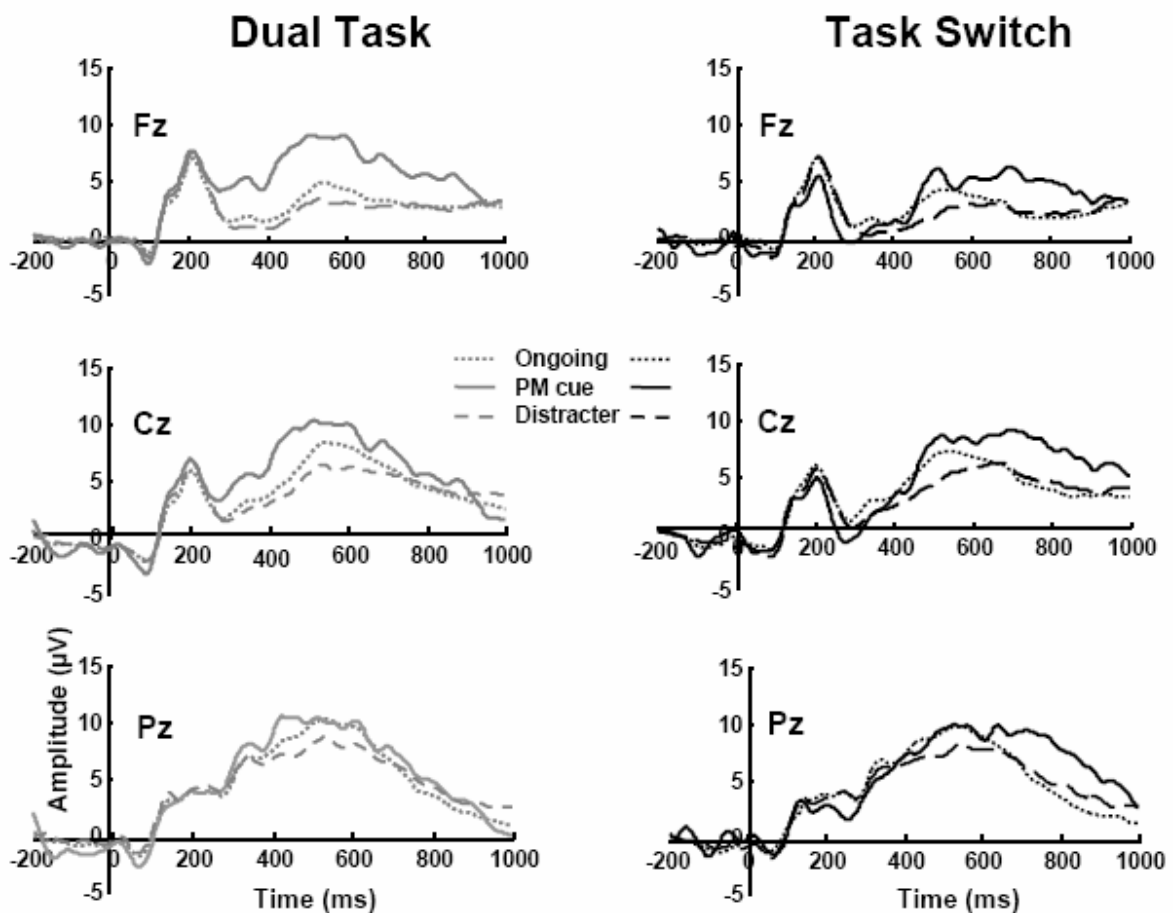
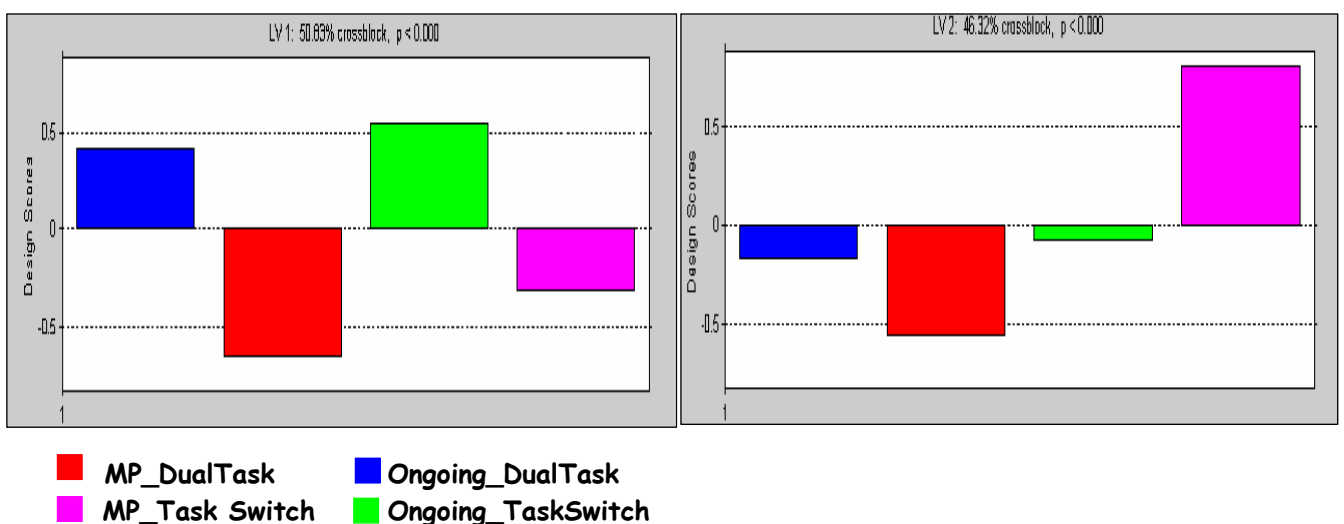


Figure 5.7. Grandaverage of event related potentials (ERPs) at frontal, central and parietal electrodes demonstrating the prospective positivity in the ongoing, prospective and distracter conditions in dual task (a) and task switch (b) version.

In summary, analyses of mean voltage revealed that the amplitude of the N300 elicited by prospective items was similar across the two task version. Analyses of the prospective positivity, in contrast, revealed that the amplitude elicited by prospective items differed between dual task and task switch versions. In fact, the prospective positivity elicited by the dual task version showed the presence of a positivity between 400 and 700ms greater over anterior electrodes respect task switch paradigm. Instead task switch showed the presence of a late positive component between 700 and 1000 ms over posterior and left electrodes respect dual task paradigm. So we might conclude that a different type of task (dual task and task switch) used in a PM task may entail different neural processes but only considering the prospective positivity.

**5.4.3 PLS analysis.** The PLS analysis included the ERPs elicited by the and ongoing activity trials and prospective memory trials in both paradigms for the entire analyzed epoch (0- 1000 ms) and all electrodes except the ocular channels. The permutation test revealed two significant latent variables (LV1 and LV2 ) ( $P < .001$ ,  $p < .001$ ) that accounted for 50.83% and 46.32% of the covariance respectively. LV1 distinguished for the ERPs elicited by prospective hits of dual task and task switching paradigm from those elicited by ongoing activity trials of the respective task. The electrode saliences for the first latent variable reflected a modulation over occipital-parietal of the scalp between 200 and 300 ms that reflects the expression of the N300, a modulation beginning at around 400 ms in frontal regions and a later modulation over parietal regions that reflects the expression of prospective positivity. The second latent variable (LV2) distinguished for the ERPs elicited by prospective hits of dual task from those elicited by prospective hits of task switching. The electrode saliences for the second latent variable reflected a modulation between at 400 and 1000 ms in frontal regions and a later modulation over parietal regions beginning at around 700 ms (*Figure 5.8*).



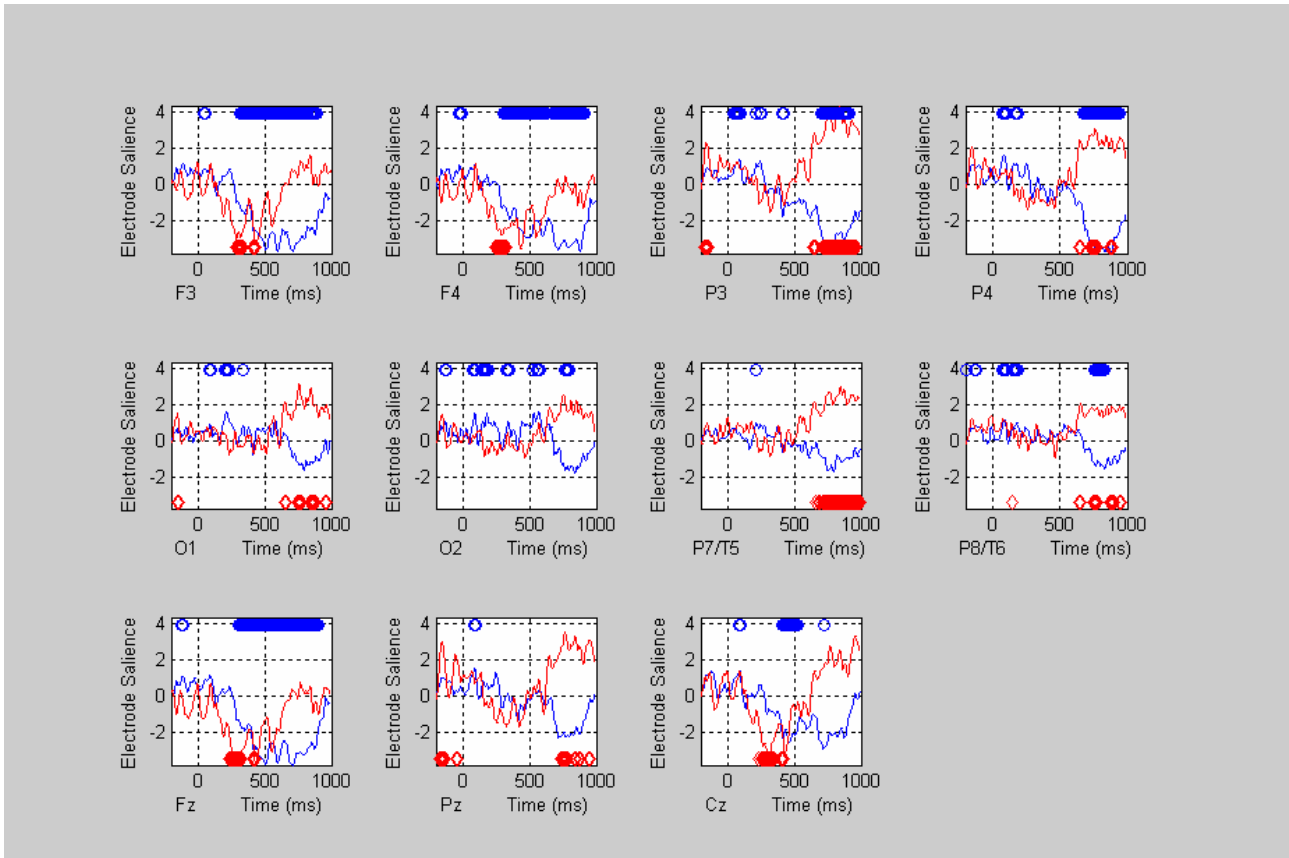


Figure 5.8 Results of the PLS analysis for Experiment 1.

The top panel portrays the design score by task condition contrast for LV1 (left) and LV2 (right). The bottom panel portrays the electrode saliences for LV1 and LV2 between 0 and 1000 ms after stimulus onset. The stable saliences for LV1 are indicated by the circles presented above the waveforms and the stable saliences for LV2 are indicated by the diamonds presented below the waveforms.

## 5.5 Conclusion

The present study reveals some evidence that it may not just be an arbitrary decision which direction an empirical procedure takes. Considered together, behavioural and electrophysiological evidence suggests (1) that the two approaches may lead to somewhat different results and (2) that a task switching approach appears to be more resource demanding. Although the present study cannot shed much more light on the exact nature and functional role of these differences, it clearly argues that different neural mechanisms may contribute to accurate PM performance when using a different type of task version. It may well be that besides the retrieval of the intended action from long-term memory as well as with post-retrieval monitoring the late positivity may also reflect the activity of a neural mechanism that supports processes of the task set reconfiguration involved in task switch processes (i.e. the ability to override and reconfigure the previously activated task set when a new external stimulus is presented; Crone et al., 2006).

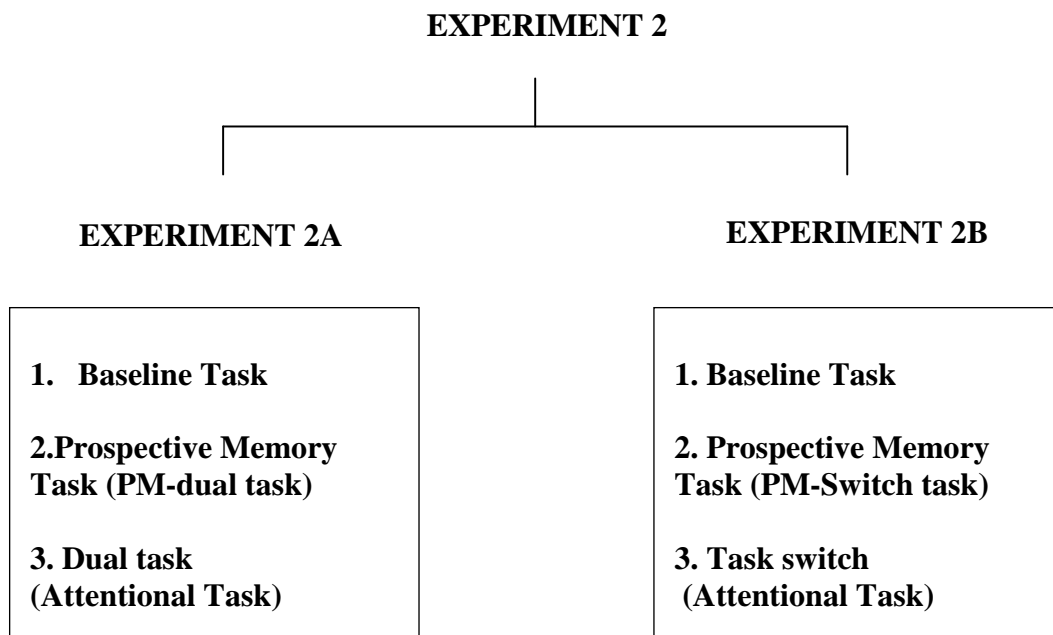
## 5A/B: Experiment 2

Results of experiment 1 showed a different PM performance when using a different type of task version: dual task or task switch version. Particularly, in accordance with the attention literature, task switching required an additional cognitive process compared to dual task in term of cognitive control (Dreher et al., 2003).

One question that might arise concerns the possibility that differences observed are caused by the type of PM task instructions, whether it is in the context of a dual task or a task switch.

Therefore, with respect to similarities in neuroimaging and electrophysiological studies, the aim of this experiment was to investigate differences between a PM task and an attentional task. So in the experiment 2A we compared a PM task with a dual task paradigm (PM-dual task) to a dual task (or attentional task) and in experiment 2B a PM task with a task switch paradigm (PM-Switch task) to a task switch (attentional task) (Figure 5A/B).

Accuracy, reaction times (RTs), and event related potentials (ERPs) were analysed.



*Figure 5A/B.* Experimental Paradigm of Experiment 2A and Experiment 2B.

## 5A. Experiment 2A

### 5A.1 Method

#### 5A.1.1 Participants and design

Seventeen participants aged between 18 and 25 years ( $M = 23.25$ ,  $SD = 1.80$ ; 9 female) were enrolled in the study. Data of two subjects were excluded from the analyses due to a high level of artefact in the EEG.

All participants were right-handed according to their score on the Edinburgh-Handedness-Test (Oldfield, 1971) and they were students of the University of Padua. All were in good health, none reported brain injuries, psycho-affective medication, drug consumption or other diseases affecting brain functioning and they had normal or corrected-to-normal vision. All participants were paid 20 Euro for their participation in the experiment and were provided with descriptions of the study before informed consent was obtained. The experiment was conducted in agreement with the declaration of Helsinki.

The design of the study was a one factorial study design with the within-person factor of task type: subjects had to perform in a fixed order a baseline task, a prospective memory task (PM-dual task) and a dual task (the attentional task).

#### 5A.1.2 Material and Procedure

The design of Experiment 2A was identical to Experiment 1 with the following exceptions. At the beginning subjects had to perform a baseline task that was similar to the ongoing task of experiment 1, without PM instructions. Participants were asked to evaluate five-letter strings (e.g., DFDFD) as to whether the second and the fourth letter were identical or not. This task consisted of two blocks of 36 stimuli.

Then after completing the baseline task, subjects received the PM instructions. The PM instructions were the same of the PM task with dual task version of the first experiment. Participants were instructed that whenever they detected a PM cue they should firstly proceed in the ongoing task routine (i.e., decide whether or not the second and fourth letter are the same) and then press the PM response key (i.e., the spacebar). This task consisted of ten blocks of 36 stimuli.

The number of distracter stimuli in the PM task was reduced from ten (Exp.1) to four in each block (two representing an ongoing task Yes-response-item and two representing an ongoing task No-response-item).

At the end participants had to perform a dual task (attentional task). The instructions of the dual Task were the same of the PM task (The ongoing or the primary task required the ongoing keys



response while the presence of B target (secondary task) required first the ongoing response and then, the PM response/ spacebar) but with one exception: we varied the frequency of the appearance of the two conditions creating short unpredictable sequences of N trials (minimum 3 (10%) - maximum 11 (30%) for each condition (ongoing task and presence of B target task), see Figure 5A). This task consisted of eight blocks of 36 stimuli.

We analysed:

1. Baseline and PM-dual task: we compared the baseline task to the ongoing of the PM-Dual task in order to evidence the effect of the prospective action;
2. The ongoing task performance in PM-dual task in the main conditions (ongoing, distracter and prospective), as in the first experiment;
3. The ongoing task performance in Dual task;
4. PM-dual task / Dual task: we compared the prospective trials of the PM-Dual task to the first B target trial of each sequence of the Dual task (stimuli in red colour in Figure 5A) in order to avoid a possible effect of stimulus frequency.

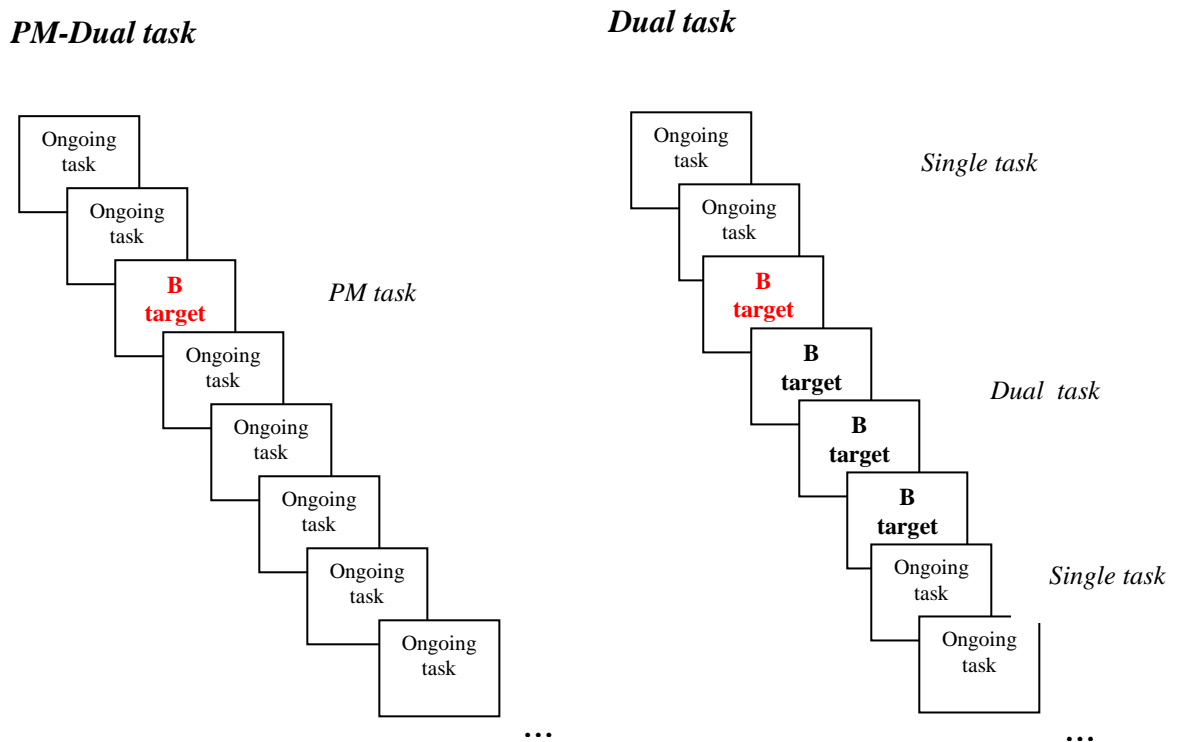


Figure 5A. Experimental design of the PM-Dual task and Dual task.

### 5A.1.3. ERPs recording

The acquisition and post-processing of the EEG data was nearly identical to the Experiment 1 with an exception. The EEG was recorded from an array of 32 Ag/AgCl scalp electrodes mounted on an elastic cap (ElectroCap International, Inc.) and positioned according to the 10-20 International System (AEEGS, 1991). According to previous studies on neural correlates of PM (West et al., 2003; West & Krompinger, 2005; West & Ross-Munroe, 2002), the montage included the following scalp positions: Fp1, Fp2, F3,F4,C3,C4,P3,P4,O1,O2, F7,F8, T3,T4, T5,T6, Cz, FZ,PZ, FCZ, CPZ,CP3,CP4,FC3,FC4, TP7,TP8,OZ, FT7, FT8, VEOG, HEOG.

### 5A.1.4. Data analysis

Accuracy, reaction times (RTs), event related potentials (ERPs), PLS and LORETA were analysed.

Regarding behavioural data, differences between Baseline and PM-Dual task, ongoing in the PM-Dual task, ongoing in the Dual task, and the presence of B target trials (pressure of bar) in PM-Dual task and Dual task were analyzed.

Regarding EEG data, differences between task versions (PM-Dual task versus ongoing and PM- Dual task versus Dual task) were examined in two epochs where the N300 and the positive component (or the prospective positivity) are typically observed in the prospective memory task (West et al., 2003; West & Krompinger, 2005; West & Ross-Munroe, 2002; Zöllig et al., 2007). ERPs of baseline condition were not analyzed.

*PLS analysis.* Partial least squares (PLS) analysis (Kovacevic & McIntosh, 2007; Lobaugh, West & McIntosh, 2001) was used to further explore potential differences between the PM-Dual task and Dual task versions (see, e.g., Zöllig et al., 2007, for a similar approach). The procedure was identical to the Experiment 1.

*LORETA analysis.* Low-resolution electromagnetic tomography (LORETA) was performed on the basis of the scalp-electrode electric potential distribution (Pascual- Marqui, 1999, 2002; Pascual-Marqui) to localize differential neural recruitment between tasks. LORETA was used to estimate the three-dimensional intra-cerebral current density distribution in 2394 voxels with a grid resolution of 7 mm and a voxel volume of 0.343 cm<sup>3</sup>. The evaluated ERPs were subjected to a LORETA analysis. The obtained images were compared on a voxel-wise basis for inter-task differences between prospective memory (PM-Dualtask) and Dual task in the condition of presence of B target. Two time frames of interest were defined reflecting the N300 and the positive component based on the mean latencies plus / minus one standard deviation. Thus the time of interest ranged for the N300 from 200 to 400 ms and for the positive component from 400 to

1000ms. The statistical comparisons were conducted using *t*-tests for paired samples corrected for multiple comparisons (Nichols & Holmes, 2002). These patterns of descriptive *p*-values were plotted in statistical probability maps (SPM). LORETA values were transformed logarithmically to achieve normal distribution.

## 5A.2. Behavioural results

### 5A.2.1 Baseline and PM-Dual task

In a first step, ongoing task performance was analyzed across the two factors *task versions* (baseline and PM task) and *item condition* (ongoing task item, prospective items and distracter item), both with respect to response times (RT) and accuracy.

A 2(task version) x 3(item condition) repeated measures analysis of variance (ANOVA) on RT data averaged across correct trials revealed a main effect of task,  $F(1,16) = 5.33$   $p < .035$ ,  $\eta^2 = .250$ , a main effect of item condition,  $F(2,32) = 46.78$ ,  $p < .001$ ,  $\eta^2 = .745$  and the interaction Task x Item Condition was reliable,  $F(2,32) = 15.87$   $p < .001$   $\eta^2 = .498$ . Post hoc analysis indicated that the addition of a PM task produce a slowing on the ongoing task ( $p < .004$ ) compared to ongoing task items of the baseline task, indicating that performance of delayed intentions makes demands on our limited attentional resources. The addition of a PM-Dual task produce also a slowing on the ongoing task in the distracter condition ( $p < .014$ ) ( Figure 5A.1) .

A 2 x 3 repeated measures analysis of variance (ANOVA) on accuracy data revealed a main effect of task ,  $F(1,16) = 9.68$ ,  $p < .07$ ,  $\eta^2 = .377$  and also the interaction Task x Item Condition was reliable,  $F(1,16) = 13.87$ ,  $p < .001$ ,  $\eta^2 = .464$ . Post hoc analysis suggested that subjects were less accurate in ongoing ( $p < .007$ ), prospective ( $p < .004$ ) and distracter items ( $p < .014$ ) of PM-Dual task compared to relative conditions of the baseline task. This finding is consistent with evidence from other studies (Smith, 2003) and may indicate that embedding a PM task in an ongoing task will reduce the resources available to the ongoing task with a slowing of RTs and low accuracy of the ongoing task of PM instruction task.

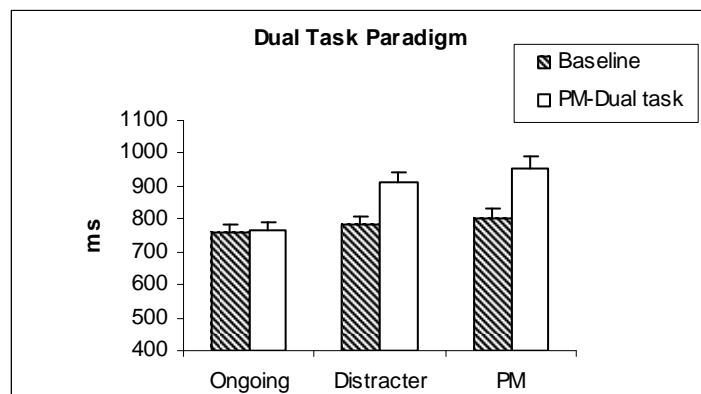


Figure 5A.1 RTs of Baseline and ongoing of the PM-Dual task.

### **5A.2.2 Ongoing task performance in PM-Dual task.**

As in the first experiment, ongoing task performance of PM-Dual task was analyzed across *item condition* factor (ongoing task item, prospective items and distracter item), both with respect to response times (RT) and accuracy.

In the PM-dual task version it was possible to compare RT ( $M = 941.65$  ms;  $SD = 120.94$ ) and accuracy ( $M = .95$ ;  $SD = .04$ ) of the ongoing task responses to the PM cue items with RT and accuracy of the ongoing task items proper and the distracter items. T-test revealed increased RTs in the PM cue items compared to both ongoing task items proper,  $t(17) = -10.149$   $p < .001$ , and distracter items,  $t(17) = -5.560$   $p < .001$ , (see Figure 5A.1) and also differences in accuracy of PM cue items compared to both ongoing task items proper  $t(17) = 2.712$   $p < .016$  and distracter items,  $t(17) = 2.621$   $p < .019$ .

Decreasing the number of distracter stimuli, there is an evident slowing of RTs and, differently from the first experiment, a reduction of accuracy. The effect of distracter item was found also in literature by West et al. (1999; 2001) in prospective lures (trials where individuals were instructed to ignore the change in case necessary for the PM response and to make a semantic judgement (ongoing task); see West et al., 2000), even if the reason for the slowed response time for prospective lures is unclear.

### **5A.2.3 Ongoing task performance in Dual task.**

Ongoing task performance was analyzed across task version (single task /or baseline and Dual task) both with respect to response times (RT) and accuracy.

Comparing single task and dual task, subjects showed a slowing in RTs when they had to execute two tasks respect to performing a single task,  $t(17) = -3.213$   $p < .02$ .

No effect in accuracy was found  $F < 1$  (Table 5A.2 ). It might due to the facility of the task.

This finding is consistent with evidence from other studies about dual task that performing dual tasks usually results in performance decrements as compared to single-task performance (for a review, see e.g. Pashler, 1994). Such decrements, evidenced in this case, as prolonged reaction times but not higher error rates, are indicative of additional cognitive demands in the dual task situation as compared to the isolated performance of the single tasks (Braun, 1998; DeJong, 1995; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997).

	<i>Single Task</i>	<i>Dual Task</i>	<i>Dual Task</i> Ongoing	Ongoing of stimulus of B target
RT (ms)	759.02	782.07	821.07	838.72
(SD)	(177.20)	(199.78)	(199.67)	(190.60)
Accuracy	.96	.962	.96	.965
(SD)	(.10)	(.22)	(.01)	(.06)

Table 5A.2. Mean and Standard deviation of RTs and accuracy in ongoing of Single task (Baseline) and of Dual Task (Attentional task). Accuracy is given in proportion correct.

#### 5A.2.4 PM-Dual task and Dual task

Comparing the presence of B target in both PM-Dual task and Dual task, behavioural results showed that RTs tended to decrease respect the condition of prospective memory, characterized by a rare frequency,  $t(17) = -5,502 < .001$ . Considering the accuracy, subjects are more accurate in Dual task respect the PM task  $t(17) = -2,145 p < .049$ .

#### 5A.3 Electrophysiological data

*ERP components.* The grandaverage ERPs portraying the N300 and the positive component between the ongoing and Prospective condition of the PM-Dual task (first comparison) and between PM-Dual task and Dual task (second comparison) are displayed in Figure 5A.3. and Figure 5A.4.

*Differences in mean amplitude for Ongoing and PM-Dual task.* The N300 was quantified as mean amplitude between 100 and 400 ms and analysed according to three factors: item condition (ongoing task item and prospective cue item) and electrode sites (occipital versus parietal sites) and hemisphere site (left: O1-P7; right: O2-P8).

We compared the Items of prospective items in PM-Dual task with the ongoing activity trials and we considered, as in Experiment 1, three time windows: 100-200 ms, 200-300 ms versus 300-400ms. We reported only reliable results ( $p < .05$ ).

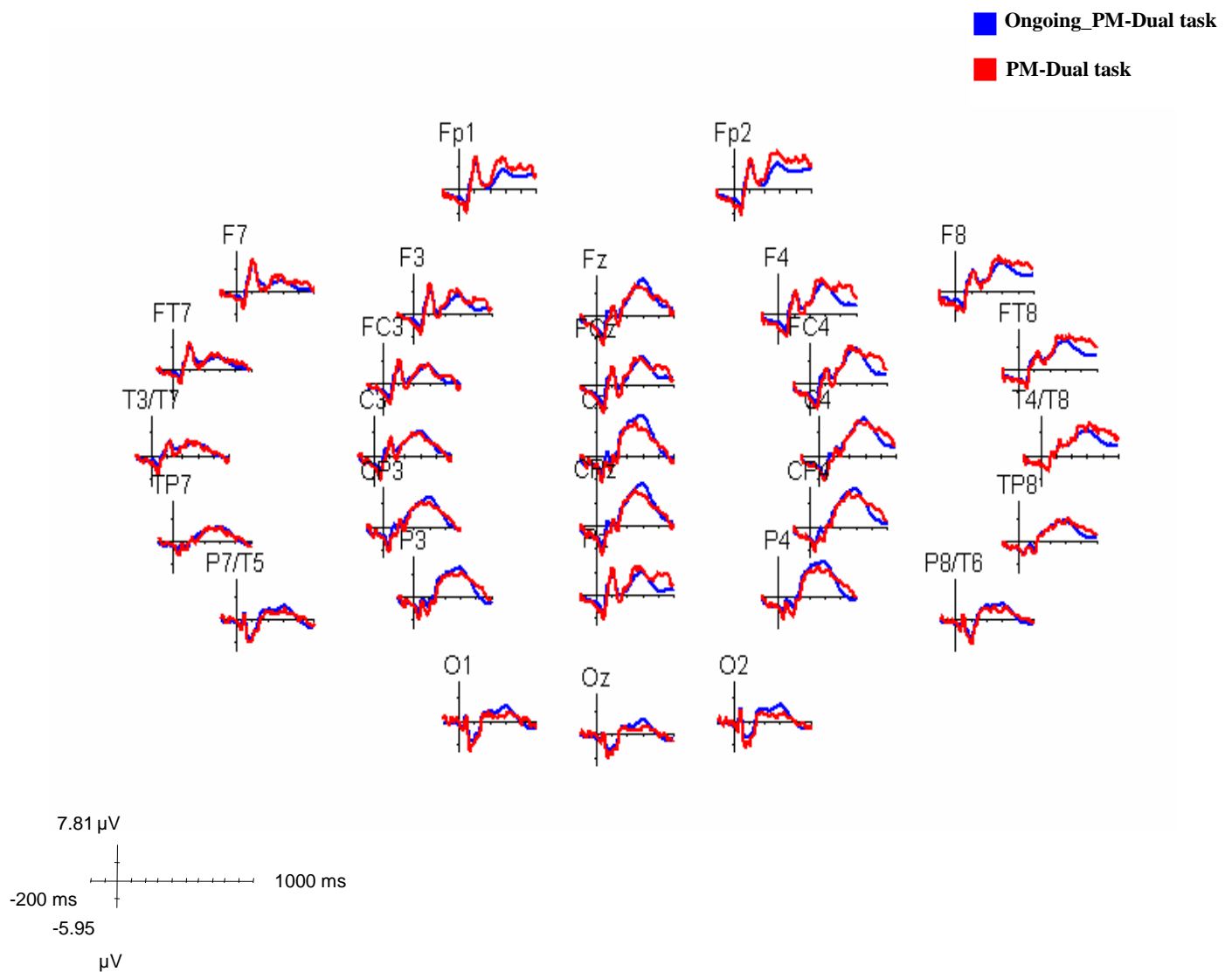


Figure 5A.3. Grandaverage event related potentials (ERPs) at electrodes demonstrating the N300 and the positive component in the ongoing and prospective condition of PM-Dual task.

A 2 x 2 x 2 repeated measure analysis of variance (ANOVA) was conducted. Analysis revealed in the time window between 200 and 300 ms, only a main effect of item condition,  $F(1,14) = 7.47$ ,  $p < .016$ ,  $\eta^2 = .348$ . Post hoc analyses showed that the amplitude elicited by prospective items over occipital-parietal sites was greater respect ongoing activity trials.

The amplitude of the positive component was quantified as mean amplitude between 400 and 1000 ms and analysed according to 3 factors: item condition (ongoing task item and prospective cue item) Hemisphere site (left: P3-C3-F3; central PZ-CZ-FZ and right P4-C4-F4) and a anterior-posterior site (parietal P3-PZ-P4, central C3-CZ-C4 and frontal F3-FZ-F4).

A 2 x 3 x 3 repeated measure analysis of variance (ANOVA) on ERPs averaged across correct trials was conducted. In time window between 400-700ms analysis revealed the interaction Task x Hemisphere, site  $F(2,28) = 8.33$ ,  $p < .001$ ,  $\eta^2 = .357$ , and the interaction Task x Hemisphere x Anterior/posterior sites,  $F(2,28) = 8.53$ ,  $p < .001$ ,  $\eta^2 = .362$ , were reliable. Post hoc analyses evidenced that the amplitude of the positive component elicited by prospective items was greater

over frontal sites of right hemisphere respect ongoing activity trials.

In time window between 700 and 1000 ms analysis revealed a main effect of Task,  $F(1,14) = 4.44$ ,  $p < .05$ ,  $\eta^2 = .228$ , a main effect of Hemisphere site,  $F(2,28) = 10.35$ ,  $p < .001$ ,  $\eta^2 = .408$ , a main effect of Anterior/posterior sites,  $F(1,14) = 14.42$ ,  $p < .002$ ,  $\eta^2 = .490$  and an interaction Task x Hemisphere x Anterior/posterior sites,  $F(2,28) = 5.62$ ,  $p < .008$ ,  $\eta^2 = .272$ . Post hoc analysis evidenced that the amplitude of the positive component in the interval between 700 and 1000 ms elicited by prospective items was greater over frontal and parietal sites of the left and right hemisphere respect ongoing activity trials.

**Differences in mean amplitude of PM-Dual task and Dual task.** The N300 was quantified as mean amplitude between 100 and 400 ms and analysed according to three factors: task versions (PM-Dual task versus Dual task), electrode sites (occipital versus parietal sites) and hemisphere site (left: O1-P7; right: O2-P8).

We compared the Items of the presence of B target trials (pressure of bar) in both task and we considered, as in Experiment 1, three time windows: 100-200ms, 200-300 ms versus 300-400ms. We reported only reliable results ( $p < .05$ ).

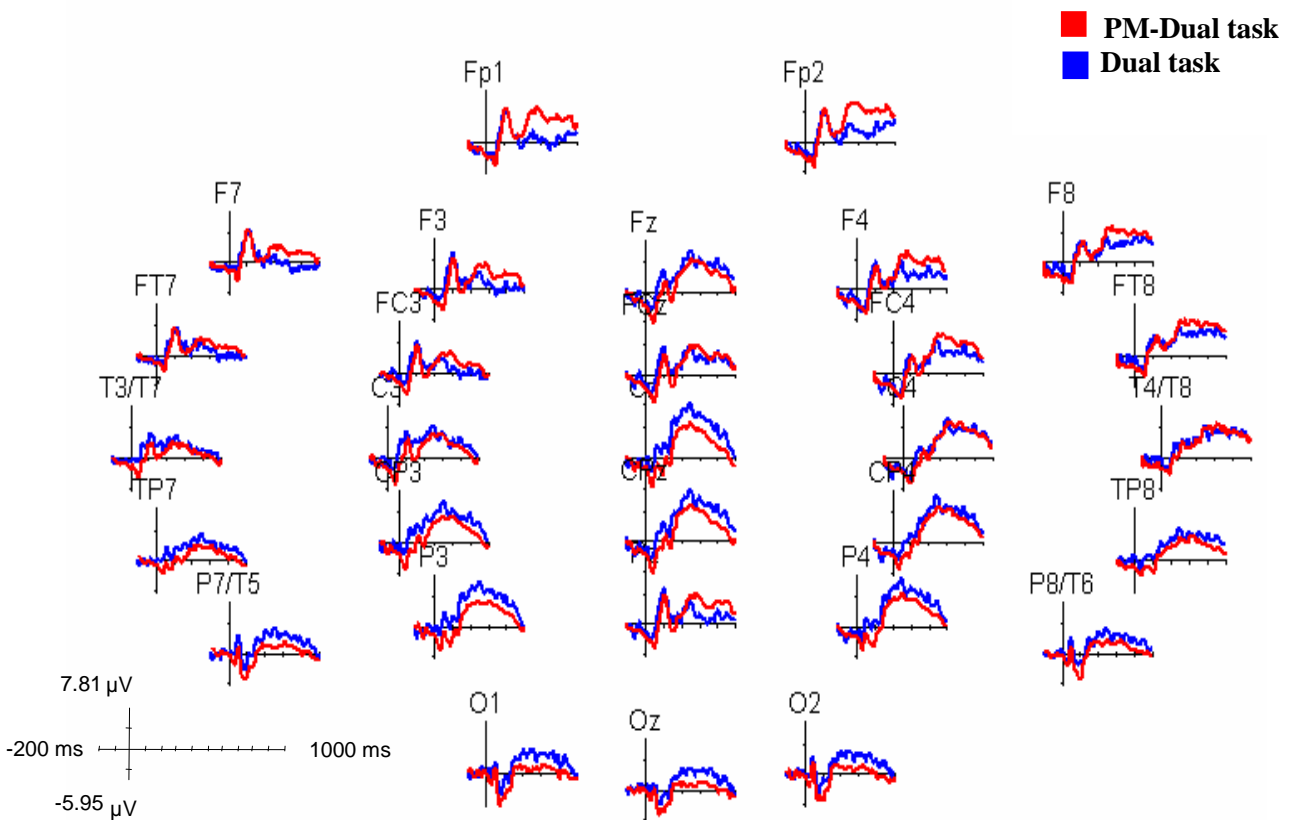


Figure 5A.4. Grandaverage event related potentials (ERPs) at electrodes demonstrating the N300 and the positive component in B target trials of prospective (PM-Dual task) versus Dual task.

A 2 x 2 x 2 repeated measure analysis of variance (ANOVA) was conducted. In this analysis the main effect of task was significant  $F(1,14) = 4.92, p < .047, \eta^2 = .291$ . Post hoc analyses revealed that the amplitude of the N300 elicited by prospective items between 200 and 300 ms over occipital-parietal sites was greater respect amplitude elicited by the presence of B target items in Dual task.

The amplitude of the positive component was quantified as mean amplitude between 400 and 1000 ms and analysed according to 3 factors: PM task version (prospective versus Dual task), Hemisphere site (left: P3-C3-F3; central PZ-CZ-FZ and right P4-C4-F4) and a anterior-posterior site (parietal P3-PZ-P4, central C3-CZ-C4 and frontal F3-FZ-F4).

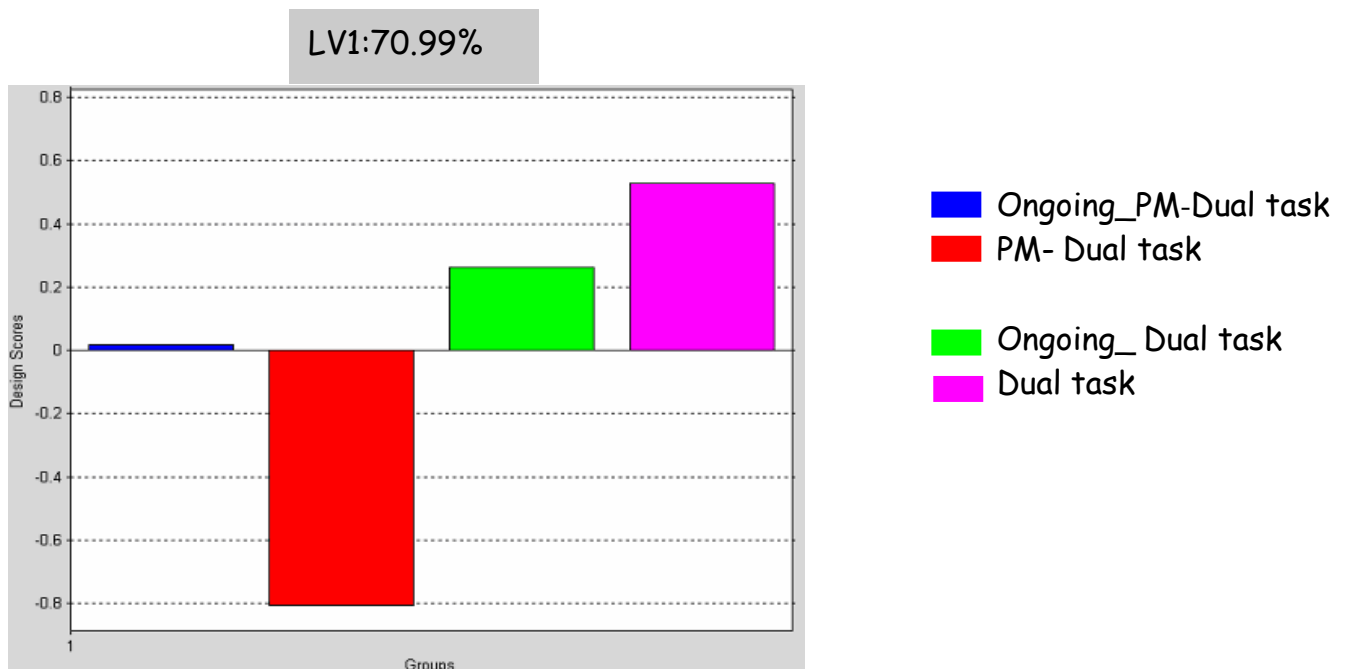
A 2 x 3 x 3 repeated measure analysis of variance (ANOVA) on ERPs averaged across correct trials was conducted. In time window between 400-700 ms analysis revealed two significant interactions: the interaction Task x Hemisphere site,  $F(2,28) = 6.03, p < .007, \eta^2 = .301$ , and the interaction Task x hemisphere sites x Anterior/posterior sites,  $F(2,28) = 9.18, p < .001, \eta^2 = .396$ . Post hoc analyses revealed that the amplitude of this positivity was greater in PM-Dual task respect Dual task in anterior site of right hemisphere respect posterior site. On the other side, the Dual task showed a greater activation on posterior sites of right hemisphere respect PM-Dual task.

In time window between 700 and 1000 ms analysis revealed the same two significant interactions: the interaction Task x Anterior/posterior sites,  $F(1,14) = 8.11, p < .013, \eta^2 = .367$  and the interaction Task x Hemisphere sites x Anterior/posterior sites,  $F(2,28) = 11.21, p < .001, \eta^2 = .445$ . Post hoc analyses revealed that the amplitude of this positivity was greater in PM-Dual task in anterior site of right hemisphere respect Dual task. The Dual task showed a greater activation on posterior sites of right hemisphere respect PM-Dual task.

In summary, analyses of mean voltage revealed that the amplitude of the N300 elicited by prospective items between 200 and 300 ms over occipital-parietal sites was greater respect amplitude elicited by the presence of B target items in Dual task. Analyses of the positive component, in contrast, revealed that the amplitude elicited by prospective items of PM-Dual task was greater over anterior sites of right hemisphere while the amplitude of this positivity was more posterior in the Dual task. It might indicate that the PM-Dual task require more an involvement of frontal areas. This data is in agreement with the finding of an overadditive activation in prefrontal regions that was interpreted as being related to additional cognitive demands present in the dual task, as compared to the summed demands of both single tasks (Szameitat et al., 2006).



**5A.4 PLS analysis.** The PLS analysis included the ERPs elicited by the presence of B target trials in both tasks for the entire analyzed epoch (0- 1000 ms) and all electrodes except the ocular channels. The permutation test revealed a significant latent variables (LV1) ( $p < .001$ ) that accounted for 70.99% of the covariance. LV1 distinguished for the ERPs elicited by prospective hits of PM-Dual task from those elicited by the presence of B target trials in the Dual task. The electrode saliences for the latent variable reflected a modulation over occipital sites (O2 site) of the scalp between 200 and 300 ms that reflects the expression of the N300, a modulation beginning at around 400 ms over frontal (F3, F4 sites) and parietal regions (P4, P7, P8 sites) and a later modulation over parietal regions (P7, P8 sites) that reflects the expression of the positive component (Figure 5A.5).



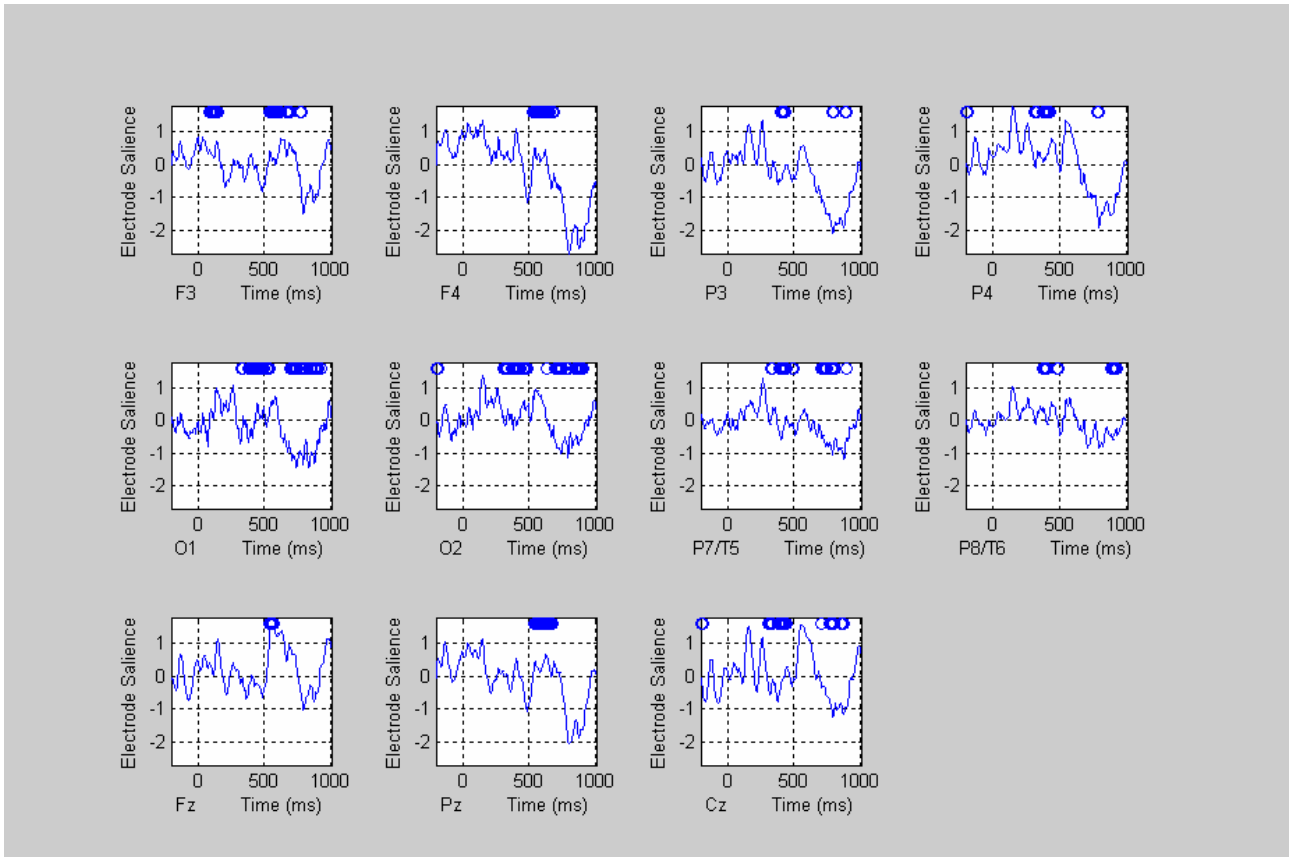


Figure 5A.5. Results of the PLS analysis for Experiment 2A. The top panel portrays the design by task condition contrast for LV1. The bottom panel portrays the electrode saliences for LV1 between 0 and 1000 ms after stimulus onset. The stable saliences for LV1 are indicated by the circles presented above the waveforms.

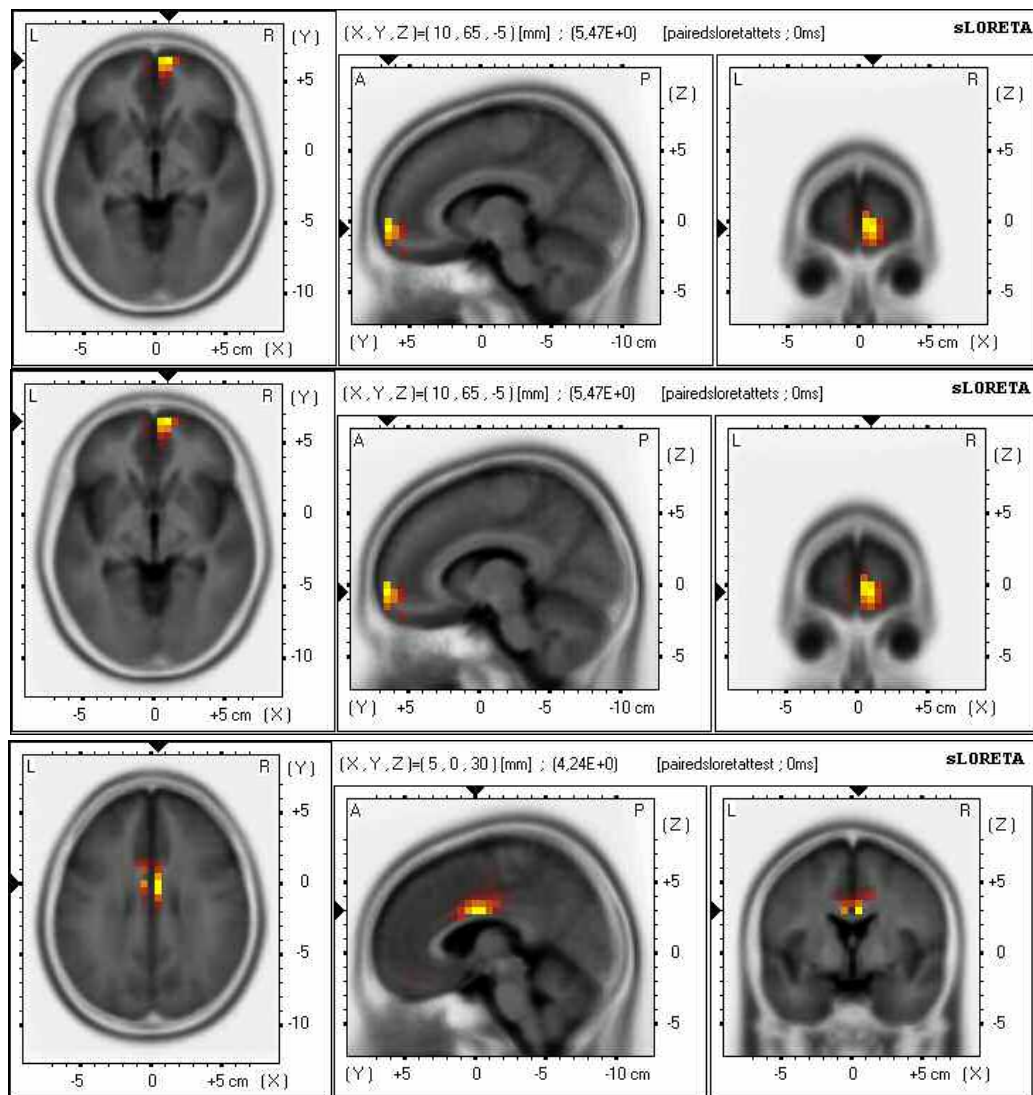
### 5A.5 LORETA analysis.

Source localization was performed to investigate differences in neural recruitment associated with prospective memory task (PM-Dual task) and Dual task that might be reflected in variation in the pattern of design scores across the tasks in the PLS analysis.

The statistical probability maps from the LORETA analyses are displayed in Figure 5A.8, local maxima of inter-task differences in the three-dimensional current density distribution for the presence of B target trials are shown for the two components N300 and the positive component considering two time windows (400-700 ms and 700-1000ms).

*N300 time frame.* Subjects had increased activation in the cingulate gyrus (BA 24) in the prospective memory task (PM- Dual task) compared to Dual task.

*Positive component time frame.* In the time-window between 400 and 700 ms subjects had increased activation in superior frontal gyrus (BA10) in prospective memory task (PM- Dual task) compared to Dual task. In time window between 700 and 1000 ms the superior temporal gyrus (BA 39) revealed greater activation in prospective memory task (PM- Dual task) compared to Dual task. To sum up, the LORETA analyses revealed different patterns of neural recruitment in PM-Dual task in comparison to Dual task in the time frames of both the N300 and positive component.



*Figure 5.6.* Statistical probability maps (SPM) of the source localization with LORETA for differences between prospective memory (PM-Dual task) and Dual task. Results are significant at the  $p < .05$  level (blue colour = significantly lower current density, red colour = higher current density).

## 5A.6 Conclusion

Experiment 2A was designed to compare a PM task with dual task paradigm to a dual task. Results of Experiment 2A showed that the cognitive processes involved in performing a PM-Dual task are different to which used in performing a Dual task (the attentional task). These differences are supported by behavioural results with an increasing of RTs and of number errors in the prospective memory task compared to the Dual task.

The ERPs elicited by prospective hits of PM-Dual task versus ongoing, were generally consistent with previous research and revealed an N300 over the occipital–parietal region and a positive component (the prospective positivity) over the parietal region of the scalp (West et al., 2001; West & Ross-Munroe, 2002).

The ERPs elicited by the presence of B target item in PM-Dual task (prospective items) and B target items in the Dual task revealed that the amplitude of the N300 elicited by prospective items between 200 and 300 ms over occipital-parietal sites was greater respect amplitude elicited by presence of B target items in Dual task. Regard the positive component, analyses revealed that the amplitude of this positivity, in the time-window between 400 and 700 ms and in the time-window between 700 and 1000 ms was greater in PM-Dual task respect Dual task in anterior site of right hemisphere respect posterior site. On the other side, the Dual task showed a greater activation on posterior sites of right hemisphere respect PM-Dual task.

PLS was used to examine the structural relationships between modulations of the ERPs differentiating the presence of B target in PM-Dual task and in Dual task.

This analysis revealed the presence of a significant latent variable. This latent variable distinguished for the ERPs elicited by prospective hits of PM-Dual task from those elicited by the Dual task and captured modulations of the ERPs associated with the detection of prospective cue (N300, over occipital-parietal of the scalp between 200 and 300 ms) and processes of retrieval (a modulation beginning at around 400 ms over frontal-parietal regions and a later modulation over parietal regions that reflects the expression of prospective positivity).

These data was supported by results of LORETA analysis. For the time frame of N300 subjects had a greater activation in the cingulate gyrus (BA 24) in the prospective memory task compared to Dual task. For the time frame of the positive component, participants showed a greater activation in prospective memory task (PMDual task) compared to Dual task in: superior frontal gyrus (BA10) in the time-window between 400 and 700 ms and a greater activation in the superior temporal gyrus (BA 39) in time window between 700 and 1000 ms. These findings are in line with previous studies using PET and fMRI suggesting a recruitment of lateral BA 10 that is involved in

maintaining an intention whilst performing an ongoing task (Okuda et al., 1998; Burgess et al., 2001, 2003).

## **5B. Experiment 2 B**

### *5B.1 Method*

#### *5B.1.1 Participants and design*

Twenty-one participants aged between 18 and 25 years ( $M = 22.62$ ,  $SD = 1.77$ ; 11 female) were enrolled in the study. 15 subjects were submitted to EEG recording and data of one subject were excluded from the analyses due to a high level of artefact in the EEG.

All participants were right-handed according to their score on the Edinburgh-Handedness-Test (Oldfield, 1971) and they were students at the University of Padua. All were in good health, none reported brain injuries, psycho-affective medication, drug consumption or other diseases affecting brain functioning and they had normal or corrected-to-normal vision. All participants were paid 20 Euro for their participation in the experiment and were provided with descriptions of the study before informed consent was obtained. The experiment was conducted in agreement with the declaration of Helsinki.

The design of the study was a one factorial study design with the within-person factor of task type : subjects had to perform in a fixed order a baseline task, a prospective memory task (PM-task switch) and Task switch.

#### *5B.1.2 Material and Procedure*

The design of Experiment 2B was identical to Experiment 2A with the following exceptions. The PM instructions of the PM-Switch task were the same of the PM task but with task switch instructions. Participants were instructed that when a prospective cue (letter 'B') was presented they should remember to directly press the spacebar of the keyboard *without* performing the ongoing task. As in experiment 2A the number of distracter stimuli in the PM- Switch task was reduced from ten (Exp.1) to four in each block (two representing an ongoing task Yes-response-item and two representing an ongoing task No-response-item).

The instructions of the Task switch were the same of the Dual task used in experiment 2A but with task switch instruction. The ongoing task required the ongoing keys response while the presence of B target required the PM response (spacebar) without the ongoing response.

In this paradigm, participants were asked to switch between two tasks and two conditions were compared: a) condition in which participants switch between the tasks on successive trials; b)

condition in which participants perform the same task on successive trials. Performance on Switch trials is compared to performance on the same task on Repeated trials (see Figure 5B).

This task consisted of eight blocks of 36 stimuli.

We analysed:

1. Baseline and PM-Switch task: we compared the baseline task to the ongoing of the PM-Switch task in order to evidence the effect of the prospective action;
2. The ongoing task performance in PM-Switch task in the main conditions (ongoing and distracter), as in the first experiment;
3. The ongoing task performance in Task switch;
4. PM-Switch task/ Task switch: we compared the prospective trials of the PM-Switch task with the first B target trial of each sequence of the Task switch (stimuli in red colour in Figure 5B) in order to avoid a possible effect of the stimulus frequency.

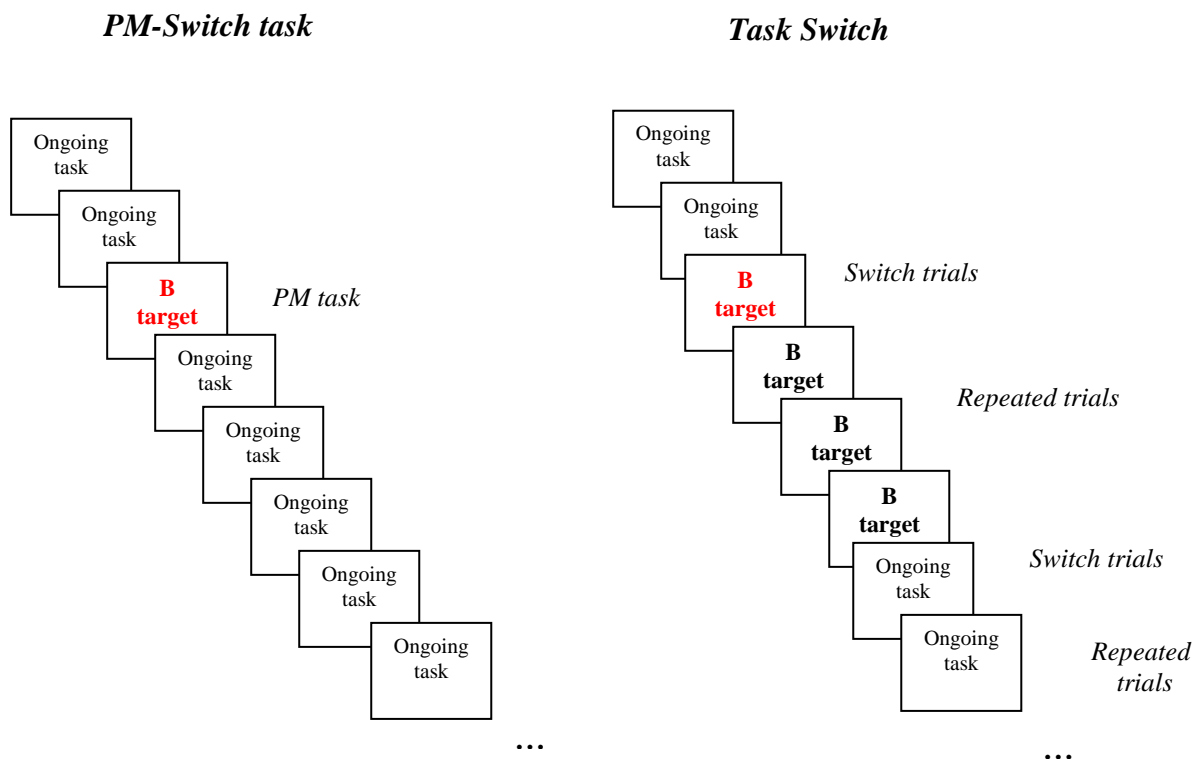


Figure 5B. Experimental design of the PM-Switch task and Task switch.

### 5B.1.3 ERPs recording and data analysis

The acquisition and post-processing of the EEG data was nearly identical to the Experiment 2A. The EEG was recorded from an array of 32 Ag/AgCl scalp electrodes mounted on an elastic cap (ElectroCap International, Inc.) and positioned according to the 10-20 International System (AEEGS, 1991).

The analysis of mean amplitude was identical to the experiment 2A. Differences between task versions (baseline, PM-Switch and Task switch) were examined in two epochs where the N300 and positive component are typically observed (West et al., 2003; West & Kropfing, 2005; West & Ross-Munroe, 2002; Zöllig et al., 2007). ERPs of baseline condition were not analyzed.

Accuracy, reaction times (RTs), event related potentials (ERPs), PLS and LORETA were analysed. Regarding behavioural data, differences between Baseline and PM-Switch task, ongoing in the PM-Switch task, ongoing in the Task switch, and pressure of bar (the presence of B target trials) in PM-Switch task and Task switch were analyzed.

Regarding EEG data differences between task versions (PM-Switch task versus ongoing and PM-Switch task versus Task switch) were examined in two epochs where the N300 and positivity complex are typically observed (West et al., 2003; West & Kropfing, 2005; West & Ross-Munroe, 2002; Zöllig et al., 2007). ERPs of baseline condition were not analyzed.

*PLS analysis.* Partial least squares (PLS) analysis (Kovacevic & McIntosh, 2007; Lobaugh, West & McIntosh, 2001) was used to further explore potential differences between the PM-Switch task and Task switch versions (see, e.g., Zöllig et al., 2007, for a similar approach). The procedure was identical to the Experiment 2A.

*LORETA analysis.* The processing of LORETA data was identical to the Experiment 2A.

## **5B.2. Behavioural results**

### **5B.2.1 Baseline and PM-Switch task**

In a first step, ongoing task performance was analyzed across the two factors: *task versions* (baseline and PM-Switch task instruction) and *item condition* (ongoing task item versus distracter item), both with respect to response times (RT) and accuracy.

A 2(task version) x 2 (item condition) repeated measures analysis of variance (ANOVA) on RT data averaged across correct trials revealed a main effect of task,  $F(1,19) = 5.24$   $p < .034$ ,  $\eta^2 = .216$ , a main effect of item condition,  $F(1,19) = 49.13$ ,  $p < .001$ ,  $\eta^2 = .721$  and the interaction Task x Item Condition was reliable,  $F(1,19) = 29.14$   $p < .001$   $\eta^2 = .605$ . Post hoc analysis indicated that the addition of a PM-Switch task produce a slowing on the ongoing task in the distracter condition ( $p < .001$ ) compared to ongoing items of baseline task (Figure 5B.1).

In a 2 x 2 repeated measures analysis of variance (ANOVA) on accuracy data, only the interaction Task x Item Condition was reliable,  $F(1,19) = 4.63$ ,  $p < .045$ ,  $\eta^2 = .196$ . Post hoc analysis suggested that subjects were less accurate in ongoing of distracter items ( $p < .001$ ) of PM-Switch task compared to relative conditions of the baseline task. This finding is consistent with evidence from

other studies (Smith, 2003) and may indicate that embedding a PM task in an ongoing task will reduce the resources available to the ongoing task with a slowing of RTs of the ongoing task.

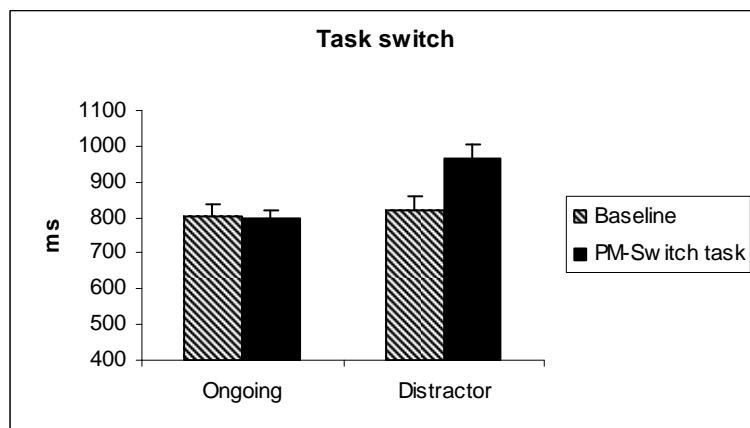


Figure 5B.1 RTs of Baseline and ongoing of the PM-Switch task

### 5B.2.2. Ongoing task performance in PM-Switch task.

As in the first experiment, ongoing task performance was analyzed across *item condition* factor (ongoing task item versus distracter item), both with respect to response times (RT) and accuracy. A T-test on RTs and accuracy data revealed a reduced overall performance in distracter item respect ongoing task item: subjects were slower,  $t(20)=-6.75$   $p < .001$ , and less accurate,  $t(20)=2.14$   $p < .045$ , when they had to inhibit the prospective response in order to execute the ongoing response.

### 5B.2.3 Ongoing task performance in Task switch.

Ongoing task of Task switch performance was analyzed across *item condition* (switch trials and repeated trials), both with respect to response times (RT) and accuracy (Table 5B.2).

Comparing repeated and switch trials in the ongoing task items subjects showed a slowing in RTs  $t(20)=-7.98$   $p < .001$  and a reduced accuracy  $t(20)=2.75$   $p < .001$  when they had to alternate trial respect to repeated trials.

Comparing repeated and switch trials in the presence of B target items subjects showed a slowing in RTs  $t(20)=-9.98$   $p < .001$  and a reduced accuracy  $t(20)=6.73$   $p < .001$  when they had to alternate trial respect to repeated trials.

Switch cost is greater in the presence of B target items respect the ongoing task. This result reflects consistent findings about task switching where latencies are longer to perform a switched task than to perform a repeated task, and this deficit is called the switch cost (Sohn et al.,2000).



<i>Task Switch</i>	<i>Switch trials</i>	<i>Repeated trials</i>	<i>Switch cost</i>
<i>Ongoing task</i>			
RTs (SD)	869.78 (192.29)	763.26 (184.61)	106.52 ms
Accuracy (SD)	.92 (.27)	.96 (.019)	
<i>Presence of B target</i>			
RTs (SD)	794.92(191.34)	569.93 (156.87)	224.99 ms
Accuracy (SD)	.86 (0.35)	.92 (0.19)	

Table 5B.2. Mean and Standard deviation of RTs and accuracy for switch and repeated trials in the ongoing and in the presence of B target items of Task switch.

#### 5B.2.4 PM-Switch task and Task switch

Comparing the presence of B target in both PM-Switch task and Task switch, behavioural results showed that RTs tended to decrease in the Task switch respect the condition of prospective memory, characterized by a rare frequency  $t(20) = -4.66$   $p < .001$  (see Figure 5B.3).

Differently from results found in experiment 2A, no main effect in the accuracy (Mean of PM-Dual task= 86%; Mean of Duall task= 84%) was obtained,  $F < 1$ . This finding is consistent with evidence from other studies (Dreher et al., 2003) and may indicate that task switch requires an additional cognitive process compared to dual task in term of cognitive control.

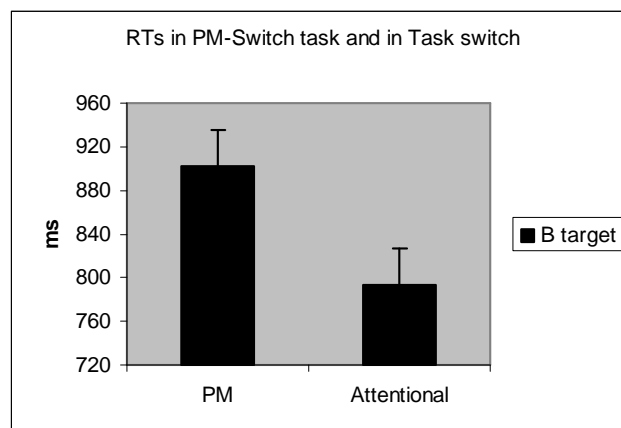


Figure 5B.3. Reaction times of the presence of B target in PM-Switch task and Task switch.

### 5B.3 Electrophysiological data

*ERP components.* The

grandaverage ERPs portraying the N300 and the prospective positivity between ongoing and PM-Switch task and between PM-Switch task and task switch are displayed in Figure 5B.4 and Figure 5B.5.

*Differences in mean amplitude for Ongoing and PM task.* The N300 was quantified as mean amplitude between 100 and 400 ms and analysed according to three factors: item condition (ongoing task item and prospective cue item) and electrode sites (occipital versus parietal sites) and hemisphere site (left: O1-P7; right: O2-P8).

We compared the Items of prospective items in PM-Switch task with the ongoing activity trials and we considered, as in Experiment 1, three time windows: 100-200 ms, 200-300 ms versus 300-400ms. We reported only reliable results ( $p < .05$ ).

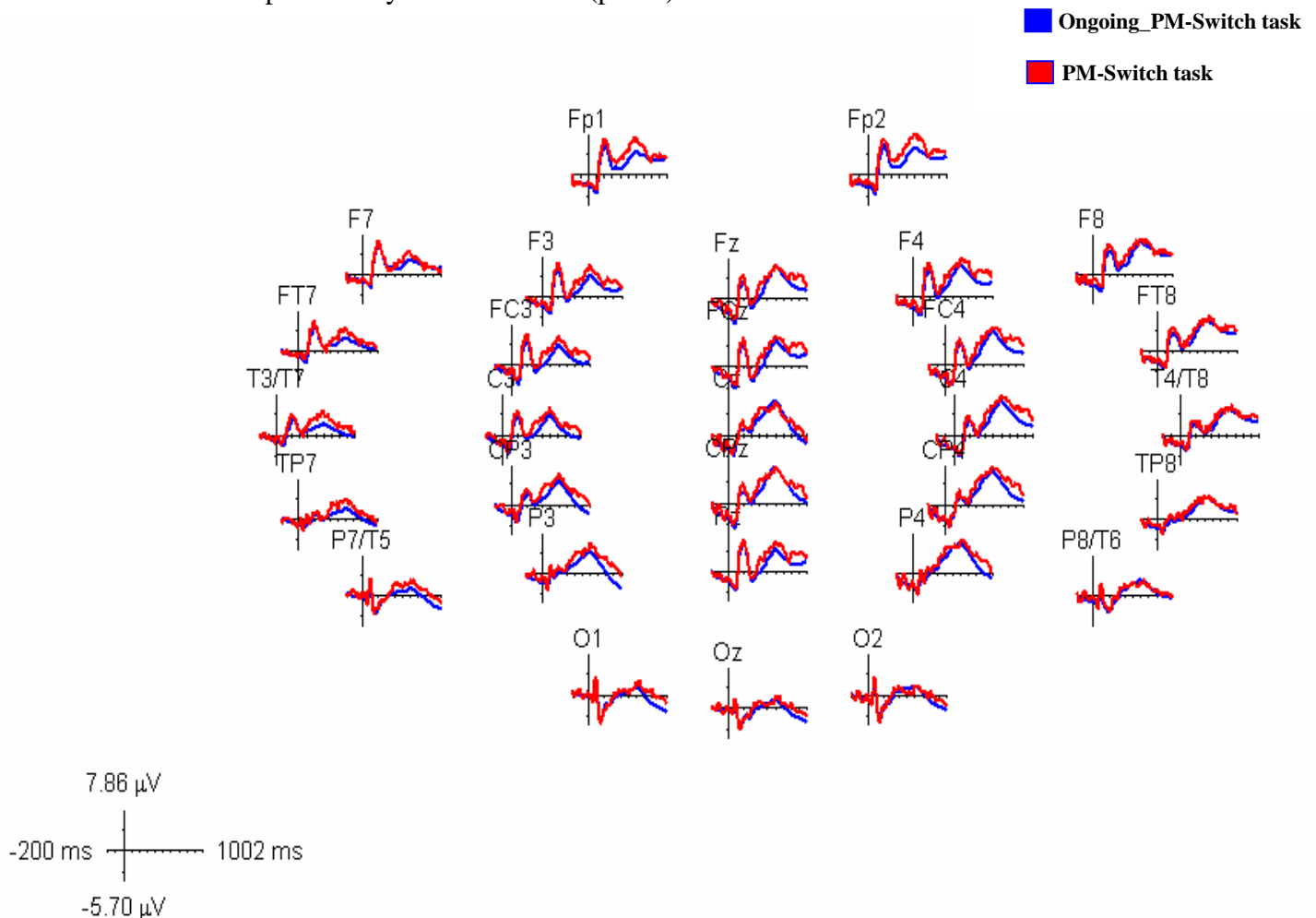


Figure 5B.4. Grandaverage event related potentials (ERPs) at electrodes demonstrating the N300 and the positive component in ongoing and prospective condition of the PM-Switch task.

A 2 x 2 x 2 repeated measure analysis of variance (ANOVA) was conducted. In this analysis, the amplitude of N300 did not differ from PM-Switch task and ongoing task ( $F < 1$ ).

The amplitude of the positive component was quantified as mean amplitude between 400 and 1000 ms and analysed according to 3 factors: PM task version (prospective versus ongoing activity task), Hemisphere site (left: P3-C3-F3; central PZ-CZ-FZ and right P4-C4-F4) and an anterior-posterior site (parietal P3-PZ-P4, central C3-CZ-C4 and frontal F3-FZ-F4).

A 2 x 3 x 3 repeated measure analysis of variance (ANOVA) on ERPs averaged across correct trials was conducted. In the time window between 400-700ms analysis revealed the interaction Task x Hemisphere site,  $F(2,28) = 6.61$ ,  $p < .004$ ,  $\eta^2 = .321$ , and the interaction Task x Hemisphere x Anterior/posterior sites,  $F(2,28) = 12.14$ ,  $p < .001$ ,  $\eta^2 = .464$ , were reliable. Post hoc analyses evidenced that the amplitude of the positive component elicited by prospective items was greater over frontal but also parietal sites of right hemisphere respect ongoing activity items.

In the time window between 700 and 1000 ms analysis revealed a main effect of Task,  $F(1,14) = 8.35$ ,  $p < .012$ ,  $\eta^2 = .373$ , a main effect of Hemisphere site,  $F(2,28) = 7.43$ ,  $p < .003$ ,  $\eta^2 = .347$ , and a main effect of Anterior/posterior sites,  $F(1,14) = 15.15$ ,  $p < .002$ ,  $\eta^2 = .520$ . Post hoc analysis evidenced that the amplitude of the positive component in the interval between 700 and 1000 ms elicited by prospective items was greater respect ongoing activity items. In both tasks the positive component was greater over right hemisphere and over posterior sites.

*Differences in mean amplitude in PM-Switch task and Task switch.* The N300 was quantified as mean amplitude between 100 and 400 ms and analysed according to three factors: task version (PM-Switch task versus Task switch), and electrode sites (occipital versus parietal sites) and hemisphere site (left: O1-P7; right: O2-P8).

We compared the Items of the presence of B target trials in both tasks (prospective items in PM-Switch task and alternate trials in Task switch) and we considered, as in Experiment 1, three time windows: 100-200ms, 200-300 ms versus 300-400ms. We reported only reliable results ( $p < .05$ ).

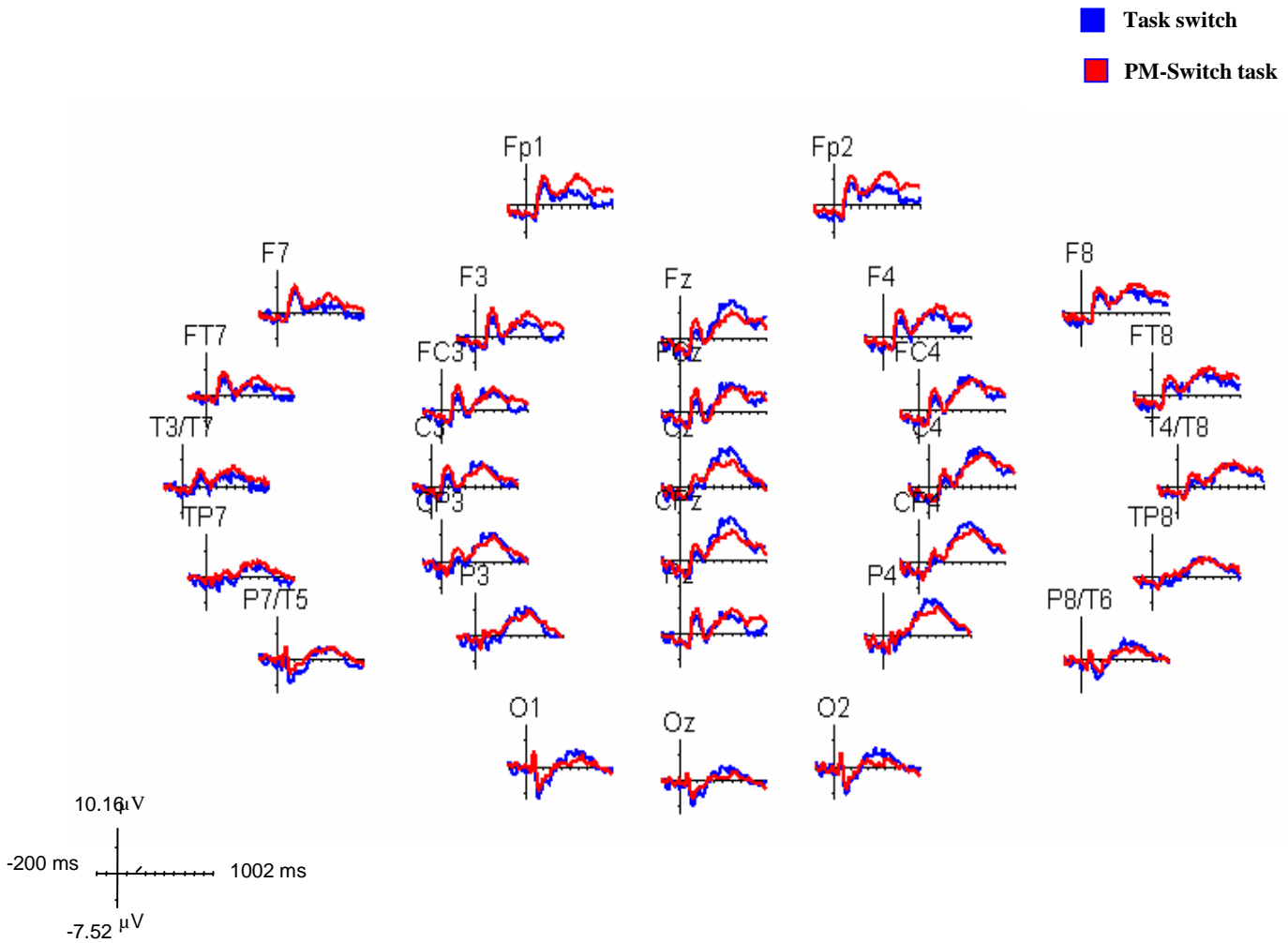


Figure 5B.5. Grandaverage event related potentials (ERPs) at electrodes demonstrating the N300 and positive component in the B target trials of prospective (PM-Switch task) versus Task switch.

A  $2 \times 2 \times 2$  repeated measure analysis of variance (ANOVA) was conducted. In this analysis, the amplitude of N300 did not differ from PM-Switch task and Task switch ( $F < 1$ ).

The only reliable effect was the interaction hemisphere  $\times$  electrode,  $F(1,14) = 4.91$ ,  $p < .045$ ,  $\eta^2 = .274$ . Post hoc analyses revealed that the amplitude of the N300 (between 200 and 300 ms in the condition pressure of the bar) was greater over occipital sites of left hemisphere respect parietal sites.

The amplitude of the positive component was quantified as mean amplitude between 400 and 1000 ms and analysed according to 3 factors: task version (PM-Switch task versus Task switch), Hemisphere site (left: P3-C3-F3; central PZ-CZ-FZ and right P4-C4-F4) and an anterior-posterior site (parietal P3-PZ-P4, central C3-CZ-C4 and frontal F3-FZ-F4).

A  $2 \times 3 \times 3$  repeated measure analysis of variance (ANOVA) on ERPs averaged across correct trials was conducted. In time window between 400-700 ms analysis revealed the effect of task,  $F(1,14) = 5.55$ ,  $p < .040$ ,  $\eta^2 = .357$  and the interaction Task  $\times$  hemisphere,  $F(2,28) = 6.61$ ,  $p < .01$ ,  $\eta^2 = .298$ .

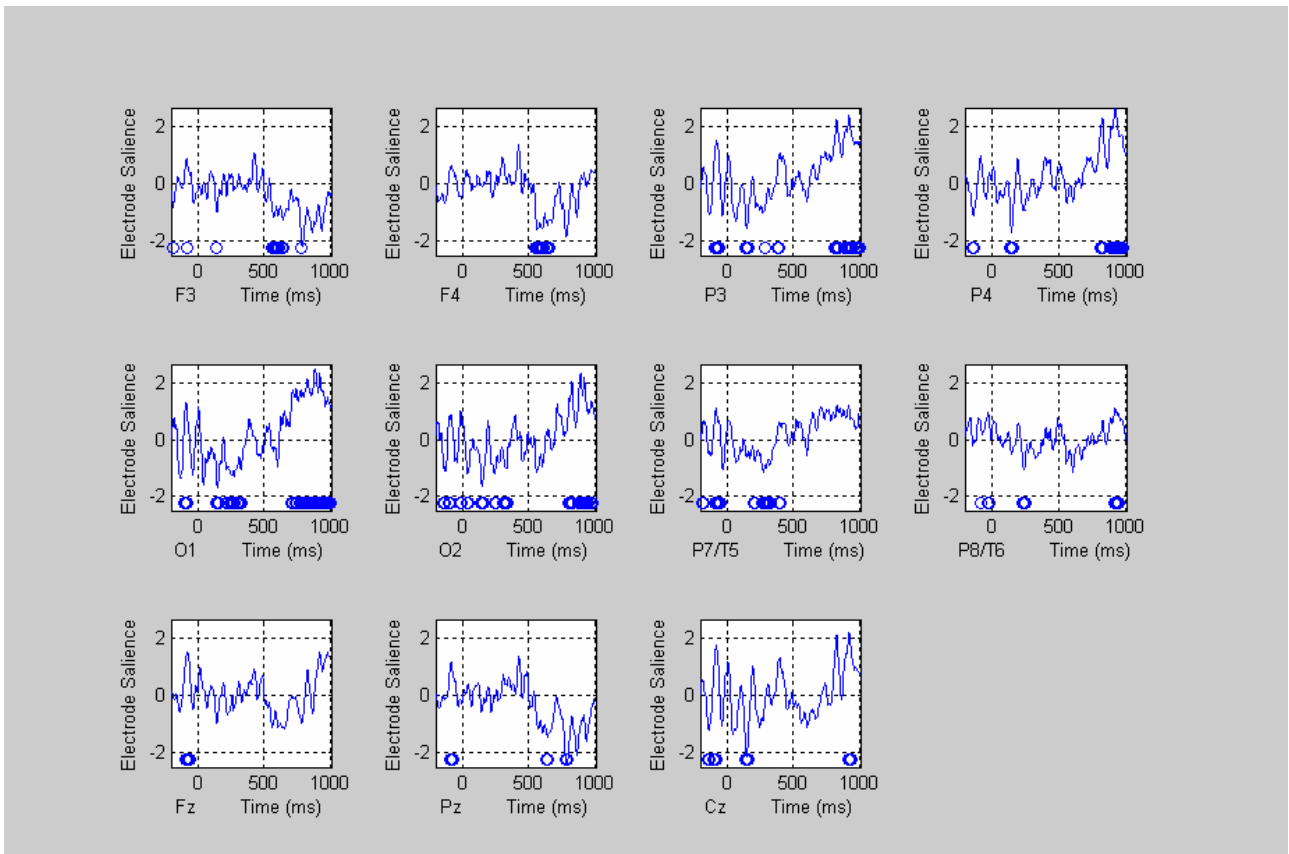
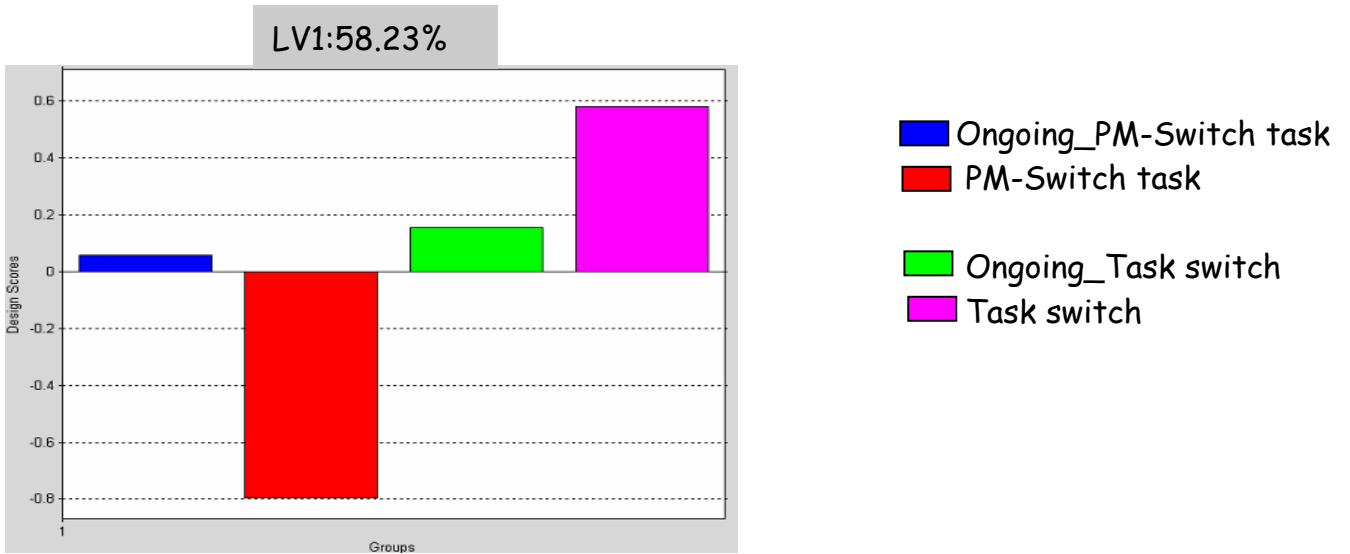
Post hoc analyses revealed that the amplitude of this component was greater in the time-window between 400 and 700ms in the PM task respect Task switch in F3, F4 and in the Task switch respect PM-Switch task in centro-parietal sites (CPz).

The interaction electrode x Anterior/posterior sites was reliable,  $F(2,28) = 11.59$ ,  $p < .001$ ,  $\eta^2 = .537$  revealing that the amplitude of this component for both tasks was greater in posterior sites over left and right hemisphere respect anterior sites.

In time window between 700 and 1000 ms analysis the effect of Task tend to be reliable,  $F(1,14) = 4.72$ ,  $p < .053$ ,  $\eta^2 = .300$ . Post hoc analyses revealed that in PM-Switch task the positive component elicited by prospective items had greater amplitude respect of that elicited by the presence of B target items in the Task switch. The interaction electrode x Anterior/posterior sites was also reliable,  $F(2,28) = 7.19$ ,  $p < .004$ ,  $\eta^2 = .418$ , revealing that the amplitude of this component was greater in posterior sites over left and right hemisphere while in anterior sites over central hemisphere.

In summary, analyses of mean voltage revealed no differences in the amplitude of the N300 (between 200 and 300 ms over occipital-parietal sites) elicited by prospective items in PM-Switch task and by the presence of B target items in Task switch. Analyses of the positive component, in contrast revealed that the amplitude elicited by prospective items of the PM-Switch task was greater respect to those of the Task switch in the window between 400 and 700ms in F3, F4 sites and in the Task switch respect PM-Switch task in centro-parietal sites (CPz). In time window between 700 and 1000ms the amplitude of the positive component elicited by prospective cues was greater in the PM-Switch task the respect of that elicited by the presence of B target items in the Task switch.

**5B.4 PLS analysis.** The PLS analysis included the ERPs elicited by the presence of B target trials in both tasks for the entire analyzed epoch (0-1000 ms) and all electrodes except the ocular channels. The permutation test revealed a significant latent variables (LV1) ( $p < .001$ ) that accounted for 58.23 % of the covariance. LV1 distinguished for the ERPs elicited by prospective hits of PM-Switch task from those elicited by the presence of B target trials of the Task switch. The electrode saliences for the latent variable reflected a modulation over occipital-parietal (O1, O2, P7, P8 sites) of the scalp between 200 and 300 ms that reflects the expression of the N300, a modulation beginning at around 400 ms in frontal regions (F3, F4 sites) and a later modulation over parietal regions (P3, P4 sites) that reflects the expression of the positive component (Figure 5B. 7).



*Figure 5B.7* Results of the PLS analysis for Experiment 2B. The top panel portrays the design by task condition contrast for LV1. The bottom panel portrays the electrode saliences for LV1 between 0 and 1000 ms after stimulus onset. The stable saliences for LV1 are indicated by the circles presented above the waveforms.

### 5A.5 LORETA analysis.

Source localization was performed to investigate differences in neural recruitment associated with prospective memory task (PM-Switch task) and Task switch that might be reflected in variation in the pattern of design scores across the tasks in the PLS analysis.

The statistical probability maps from the LORETA analyses are displayed in Figure 5B.8, local maxima of inter-task differences in the three-dimensional current density distribution for the presence of B target trials are shown for the two components N300 and the positive component considering two time windows (400-700ms and 700-1000ms).

*N300 time frame.* Subjects had increased activation in the superior temporal gyrus (BA 39) in the prospective memory task (PM-Switch task) compared to Task switch.

*Positive component time frame.* In the time-window between 400 and 700 ms cingulated gyrus (BA 31) revealed greater activation in Task switch compared to prospective memory task (PM-Switch task).

In time window between 700 and 1000 ms the activation of the inferior temporal gyrus (BA 37) didn't differ between prospective memory task (PM-Switch task) and Task switch.

To sum up, the LORETA analyses revealed different patterns of neural recruitment in PM-Switch task in comparison to Task switch in the time frames of both the N300 and the positive component but only in the time window between 400 and 700 ms.

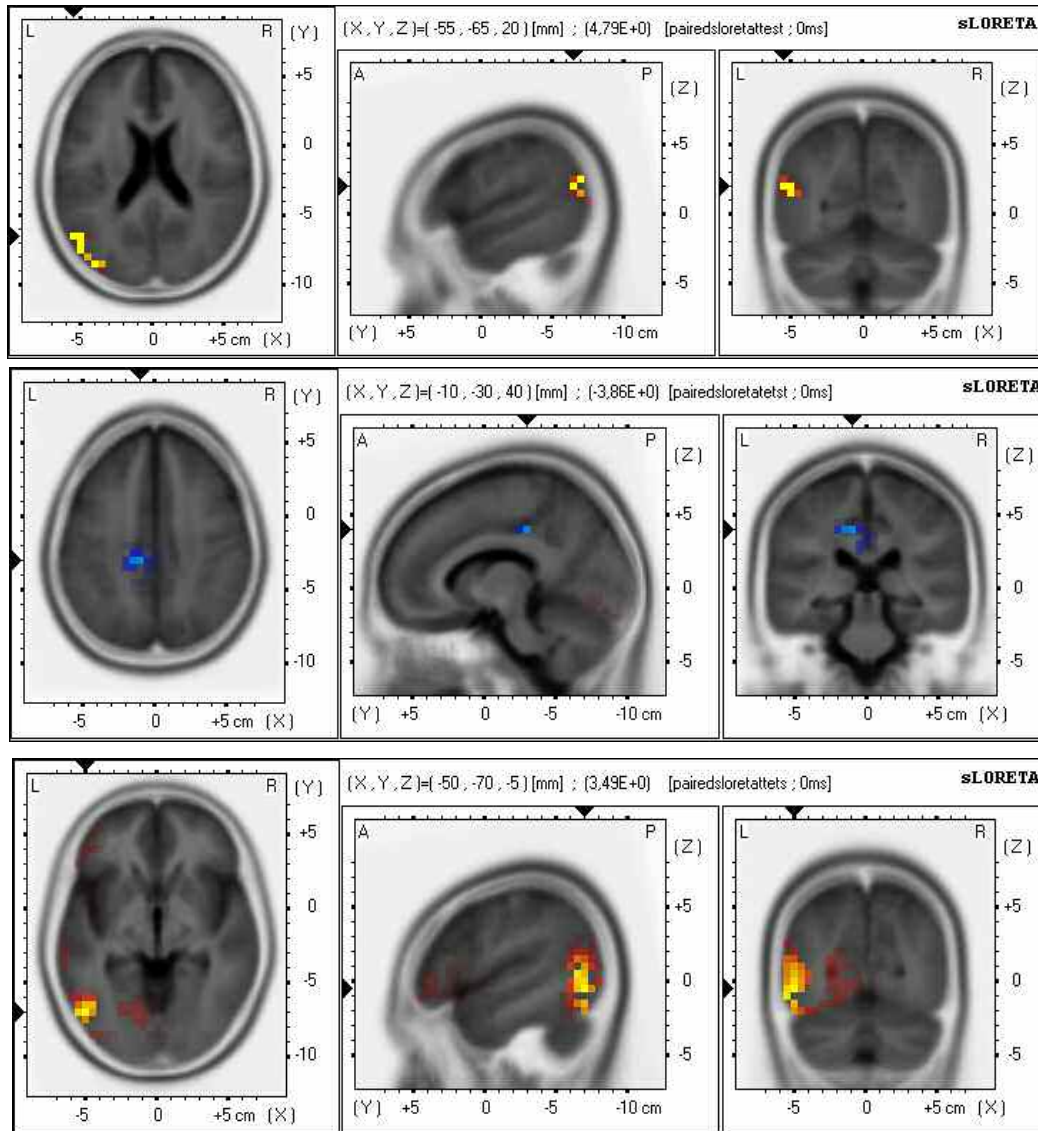


Figure 5B.8. Statistical probability maps (SPM) of the source localization with LORETA for differences between prospective memory (PM-Dual task) and Dual task. Results are significant at the  $p < .05$  level (blue colour = significantly lower current density, red colour = higher current density).

## 5B.6 Conclusion

Experiment 2B was designed to compare a PM task with task switch paradigm to a task switch. Results of Experiment 2B showed that performing a PM-Switch task is different to performing an Task switch. These differences are supported by behavioural results with an increasing of RTs in the prospective memory task (PM-Switch task) compared to the Task switch. No differences were



found in the level of accuracy; it may be due to the additional cognitive processes required to execute a task switch paradigm (Dreher et al., 2003).

The ERPs elicited by prospective hits of PM-Switch task versus ongoing, revealed only differences in the positive component (prospective positivity) over the frontal and parietal region of the scalp (West et al., 2001; West & Ross-Munroe, 2002).

Also the ERPs elicited by the presence of B target item in PM-Switch task (prospective items) and in Task switch revealed differences in the positive component revealing a greater amplitude elicited by prospective items of the PM-Switch task respect to those of Task switch in the window between 400 and 700 ms in F3, F4 sites and in the Task switch respect PM-Switch task in centro-parietal sites (CPz). In time window between 700 and 1000ms the amplitude of the positive component elicited by prospective cues was greater in the PM-Switch task respect of that elicited by the presence of B target items in the Task switch.

PLS was used to examine the structural relationships between modulations of the ERPs differentiating presence of B trials in PM-Switch task and in Task switch.

This analysis revealed the presence of a significant latent variable. This latent variable distinguished for the ERPs elicited by prospective hits of PM-Switch task from those elicited by the presence of B target trials of the Task switch and captured modulations over occipital-parietal (O1, O2, P7, P8 sites) of the scalp between 200 and 300 ms that reflects the expression of the N300, and a modulation beginning at around 400 ms in frontal regions (F3, F4 sites) and a later modulation over parietal regions (P3, P4 sites) that reflects the expression of the positive component

LORETA analysis showed differences in the time frame of N300: subjects had a greater activation in the superior temporal gyrus (BA 39) in the prospective memory task (PM-Switch task) compared to Task switch. For the time frame of the positive component, participants showed only a greater activation in the time-window between 400 and 700 ms in cingulate gyrus (BA 31) in Task switch compared to prospective memory task (PM-Switch task).

## CHAPTER 6

### GENERAL DISCUSSION

While the literature on (event-based) prospective memory agrees upon the general methodology of embedding prospective memory cues within an ongoing activity that keeps participants busy during the experimental session, so far the relation of the ongoing task and the intention execution has been underspecified in at least one aspect. Across the empirical literature it has largely been just a matter of preferential choice as to whether participants were instructed to stop working on the ongoing task whenever they encountered a prospective memory cue or whether they were encouraged to first respond to the ongoing task demands of the cue and then execute the prospective memory action. The first experiment of the present study reveals some evidence that this might not be an arbitrary decision. Taken together, behavioural and electrophysiological data suggest (1) that the two approaches may lead to somewhat different results and (2) that a task switching approach appears to be more resource demanding.

Both conclusions are clearly supported by the behavioural results. At first, the level of accuracy in the PM performance was higher in the dual-task version than in the task-switch version. This is in line with data from the developmental and aging data of PM where several studies have shown that the need for active and immediate ongoing task interruption and task switching results in decreased overall performance levels and elevated age differences (Kliegel et al., in press; Kvavilashvili et al., 2001; Wang et al., in press, Bisiacchi et al, in press). From a broader conceptual perspective, these results are also consistent with the traditional literature on task switching. For example, Dreher et al. (2003) suggest that task switching requires an additional cognitive process compared to dual tasks in terms of cognitive control. Specifically, cognitive control is particularly needed when taxing the capacity or computational limitations of the cognitive system as in the case of rapidly changing stimuli-response associations (as in the task switch situation). The nature of the residual component of the task switch is not clear (Meiran et al., 2000). It may be a consequence of a second executive control process that only occurs after the onset of the first stimulus in the new task or it may be a reflection of interference from the old task (Meiran et al., 2000; Monsell et al., 2000; Wylie & Allport, 2000).

In addition, also the results on the performance in the ongoing task component argue in the same direction. When comparing accuracy in responses to ongoing task items proper and prospective distracter items, a reduced accuracy for distracter items in terms of confusion errors was

found. This finding is consistent with the findings from previous research (e.g., West & Craik, 1999; 2001) and suggests that distracter items need additional resources to be identified and rejected, thus, the slowed response times for lures could result from a tendency for these stimuli to capture attention when they are encountered.

However, importantly, this effect only occurred in the task switch condition. Two not mutually exclusive explanations for this differential finding are possible. The data might suggest that the task switch instructions might have placed a generally increased cognitive load on the cognitive system and thus lead to a higher error rate. Alternatively, one might argue that a task switch instruction results in a especially high response bias towards the prospective action and thus leads to more false alarms than the dual-task instruction. Either way, the conclusion is that it appears to make a difference with regard to several key dependent PM measures whether a PM task is instructed as a dual-task or a task-switch procedure.

Besides behavioural data, in the present study also electrophysiological data was collected to further explore possible differential effects of the two task versions. Supporting the main conclusions, also the ERP results argue in favour of the main conclusion: the choice of the task version matters. In detail, while the N300, the component mainly reflecting cue detection, did not differ between the two task versions, there were reliable differences in the prospective positivity; the component associated with the retrieval of the intended action from long-term memory as well as with post-retrieval monitoring. Thus, cue detection and monitoring for the prospective cue do not seem to be affected by the different task versions; the main difference appears to occur in later components. In more detail, analyses of the mean amplitude data revealed that the amplitude of the prospective positivity elicited by prospective items differed between dual task and task switch version in several ways. The dual task version showed the presence of a positivity between 400 and 700ms that was greater over anterior electrodes when compared with the task switch paradigm. In contrast, the task switch version showed the presence of a late positive component between 700 and 1000ms over posterior regions and left electrodes when compared with the dual task version. Although the present study cannot shed light on the exact nature and functional role of these differences, it clearly shows that different neural mechanisms contribute to accurate PM performance in the two different task versions. It may well be that besides the retrieval of the intended action from long-term memory as well as post-retrieval monitoring the late positivity may also reflect the activity of a neural mechanism that supports processes of the task set reconfiguration involved in task switch processes (i.e. the ability to override and reconfigure the previously activated task set when a new external stimulus is presented; Crone et al., 2006). This, however, awaits further empirical testing.

Finally, the traditional ERP results were supported by the PLS analysis. In fact, the first latent variable revealed a different pattern of design scores between prospective memory tasks (dual-task and task switching paradigm) and the respective ongoing tasks reflecting an enhancement of N300 and prospective positivity (over frontal and parietal regions). These results are in line with previous researches on PM (for a review see West, Herndon & Ross-Munroe, 2000). In contrast, the second latent variable revealed a different pattern of design scores between the dual-task version and the task switching version reflecting a positivity between at 400 and 1000 ms in frontal regions and a later positivity over parietal regions beginning at around 700 ms. Again, while the functional role of these differences awaits further investigation, they support our main conclusion: choosing a task switching or a dual task approach will influence the results.

Results of experiment 1 agree with data found in attentional literature of dual task and task switch paradigms (Dreher et al., 2003). When analyzing the literature on neuroimaging attentional studies and comparing areas activated by dual task and task switch paradigms with areas activated by PM tasks (with dual task and task switch paradigms respectively), it was very interesting to find the activation of common areas: i.e. ‘the rostral part of the anterior cingulate gyrus (BA 24/32), the precuneus and the right inferior frontal gyrus’ for the dual task paradigms (Herath et al., 2001; Okuda et al., 1998; 2007); and ‘the fronto-polar cortex bilaterally (BA 10)’ and parietal cortex ‘for task switch paradigms (Dreher et al., 2003; Burgess et al., 2003; Simons et al., 2006; den Ouden 2005).

Thus, the aim of this experiment was to investigate differences between a PM task and an attentional task. So in the experiment 2A we compared a PM task and an attentional task respectively with a dual task paradigm and in experiment 2B a PM task and an attentional task with a task switch paradigm. The second experiment (experiment 2A and 2B) reveals that a PM task requires different processes from that required to perform an attentional task.

It might indicate that performing a PM task characterized by the rare frequency of the stimulus requires different cognitive processes respect to those required in an attentional task. This data concerns with the distinct cognitive processes that have been identified as playing the predominant roles during the completion of the main phases of prospective memory (e.g., Kliegel et al., 2002). During intention formation (first phase), *planning skills* are assumed to be the most influential cognitive function, especially when an intention is somewhat complex. Furthermore, an *efficient encoding* of the intention is needed during this first phase of prospective remembering. Intention retention seems to primarily require storing the content of the intention in *retrospective memory*. Finally, intention initiation and execution seem to rely on processes such as *monitoring, cognitive flexibility, or inhibition*.

Behavioural and electrophysiological results (ERPs, PLS analysis and LORETA analysis) supported our conclusion, especially when we used a dual task paradigm.

In both experiments, behavioural results showed an increase of RTs in the prospective memory tasks (PM-Dual task/PM-Switch task) as compared to attentional task (Dual task/Task switch). It could indicate that participants were monitoring each trial of the task in order to execute the prospective action at the appropriate moment. Thus, it might mean that participants have formed and encoded an intention and that they are retaining this intention in their memory.

With regard to accuracy, subjects were more accurate in the Dual task than in the PM-Dual task (experiment 2A). According to Dreher et al., (2003) this could indicate that a task switch paradigm requires more demanding resources both in PM-Switch task (when the target stimuli are rare) and in Task switch (when the target stimuli are more frequent).

Comparing the ERPs elicited by the prospective cues respect to the ongoing trials of PM task, results evidence the same components found in the first experiment. So a PM task with a dual task paradigm revealed the presence of a N300 and of a prospective positivity that was greater in the frontal sites of the right hemisphere in the time window between 400 and 700 ms. In contrast a PM task with a task switch paradigm revealed the presence of a late positive component greater on parietal sites.

The second comparison was between ERPs elicited by the B target trials of the PM tasks and the first B target trials of the attentional task, so that comparing the same cognitive processes implied and avoiding a possible effect of the stimulus frequency.

Results of the experiment 2A showed that the amplitude of the N300 elicited by prospective items (PM-Dual task) between 200 and 300 ms over occipital-parietal sites was greater respect amplitude elicited by the presence of B target items in Dual task. Regarding the positive component, analyses revealed that the amplitude of this positivity, in the time-window between 400 and 700 ms and in the time-window between 700 and 1000 ms was greater in PM-Dual task respect Dual task in anterior site of right hemisphere respect posterior site. On the other side, the Dual task showed a greater activation on posterior sites of right hemisphere respect PM task. These data are in agreement with most of the studies about dual task in attentional literature revealing the sensitivity of the P3 component in processing resources in dual-task paradigms (Kok, 1997).

Results of experiment 2B revealed only differences in the positive component revealing that a greater amplitude elicited by prospective items of the PM-Switch task respect to those of the Task switch in the window between 400 and 700ms in F3, F4 sites and in the Task switch respect PM-Switch task in centro-parietal sites (CPz). ERP studies using cued task-switching paradigms have also reported a parietal switch-related positivity emerging around 400–500 ms after cue presentation

(Miniussi et al., 2005; Nicholson et al., 2005; Nicholson et al., 2006; Rushworth et al., 2002, 2005).

In time window between 700 and 1000ms the amplitude of the positive component elicited by prospective cues was greater in the PM-Switch task the respect of that elicited by the presence of B target items in the Task switch.

The results of the PLS analysis support the proposal that the cognitive processes required by a PM task (PM-Dual task/PM-Switch task) defer from those required by an attentional task (Dual task /Task switch). The latent variables reflected modulations of the ERPs over occipital-parietal (O1, O2, P7,P8 sites) of the scalp between 200 and 300 ms that reflects the expression of the N300, and a modulation beginning at around 400 ms in frontal regions and a later modulation over parietal regions that reflects the expression of the positive component.

The results of the LORETA analysis indicate differences in neural recruitment between the PM-Dual task and Dual task in Experiment 2A. In the time frame of the N300 subjects had a greater activation in the cingulate gyrus (BA 24) in the prospective memory task as compared to the Dual task (see Zolig et al., 2007). Burgess, Veitch, de Lacy Costello, and Shallice (2000) also found regions of the posterior cingulate to be involved in both prospective and retrospective components of multi-tasking. Previous findings have linked these areas with functions related to retrieval of stored mnemonic information (for a review see Wagner, Shannon, Kahn, & Buckner, 2005). For the time frame of the prospective positivity, participants showed a greater activation in the prospective memory (PM-Dual task) as compared to the Dual task in the superior frontal gyrus (BA10) in the time-window between 400 and 700 ms and a greater activation in the superior temporal gyrus (BA 39) in the time window between 700 and 1000 ms.

Thus, it is evident a greater activation of frontal areas in the context of dual task paradigm. This finding is in agreement with neuroimaging studies who investigated neuronal processes in PM and attentional tasks. For example, Okuda et al. (1998) found increases in the left frontal pole in prospective memory conditions relative to the ongoing task alone and Goldberg et al., (1998) and Schubert and Szameitat (2003) showed that the dorsolateral prefrontal cortex is involved in the allocation and coordination of attentional resource. The role of the lateral BA 10 confirms the view from previous neuroimaging studies that this region is likely to be of central importance to prospective memory (Okuda et al., 1998; Burgess et al., 2001, 2003; den Ouden et al., 2005). To recapitulate, Okuda et al. (1998) reported activation in the left frontal pole (BA 10) in the right dorsolateral and ventrolateral prefrontal cortices (BA 8/9/47) as well as in the anterior cingulate (BA 24), when participants remembered and acted upon a list of target words relative to performing an ongoing routine activity (word repetition). Activation in the frontal pole (BA 10, bilaterally) was also found by Burgess et al. (2001) across several cognitive tasks. Burgess et al. (2003) extended

these results by showing that the bilateral activation of the lateral BA 10 associated with retrieving a delayed intention was accompanied by a deactivation of the medial BA 10. Recently, den Ouden et al. (2005) reported activation in the lateral BA 10, the lateral parietal cortex and the precuneus, when participants kept an intention in mind while performing the ongoing task of responding to questions about intentions and actions. The overadditive activation in prefrontal regions is interpreted as being related to additional cognitive demands present in the dual task as compared to the summed demands of both single tasks (Szameitat et al., 2006). The ability to coordinate concurrent cognitive processes is a crucial executive function (Baddeley, 1996).

On the other hand, LORETA results' of the Experiment 2B data showed a greater activation of the superior temporal gyrus (BA 39) in the prospective memory task (PM-Switch task) as compared to the Task switch in the time frame of the N300. For the time frame of the prospective positivity, participants showed only a greater activation of the cingulate gyrus (BA 31) in the time-window between 400 and 700 ms in the Task switch as compared to the prospective memory task (PM-Switch task).

Thus, a task switch paradigm seems to activate frontal and more parietal sites. *Den Ouden et al.* (2005) found additional right parietal cortex activation in the prospective memory condition compared with a conditions in which subject did not execute the prospective memory task. Overall, the studies on task switching (Sohn et al., 2000; Braver et al., 2003; Dove et al., 2000; Rushworth et al., 2001; DiGirolamo et al., 2001; Kimberg et al., 2000. Smith et al., 2001; Dreher et al., 2002; 2003) identify medial and lateral regions of the prefrontal cortex and the parietal cortex as brain areas of potential relevance to task-switching operations.

In summary, our findings lead to the conclusion that a PM task requires different processes from those required for an attentional task, especially when we used a dual task paradigm. Less evident were differences between the PM task and the attentional task when we used a task switch paradigm.

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## **Appendix 1: Partial Least Squares analysis (PLS) and Low resolution brain electromagnetic tomography- LORETA.**

PLS analysis is a multivariate data analytic technique that allows one to identify spatiotemporal relationships between neural activity and experimental design (Lobaugh et al., 2001; McIntosh et al., 1996). Then, given the potential for component overlap in the ERP data resulting in the confounding of the parietal old–new effect and the prospective positivity (West and Kropfing, 2005), Partial Least Squares analysis (PLS; Wold, 1975) is used to examine the relationship between ERP amplitude and task design. PLS analysis bears some resemblance to principle components analysis (PCA) in that it uses singular value decomposition (SVD) to identify latent variables that are spatially and temporally confounded in manifest ERP waveforms. The primary difference between PLS analysis and PCA is that PLS analysis uses a constrained covariance matrix that, in most applications on Pm tasks, is limited to task-related variance (i.e., differences between task conditions) in the ERP dataset. The ERP data matrix for the PLS analyses contained subjects and conditions in the rows, and ERP amplitudes for all time points and channels, except for the four ocular electrodes, in the columns (0–1200 ms, at each electrode). The input data matrices for the analyses were obtained by mean-centering the columns of the ERP data matrix with respect to the grand mean.

The averages within task were thus expressed as deviations around zero. SVD was then performed on these matrices to identify the structure of the latent variables. Three outputs were derived from the SVD that were used to interpret the relationships between ERP amplitude and task design. The first was a vector of singular values, which represents the unweighted magnitude of each latent variable and can be used to calculate the proportion of the cross-block covariance matrix (i.e., the percentage of task-related variance) attributable to each latent variable. The second and third outputs contain the structure of the latent variables and are orthogonal pairs of vectors (salience). One vector defines the design scores representing contrasts between task conditions across the latent variables. The other vector represents the electrode saliences that characterize the temporal and spatial expression of the latent variable across the scalp. The significance of the latent variables singular values was determined using a permutation tests (500 replications) that provides an exact probability of observing the singular value by chance (e.g.,  $p=.001$ ). The stability of the ERP saliences at each time point and location in space was established through bootstrap resampling (500 replications) that provides a standard error. The ratio of the salience to its bootstrapped standard error is approximately equal to a z-score; therefore, bootstrap ratios greater than 2.5 can be taken to indicate stable saliences or points that differ from zero. Matlab code to perform the PLS analyses can be obtained at (<http://www.rotman-baycrest.on.ca/pls>).

*In West & Krompinger (2005): “ PLS analysis.* The PLS analysis included the ERPs elicited by prospective cue hits, recognition hits, prospective lures, and ongoing activity trials for the entire analyzed epoch (0–1200 ms) and all electrodes except the ocular channels.

The permutation test revealed two significant LVs ( $P = .000, .006$ ) that accounted for 70.83 and 25.80% of the covariance, respectively. LV1 distinguished the ERPs elicited by recognition hits and prospective hits from those elicited by prospective lures and ongoing activity trials and reflected an enhancement of the P2, the FN400, the recognition positivity, and the frontal slow wave. LV2 distinguished the ERPs elicited by prospective hits from those elicited by prospective lures and recognition hits and reflected a phasic effect at around 150–200 ms over the parietal region, the N300 between 250 and 400 ms over the right occipital region, and the prospective positivity over the parietal and frontal regions from 600 ms to the end of the epoch.”

### **Low resolution brain electromagnetic tomography- LORETA**

Low resolution brain electromagnetic tomography (LORETA) (Pascual-Marqui et al. 1994, Pascual-Marqui 1999) is a functional imaging method based on the electrophysiological and neuroanatomical constraints previously described. For instance, the cortex can be modeled as a collection of volume elements (voxels) in the digitized Talairach atlas provided by the Brain Imaging Center, Montreal Neurological Institute (Talairach et al., 1988). In this case, the LORETA inverse solution (which is consistent with the EEG/MEG measurements) corresponds to the 3D distribution of electric neuronal activity that has maximum similarity (i.e., maximum synchronization), in terms of orientation and strength, between neighbouring neuronal populations (represented by adjacent voxels). In another example, the cortical surface can be modelled as a collection of surface elements with known orientation. LORETA can accommodate this neuroanatomical constraint, and find the inverse solution that maximizes only the synchronization of strength between neighboring neuronal populations.

Zollig et al., (2007) are the first study who examined the neural correlates of prospective memory in adolescent, younger adults and older adults using the low-resolution electromagnetic tomography on the basis of the scalp-electrode electric potential distribution (LORETA, Pascual-Marqui, 1999, 2002) to localize differential neural recruitment between groups and conditions.

In this study, ERPs data revealed differential patterns of neural recruitment in adolescents, younger adults, and older adults. Analysis of the mean voltage data revealed that there was little difference across the three age groups in the amplitude of the N300 for prospective execute trials; in contrast,

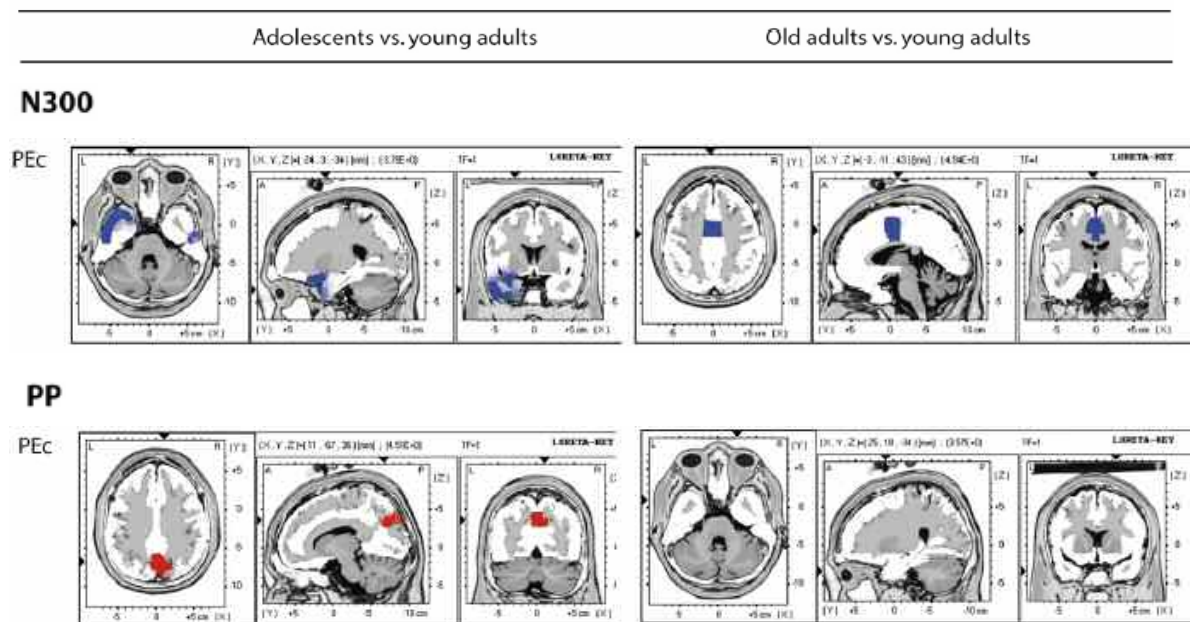
for prospective inhibit trials the N300 was elicited in adolescents and older adults but not younger adults.

The absence of age-related differences between younger adults and older adults in the amplitude of the N300 was surprising given previous research that has consistently revealed an attenuation of this modulation in older adults (West & Bowry, 2005; West & Covell, 2001; West et al., 2003).

Analysis of the mean amplitude data also revealed that the amplitude of the prospective positivity was substantially greater in adolescents than in younger adults and was attenuated in older adults relative to younger adults (West et al., 2003).

LORETA analysis showed that in the N300 time-frame for *Prospective execute trials* (we did not report correlates of ongoing trials and prospective inhibit trials) adolescents had reduced activation in the right inferior and middle temporal gyrus as well as the uncus compared to younger adults. The activity of older adults was reduced in the cingulate gyrus, the medial frontal gyrus, and the paracentral lobule.

*Prospective positivity time frame for prospective execute trials* revealed a greater activation in adolescent compared to younger adults in The right and medial precuneus and cuneus. The pattern of activation in old adults and young adults did not differ significantly. To sum up, the LORETA analyses revealed different patterns of neural recruitment in adolescents and older adults in comparison to younger adults in the time frames of both the N300 and the prospective positivity (Figure 1).



**Figure 1** Statistical probability maps (SPM) of the source localization with LORETA for differences between adolescents/young adults and old adults/young adults. (blue colour = significantly lower current density; red colour = higher current density). *In Zollig et al.(2007).*

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