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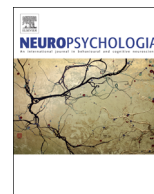
ERPs and their brain sources in perceptual and conceptual prospective memory tasks: Commonalities and differences between the two tasks

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ABSTRACT

The present study examined whether Event-Related Potential (ERP) components and their neural generators are common to perceptual and conceptual prospective memory (PM) tasks or specific to the form of PM cue involved. We used Independent Component Analysis (ICA) to study the contributions of brain source activities to scalp ERPs across the different phases of two event-based PM-tasks: (1) holding intentions during a delay (monitoring) (2) detecting the correct context to perform the delayed intention (cue detection) and (3) carrying out the action (realisation of delayed intentions). Results showed that monitoring for both perceptual and conceptual PM-tasks was characterised by an enhanced early occipital negativity (N200). In addition the conceptual PM-task showed a long-lasting effect of monitoring significant around 700 ms. Perceptual PM-task cues elicited an N300 enhancement associated with cue detection, whereas a midline N400-like response was evoked by conceptual PM-task cues. The Prospective Positivity associated with realisation of delayed intentions was observed in both conceptual and perceptual tasks. A common frontal-midline brain source contributed to the Prospective Positivity in both tasks and a strong contribution from parieto-frontal brain sources was observed only for the perceptually cued PM-task. These findings support the idea that: (1) The enhanced N200 can be understood as a neural correlate of a 'retrieval mode' for perceptual and conceptual PM-tasks, and additional strategic monitoring is implemented according the nature of the PM task; (2) ERPs associated with cue detection are specific to the nature of the PM cues; (3) Prospective Positivity reflects a general PM process, but the specific brain sources contributing to it depend upon the nature of the PM task.

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1. Introduction

Prospective Memory (PM) or memory for delayed intentions is the ability to successfully perform previously planned actions at a later time and place, while attending to unrelated ongoing activities in the meantime. PM underlies many everyday tasks (Boelen et al., 2011; Kliegel et al., 2008), such as remembering to turn off the oven after 30 min, to pay the electricity bill at the beginning of the month, or to pick up the children after school. Even for apparently simple tasks, failures are common, and on occasion, with disastrous consequences (Dismukes, 2008, 2012). Impaired PM is a common consequence of brain injury, and can affect people's independence, productivity and social engagement (Brandimonte and Ferrante, 2008). Understanding brain mechanisms underlying

PM is therefore fundamental to developing strategies to support performance in daily life activities for people in need of cognitive rehabilitation.

Event-Related Potentials (ERPs) have been widely used to study the temporal dynamics of cognitive processes underlying event-based PM (see West, 2011 for a review). Computerised paradigms of event-based PM tasks require participants to detect low-probability events embedded in an ongoing task and to retrieve and execute the delayed intention in response. Typically, around 10% of the task events correspond to PM cues, in order to prevent continuous conscious rehearsal of the PM intention (Burgess et al., 2003). The majority of studies use perceptually distinctive cues (e.g., different from other stimuli in colour and/or size, letter or word features, West, 2011). Only a few studies have used conceptually relevant PM cues (e.g. different semantic categories of words, Wang et al., 2013; Wilson et al., 2013). This leads to the question of whether the ERP modulations previously described in the PM literature correspond to specific modulations related to processing of perceptually relevant targets or whether these

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modulations are "neural markers" common to different forms of event-based PM. As far as we know, only Cousens et al. (2015) have presented a study that addressed this question by directly comparing perceptual versus conceptual PM paradigms, their results showing that ERP modulations associated with detection of PM cues were only evident in perceptual PM tasks, whereas ERPs associated with realisation of delayed intentions constitute a general marker of PM. In the present study, we extend these findings by examining ERPs and their neural generators, not only related to cue detection and realisation of delayed intentions, but also during monitoring for PM cues. As far as we know, there are no ERP studies of PM that explore the neural generators of the modulations observed at the scalp.

Monitoring in PM has been defined as the strategic allocation of attention to detect prospective memory cues (Smith and Bayen, 2004). Traditional experimental designs in PM evaluate monitoring by comparing performance of an ongoing task performed in conjunction with a PM task (ongoing+PM task condition) with the performance of the same task without the PM task embedded (ongoing-only task condition) (Czernochowski et al., 2012; Guynn, 2003, 2008; Marsh et al., 2003; Smith, 2003, 2010; Smith et al., 2007). The same approach has been used to explore the neural correlates of monitoring in PM (Cona et al., 2012; Czernochowski et al., 2012; Knight et al., 2010; West et al., 2006; West et al., 2007). West et al. (2006, 2007) showed the first evidence of a monitoring effect (called the prospective interference effect in their studies) using perceptually salient PM cues. They showed an increased posterior negativity around 200 ms (N200) for ongoing task events performed concurrently with a PM task, relative to 'ongoing-only task' performance. This evidence has been corroborated by other researchers (Czernochowski et al., 2012; Knight et al., 2010). Thus, the first question we address in this study is: can the N200 also be found when monitoring conceptual PM cues or is it specific to the monitoring of perceptual PM cues?

ERPs related to cue detection are characterised by a negativity over occipital-parietal regions, beginning 200 ms after stimulus onset, with a maximum amplitude observed around 300–400 ms, coupled with a frontal positivity observed over the midline frontal regions (West et al., 2001). These findings have been replicated for perceptual PM paradigms only (Cousens et al., 2015; Knight et al., 2010; West, 2011). In the comparison of perceptual versus conceptual PM tasks, Cousens et al. (2015) observed that only the perceptual task condition elicited the N300, concluding that this modulation may correspond to a specific rather than a general marker of perceptual cue detection. Description of ERPs associated with cue detection in conceptual PM tasks has not been consistent in the literature. Cousens et al. (2015) did not observe any modulation associated with detection of conceptual PM-cues; similar results were reported by Wang et al. (2013). In contrast, West (2011) referred to a study in an unpublished thesis, which found evidence of left-frontal negativity around 400 ms that appeared to be supporting conceptual cue detection. Wilson et al. (2013) described a similar finding, an enhanced negativity in the left-parietal region. Thus, the second question we address is: can we find ERP modulations particularly associated with conceptual cue detection?

Finally, realisation of delayed intentions has been associated with a sustained positivity broadly distributed over the central, parietal and occipital regions of the scalp, between 400 and 1200 ms (West et al., 2001; West and Krompinger, 2005). Unlike the N300 associated with perceptual cue detection only, the appearance of a prospective positivity has been observed in both perceptual and conceptual PM tasks (Bisiacchi et al., 2009; Cousens et al., 2015; West et al., 2006; West and Wymbs, 2004; Wilson et al., 2013). Cousens et al. (2015) showed that the prospective positivity elicited by perceptual and conceptual cues did not differ in amplitude, supporting the idea that the prospective positivity may reflect general mechanisms associated with retrieval of intentions from memory and post-retrieval processes. However, it is well known that similar appearing scalp ERPs may be produced by a mix of different components (Luck, 2005). Accordingly, studies carried out by West and collaborators have shown that a variety of processes may be contributing to the prospective positivity depending on the nature of the PM task (West, 2011), for example, the P3b component (Kok, 2001; West et al., 2006; West and Wymbs, 2004), the recognition old-new effect (West and Krompinger, 2005) and a late positive complex associated with task configuration (Bisiacchi et al., 2009; McNerney's thesis cited in West, 2011). Additionally, Bisiacchi et al. (2009) showed that the late positive complex may reflect different cognitive processes, depending on whether the instructions given to participants have a task-switch or dual-task approach. Thus, the third question we address in our study is: what are the underlying cognitive processes and neural generators of the prospective positivity in conceptual and perceptual PM tasks?

To answer the questions stated above we examined ERPs and their neural generators, obtained from perceptual and conceptual PM paradigms. In order to refine source localisation, we used Independent Component Analysis (ICA) (Makeig et al., 1996) applied to a high-density EEG. We hypothesised that: (1) a greater N200 would be associated with perceptual PM-task cue monitoring (early stages of stimulus processing). Whereas, for Conceptual PM-task monitoring we expected to observe modulation of ERP components associated with later stages of stimulus processing. (2) Perceptual cue detection would be associated with an early posterior cortical response (N300) whereas conceptual cue detection would be associated with a later (~400 ms) fronto-temporal response, related to semantic processing. (3) Finally, prospective positivity would be observed in both perceptual and conceptual PM-tasks, but we expect to obtain differential brain sources contributing to it in the different PM-tasks.

2. Materials and methods

2.1. Participants

Twenty-five university students, 16 females and 9 males, were recruited from Glasgow University, all native English speakers, mean age 23 years (SD 5.19), right handed, with no history of neurological disorders and normal/corrected-to-normal visual acuity. They received monetary compensation (£18) for their participation. Ethical approval was obtained from the Ethic Committee of the School of Psychology, University of Glasgow, and all participants provided written informed consent prior to participation.

2.2. Procedure

We used a factorial design with the following within-subjects factors: task session (perceptual, conceptual), task condition (ongoing-only, ongoing+PM) and event type (related words, unrelated words and PM events). Participants performed the experiment in two counterbalanced sessions separated by one week. In each session participants performed one of 2 PM tasks that involved the same demand for intention retrieval (press 'x' when you see the PM target), but varied in the form of PM-task cue (conceptual or perceptual PM stimulus). Both PM-task stimuli were embedded in the same ongoing-task stimulus stream and the cue stimuli used were identical in both sessions. Stimuli were presented in white Courier New font against a black background, font size 18.
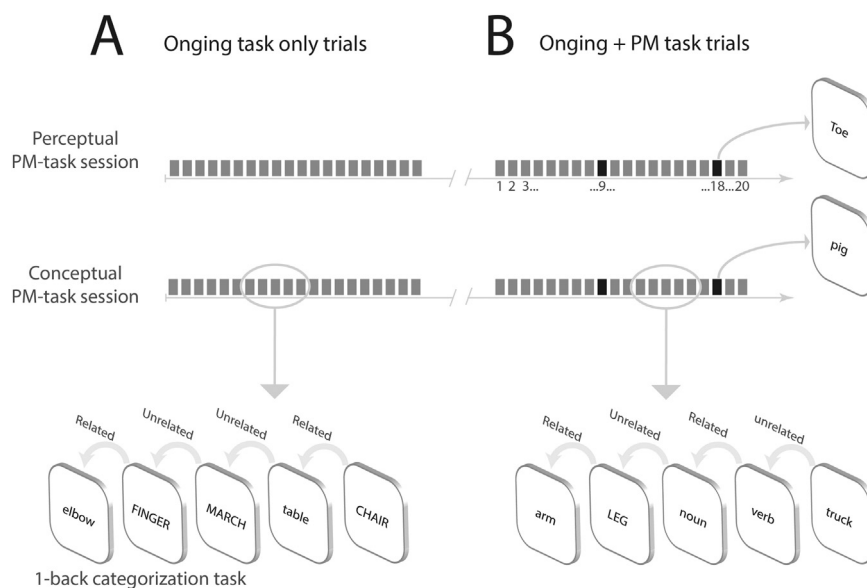
Fig. 1. Experimental paradigm. (A) Conceptual and perceptual sessions began with a 1-back word category matching task exemplified at the bottom, direction of the arrows indicates that responses were given in relation to the previous word. Related words were those following a word in the same category, whereas Unrelated words followed a word that did not belong to the same category. (B) The Prospective memory task was embedded in the ongoing task. Examples of PM-task cues are depicted at the right of the figure. Light grey bars represent ongoing task trials and black bars represent PM-task cues.

Both sessions began with performance of the 'ongoing-only task' (Fig. 1A). Participants were then given instructions for performing the PM-task and immediately after were asked to perform a different computerised task, with the aim of distracting participants from sustained rehearsal of the PM-task instructions. The computerised task lasted for about two minutes. It consisted of indicating, on a response pad, the number presented on the computer screen as quickly and accurately as possible. During the second part of the session (Fig. 1B) participants resumed the ongoing task while simultaneously maintaining the instructions to engage in the Prospective Memory task (i.e., performing both the Ongoing and PM tasks).

2.3. Ongoing task

The Ongoing task was a 1-back continuous performance noun categorisation task in which participants had to decide if the current word (noun) displayed on the screen belonged to the same semantic category as the previously displayed word (noun). Participants were instructed to press a key under their right index finger when the word belonged to the same semantic category (Related word) or to press a key under their right middle finger when the word did not belong to the same category (Unrelated word). The 'Ongoing-only task' condition comprised 300 trials. The 'Ongoing+PM task' condition comprised 600 trials. Each trial lasted two seconds. The word was shown on the screen for 500 ms. Note that 'Ongoing-only task' and 'Ongoing+PM task' conditions involved the same Ongoing task, the only difference being that during the latter task condition, participants were instructed to also respond to prospective memory cue stimuli by performing the PM-task response (West et al., 2001). Participants were given breaks after every block of 20 trials. The words in the Ongoing task were printed using either upper or lower case letters, though this distinction was not relevant to the task. The relative complexity of the Ongoing task was designed to prevent the continuous rehearsal of PM-task instructions. A long list of 60 categories (adapted to British English) was used based on the updated version of the Battig and Montague (1969) category norms (Van Overschelde et al., 2004). See the Appendix of Van Overschelde's paper for detail of categories and words included in the study.

2.4. Prospective memory task

In the perceptual PM-task session, in addition to the ongoing task, participants were asked to press a response pad key with their *left* index finger in response to words whose first letter only was written in uppercase, for example, the word 'Toe'. In the conceptual PM-task session, participants had to give the same response to animal-name words (which could be in upper or lower case), for example, the word 'pig' (Fig. 1). The participant instruction period included examples and a short practice block. PM-task cues were presented in 10% of the 600 'Ongoing+PM task' trials. Each 20-trial block contained 2 PM-task cues, presented pseudo-randomly in trials 5, 9, 17, and/or 18 (Fig. 1B), so PM-cues were never presented consecutively, to try to ensure re-engagement in the ongoing semantic categorisation task after a PM response.

2.5. EEG recording

EEG data were recorded with a common vertex reference using a 128-channel Geodesic Sensor Net (Electrical Geodesics, Inc.). The sensor net was soaked in a saline electrolyte solution and adjusted until all electrode pedestals were properly seated on the scalp. Individual sensor impedances were adjusted to be below 50 kΩ (though for some participants, some electrodes had impedances between 50 and 100 kΩ). Data were sampled at 250 Hz with an analog filter bandpass of 0.1–200 Hz. A Macintosh computer running EGI's Netstation software was used for data collection. E-Prime running on a PC was used for stimulus presentation. Two four-button response pads (one for each hand) were used to collect finger press responses to stimulus events.

2.6. Behavioural analysis

To evaluate monitoring cost on reaction time we used a 2 (Event type: Related, Unrelated) x 2 (Condition: Ongoing-only, Ongoing+PM) × 2 (Session: Perceptual, Conceptual) repeated measures ANOVA. To evaluate monitoring effects on accuracy we used the factors Condition (Ongoing-only, Ongoing+PM) and Session (Perceptual, Conceptual). Bonferroni correction was used

for all *post hoc* comparisons. To evaluate differences in accuracy and reaction time between Conceptual and Perceptual PM tasks we used *t*-tests. SPSS software was used for behavioural statistical analysis.

2.7. EEG data analysis

The EEG data preprocessing and analysis were performed using custom MATLAB (The Mathworks, Inc.) scripts operating in the EEGLAB environment (Delorme and Makeig, 2004). A high-pass finite impulse response (FIR) filter at 1 Hz (cut-off frequency, 0.5 Hz) and a low-pass FIR filter at 40 Hz (cut-off, 45 Hz) were applied to the continuous EEG. Data were first visually inspected to perform bad-channel removal. The continuous data were then cleaned using the EEGLAB functions *clean_windows()* and *detect_artifacts_by_robust_sphering_MIR();* the function *clean_windows()* computes a z-scored power for each data chunk captured by a sliding window. If their values are greater than ± 5 standard deviations, the data chunk is identified as bad and rejected. The d*etect_artifacts_by_robust_sphering_MIR()* function calculates sphering matrices on a small chunk of data (default 10 points) using a sliding window, it then computes geometric median across the sphering matrices to obtain a robust sphering matrix. The latter is used to compute a sliding-window mutual information reduction (MIR) and finally compute median absolute derivation over the results to identify bad chunk of data (Bigdely-Shamlo, 2015). Each subject's dataset was subjected to Adaptive Mixture ICA (AMICA) separately (Palmer et al., 2008) to decompose the

continuous data into source-resolved activities. The channel data were segmented into epochs of three seconds (from 1 s before to 2 s after task stimulus onsets). Noisy data epochs were rejected using the EEGLAB improbability methods for channels (threshold, SD $=10$) and IC activities (SD $=5$). Equivalent current dipole model estimation of the independent component (IC) scalp maps learned by AMICA was performed using an MNI Boundary Element Method (BEM) head model in *DIPFIT*, an EEGLAB plug-in used to fit an equivalent dipole to the scalp projection pattern of each independent component. For group level analysis we used the STUDY function that automatically exclude ICs whose dipoles were located outside the brain and those with residual variance of the best-fitting equivalent model dipole of over 15%. By this means a total of 1083 ICs were retained from the 25 participants (two sessions per participant). These ICs were clustered using k-means based on their mean power spectra, stimulus-locked ERPs from all experimental conditions, and equivalent dipole locations. Twenty IC-clusters were obtained including one eye movement cluster (containing 59 ICs) and one muscle activity cluster (containing 23 ICs), whose sources were located just below the orbital gyrus and in the inferior part of the cerebellum respectively. All the other clusters corresponded to brain IC-clusters and were included in the analysis by back projecting their activity to selected scalp locations. Participants contributed with a variable number of ICs to the final clusters, ranging from 18 to 64 ICs per participant distributed across the twenty final clusters. To find the anatomical centroid of each IC cluster, we entered the coordinates of the centroid for each cluster from the EEGLAB function *std_dipplot()*
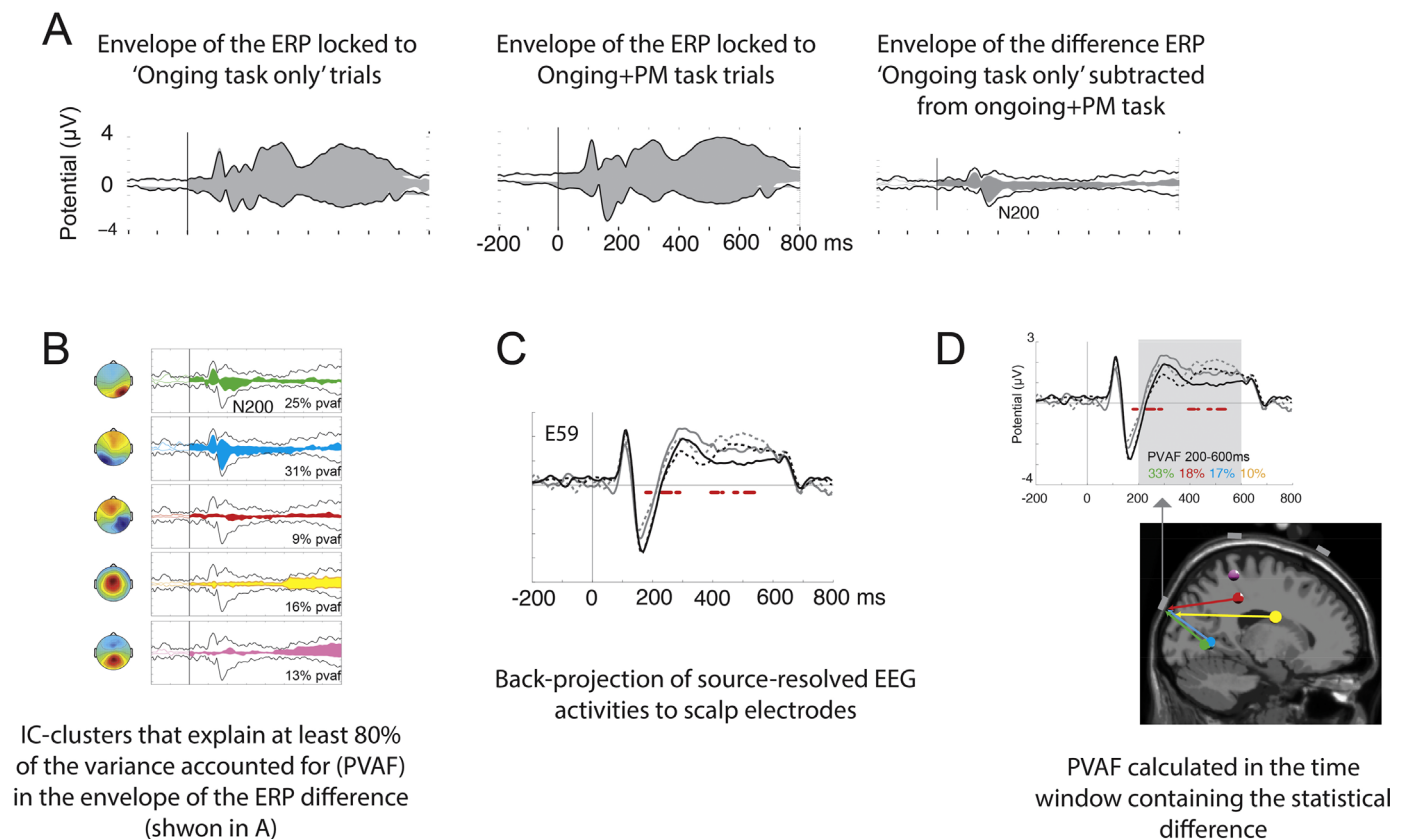
Fig. 2. Statistical analysis. (A) Envelope of the ERP locked to ongoing task events under two conditions: 'Ongoing-only task' (left) and 'Ongoing+PM task' (centre), the rightmost envelope depicts the difference between the grand-mean ERPs of the two conditions. Outer (black) envelope traces correspond to most positive and negative channel values at each epoch latency. (B) Maximally independent brain source clusters whose summed scalp projections accounted for at least 80% (PVAF) of the variance of the difference response. Colour traces represent the contribution of each cluster to the difference. (C) Scalp ERPs at the left occipital scalp channel summing the projections of all the brain-IC clusters (i.e., excluding clusters of IC sources accounting for eye movement and muscle activity artifacts); red dots indicate significant differences between 'Ongoing+PM' and 'Ongoing-only' task conditions revealed by non-parametric *t*-tests with FDR correction. (D) PVAF contributions of the clusters identified in B to the scalp ERP significant differences shown in C. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

into the online Talairach Client (Lancaster et al., 1997; Lancaster et al., 2000).

The EEG statistical analysis followed three steps; the first step involved descriptive statistics and consisted of calculating and visualising the *envelope of the ERP difference* between tasks using the EEGLAB function envtopo(). Here, the data envelope is a (2, #time_points) matrix whose rows are the most positive and most negative channel values at each latency in the ERP (Fig. 2A), calculated across all the ERPs from all the ICs per cluster. The envelope of the ERP difference is obtained by subtracting two task conditions as shown in Fig. 2A, revealing time points of greater difference which were then statistically evaluated. Second, we found the clusters of brain sources (across subjects) that explained, in total, at least 80% of the variance accounted for (PVAF) in the resulting envelope of the ERP difference (Fig. 2B), calculated using, *PVAF(Comp, Data)=100 (1 -var (Data-Comp)/ var(Data)),* where *Data* is the ERP, *Comp* is the (summed) contribution of one (or more) IC processes to the *Data*, and *var*() is variance. Note that PVAF of two or more component projections (the scalp channel data accounted for by the component process), summed at each scalp channel, is in general not equal to the sum of the PVAF values for the IC projections, as these may be negative and positive respectively, and partially cancel each other when they sum in the scalp channels. Third, we projected the source-resolved IC activities (excluding eye movement and muscle activity components) to the scalp regions that have been reported to show prospective memory effects (West, 2007; West and Ross-Munroe, 2002): occipital-parietal (electrode E59, E85), parietal (electrode E62) and frontal (electrode E9). Resulting ERPs were subjected to a set of planned comparisons (Ruxton, 2008) using permutation-based nonparametric *t*-tests performed on each of the 200 data points in the time window − 200 ms to 800 ms, then corrected for multiple comparisons using False Discovery Rate (FDR) at the $p \leq 0.01$ significance level (Fig. 2C). Using this approach we focused on the effects of interest, reducing type I error rate through avoiding comparisons that were not within the scope of the present work (Ruxton, 2008). In order to identify which IC-clusters contributed the most to the statistical difference observed at the scalp, we calculated the PVAF in smaller time windows containing the statistical difference (Fig. 2D). The planned comparisons performed were as follow; to investigate Monitoring effect we explored the difference between ERPs time locked to events in the 'Ongoing-only task' condition versus events in the 'Ongoing+PM task' condition (Related and Unrelated separately), for each PM-task session (perceptual and conceptual); to investigate PM effects, we calculated the difference between ERPs time locked to PM-task cues versus Ongoing-task Related word events and ERPs time locked to PM-task cues versus Ongoing-task Unrelated word events, for perceptual and conceptual PM sessions separately.

3. Results

3.1. Behavioural data

3.1.1. Monitoring cost

The repeated measures ANOVA applied to mean reaction times, revealed a main effect of Event Type, $F(1,24)=57.1$, $p < 0.001$, such that responses to Related words were faster than responses to Unrelated words. We also found a significant interaction between the three factors: Event Type (Related, Unrelated), Session (Conceptual, Perceptual) and Condition (Ongoing-only, Ongoing+PM), F $(1,24)=5.37$, $p < 0.05$. In *post hoc* analysis, a new ANOVA was run separately for each PM-task session, using the factors Condition and Event Type, with significance level corrected at 0.05 divided by 2, the number of tests for simple main effects (Kinner and Grey, 2008).

Results for the Perceptual PM-task session showed a main effect of Event Type, $F(1,24)=52.6$, $p < 0.001$, such that responses for Unrelated words were considerably slower than Related words, independent of Task Condition. No Condition effect, $F(1,24)=0.5$, $p > 0.05$, or interaction effects were found $F(1,24)=1$, $p > 0.05$. This result suggests that maintaining the PM intention to respond to perceptually distinctive cues did not interfere with the performance in the Ongoing task.

The conceptual PM-task session also showed a main effect of Event Type, $F(1,24)=47.1$, $p < 0.001$, showing that responses for Unrelated words were considerably slower than Related words. In addition, we also found a significant 'Condition x Event Type' interaction effect, $F(1,24)=23.8$, $p < 0.001$. *Post hoc* analysis showed that while reaction times for Related words were always slower than reaction times for Unrelated words, the reaction times for the latter were significantly slower during the 'Ongoing+PM task' condition compared to the 'Ongoing-only task' condition, $F(1,24)= 8.7$, $p < 0.01$. By contrast, reaction times for Related words were similar in both task conditions. This result suggests that responses to Unrelated words were slower when the conceptual PM task intention was embedded in the ongoing task. The accuracy of responses in the 'Ongoing+PM task' was not different from the accuracy during the 'Ongoing-only task' condition, meaning that no monitoring cost in the 'Ongoing+PM task' condition was observed in terms of accuracy (Table 1).

In summary, the behavioural results showed that reaction times to Unrelated words in the Ongoing task were slower when participants had to identify an animal word as the PM cue (Conceptual PM-task session). Thus, only Unrelated items in the conceptual PM task exhibited a cost of PM-task monitoring. No behavioural signs of a PM-task monitoring cost were observed in the perceptual PM-task condition.

Table 1. Accuracy and Reaction Times for 'Ongoing-only task' and 'Ongoing+PM task' for both PM task sessions (Perceptual and Conceptual). Results for both PM tasks are also shown.

3.1.2. Prospective memory performance

T-tests showed that reaction times following PM-task cue recognition were faster for perceptual cues than for conceptual cues, $t(24)=-4$, $p < 0.001$. Accuracy for conceptual cues was lower than accuracy for perceptual cues, $t(24)=3.8$, $p < 0.001$. In summary, the results showed that perceptual PM-task cues were more often detected and responded to appropriately than conceptual PM-task cues.

3.2. EEG results

We used an ICA source-decomposition approach applied to a

Table 1
Behavioural results.

Ongoing-only	Perceptual Mean (SD)	Conceptual
RT Related (ms)	712 (129)	687 (116)
RT Unrelated	788 (160)	752 (112)
Accuracy (%)	95 (3)	95 (3)
Ongoing+PM		
RT Related	716 (105)	687 (99)
RT Unrelated	801 (137)	791 (108)
Accuracy	94 (2)	95 (2)
Prospective Memory		
RT	697(88)	752 (87)
Accuracy	88(8)	78(14)

Note. Accuracy (%) and Reaction Times (ms) per session (standard deviation in parenthesis).

high-density EEG recording to identify brain sources that underlie differences observed at the scalp channel level. The clusters contributing the most to the effects shown by the scalp ERP differences, and their location inside the brain, are detailed in Table 2 and depicted in Figs. 3–6. The results presented here show commonalities and differences in the ERPs and their neural generators involved in both types of PM tasks, conceptual and perceptual.

3.2.1. PM monitoring effect: N200 associated with intention maintenance during the ongoing task

To study the monitoring effect associated with detection of perceptually and conceptually relevant PM cues, we explored the differences between the 'Ongoing-only task' and 'Ongoing+PM task' conditions. PM-task trials were excluded from this comparison. Only correct responses were considered (as the error rate was low). Fig. 3A shows the envelope of the difference ERP ('Ongoing+PM task' minus 'Ongoing-only task'), revealing that the main differences seem to be around 200 milliseconds for perceptual and conceptual PM-task sessions. The five IC clusters that contributed most to the variance shown by the envelopes (between 0 and 800 ms) are also shown. There are two occipital clusters (left and right) and one right parietal cluster common to perceptual and conceptual tasks that explain most of this monitoring effect. In addition, a frontal-midline and superior parietal IC-cluster seem to contribute to perceptual PM-task monitoring, while two left temporal IC-clusters seem to contribute to the conceptual PM-task. The contribution of each cluster to the variance shown by the envelope is expressed in terms of the percentage of the variance accounted for (PVAF, see methods). In order to examine statistical difference at scalp level, all brain clusters (except eye-movement and muscle activity clusters) were projected to selected occipital and parietal regions (Fig. 3B). For both PM-task sessions, the Ongoing-task stimulus ERP at the occipital scalp site had a significantly larger negativity near 200 ms in 'Ongoing+PM task' trials relative to the 'Ongoing-only task' trials. Only the Unrelated word responses showed significant differences; although Related word responses exhibited differences in the same direction, these were not significant. The perceptual PM-task comparison between responses to 'Ongoing-only task' and 'Ongoing+PM task' events exhibited significant differences at a larger number of latencies – the period of significant difference was close to the length of stimulus presentation (500 ms) – whereas in the conceptual PM-task, the latencies of significant difference were focused around 200 ms. The results also showed a monitoring effect specific to the conceptual PM task. Responses to unrelated words in the 'Ongoing+PM task' contained a long-lasting positivity relative to responses to unrelated words in the 'Ongoing-only task'; this difference was significant near 700 ms.

In order to identify how brain clusters revealed by the envelope analysis (Fig. 3A) contributed to statistical differences shown by the scalp ERPs (Fig. 3B), we calculated the PVAF in smaller time windows that contained the statistical difference (Fig. 4): between 200 and 600 ms for the perceptual PM-task session; and between 180–300 ms and 600–800 ms for the conceptual PM-task session. The effects shown at the selected occipital scalp site, in both types of PM-tasks, are mostly accounted for by the two occipital IC clusters and the right parietal IC cluster. In terms of the late monitoring effect found for the conceptual PM-task session the main brain sources contributing to this effect were from the right parietal and left temporal IC clusters.

In summary, both PM tasks showed evidence of monitoring at an early stage of stimulus processing expressed as an increase in the amplitude of the N200 component, this effect being significant for a longer time in the perceptual PM-task session. Occipital and right tempoto-parietal clusters explain these effects. Only the conceptual PM task showed evidence of monitoring at a later stage of processing, possibly associated with response production for the unrelated words (which are similar to the conceptual PM-task cues).

3.2.2. Prospective memory effects: cue detection and realisation of delayed intentions

We studied ERP modulations associated with PM-task events by examining the difference between PM-task and 'Ongoing+PM task' grand-mean ERPs. Fig. 5A shows the difference between the envelope ERPs for perceptual and conceptual PM-task sessions. Visual inspection of the envelopes reveals an early ERP peak associated with detection of perceptual PM-task events (N300) and a later sustained positivity (the so called prospective positivity) for both, perceptual and conceptual PM tasks. The main five contributing IC-clusters that explain at least 80% of the variance shown by the envelopes are depicted for each PM-task session. From these, only the frontal-midline IC cluster is common to perceptual and conceptual PM-tasks (yellow envelope in Fig. 5A). Involvement of differential IC-clusters for each PM task will be explained below in relation to ERP modulations associated with cue detection and realisation of delayed intentions.

N300 and N400. Non-parametric statistics were applied to the projection of all IC clusters (excluding eye-movements and muscle activity clusters) towards selected scalp locations (Fig. 5B), revealing that the increased amplitude around 300 ms for perceptual PM-task ERP was significant. This negativity resembles the N300, previously associated with detection of prospective memory cues based on perceptual attributes and it was not observed for the conceptual PM-task ERP. Instead, an N400-like waveform was observed for conceptual PM-task cues, this ERP component resembled the N400 depicted by the ERPs of unrelated words in the Ongoing task. Note that both tasks, conceptual PM and 'Ongoing+PM', required semantic categorisation to select the response, suggesting that N400 may be an indicator (here) of conceptual cue recognition.

We then explored how the brain clusters revealed by the

Table 2
Summary of IC clusters.

| Scalp distribution	Talairach coordinates of IC cluster centroid	Brain region	Colour in figures
Left occipital	−39 −61 3	BA37 / Left occipito-temporal area	Light blue
Left Temporal	−51 −11 −1	BA22 or BA21 / Left temporal gyrus	Dark pink
Left frontal	−36 27 26	BA9 / Left middle frontal gyrus	Dark green
Left parieto-temporal	−36 −21 50	BA4 / Precentral gyrus	Light brown
Right occipital	38 −65 3	BA37 / Right occipito-temporal area	Light green
Right Parietal	44 −34 40	BA40 / Right parietal cortex	Red
Right middle frontal	35 7 44	BA6 / Right middle frontal gyrus	Purple
Deep-Frontal	0 −3 −16	Grey matter	Dark brown
Frontal-midline	2 −3 22	BA24 / Anterior Cingulate Cortex	Yellow
Centro-Parietal	6 −37 59	BA5 / Superior Parietal Cortex	Pink
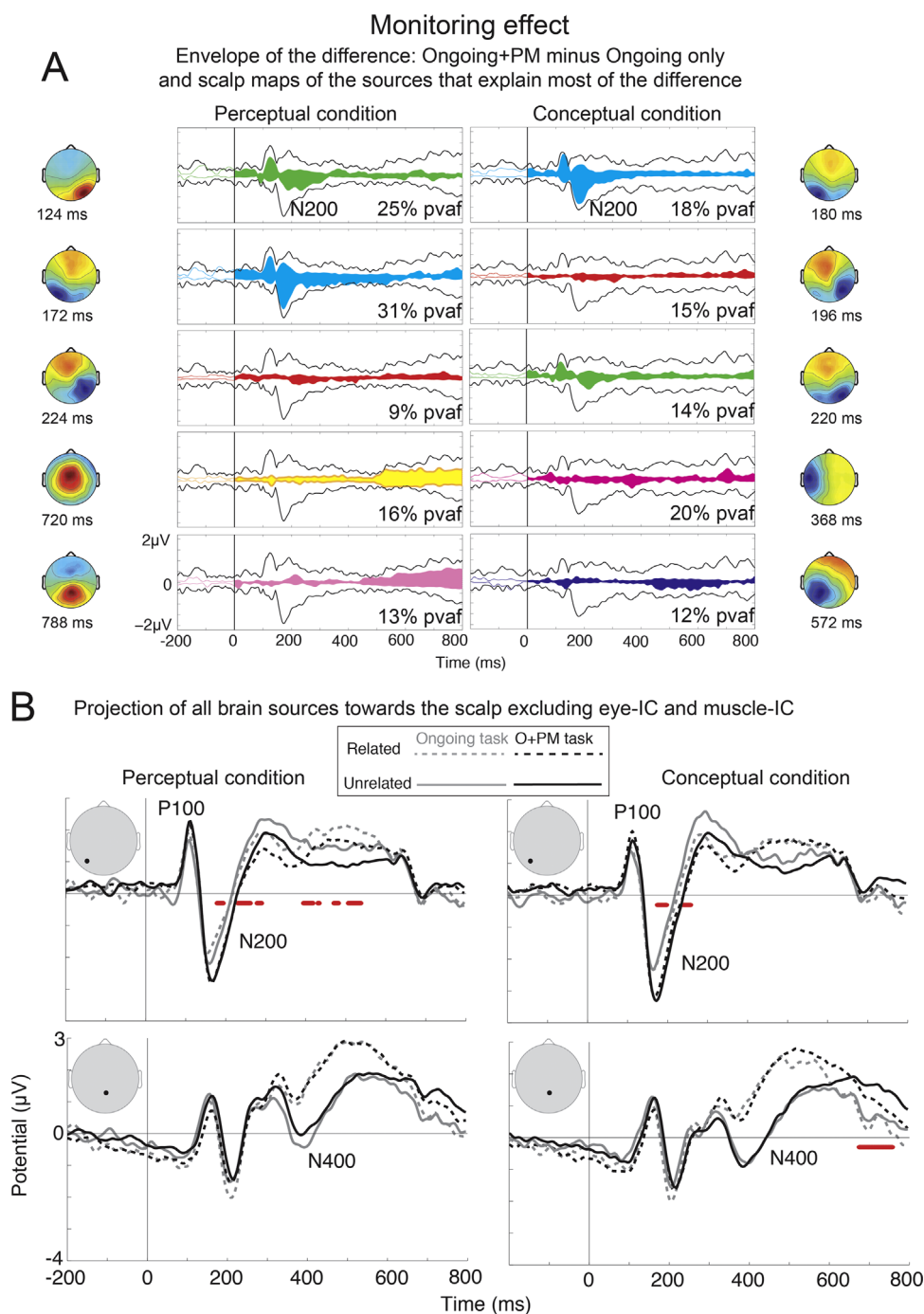
Fig. 3. PM monitoring effect. (A) Envelope of the difference ERP indicating the IC-clusters with highest PVAF values within the whole ERP time window (0–800 ms). Outer (black) envelope traces correspond to most positive and negative channel values at each epoch latency. Inner (colour) traces indicate the contribution of each cluster to the envelope of the difference ERP. Note the increase of the amplitude around 200 ms for both sessions. Scalp maps and peak PVAF latencies (time point of largest contribution for each IC-cluster) are shown (PVAF: percent variance accounted for) to the left and right for perceptual and conceptual PM-task session respectively. (B) ERPs at two occipital (E59) and parietal (E62) scalp locations, indicated in the top-left corner of each ERP. A permutation t-test was applied to each data point (−200–800 ms) and was corrected using FDR (p < 0.01). Time points of significant difference for unrelated words (continuous line) are shown in red. The difference between related words (dashed line) was not significant.

envelope analysis (Fig. 5A) contributed to the N300 and N400. We calculated the PVAF in smaller time windows that contained the time points with a statistical difference (Fig. 6). The main contributing cluster that explained most of the effect observed at 300 ms in the perceptual PM-task condition corresponded to the right-occipital cluster and to a lesser extent the centro-parietal cluster (Fig. 6; light green, 44% PVAF and pink, 28% PVAF IC-clusters). In the conceptual PM-task, the main contributing clusters that explain most of the difference around 400 ms are the frontal-

midline, deep-frontal (note that depth is the dimension of least certainty, Akalin Acar and Makeig, 2013) and a left-parietal cluster (Fig. 6; yellow, 32% PVAF; dark brown, 32% PVAF and light brown, 23% PVAF IC-clusters respectively). In summary, the N300 is associated with detection of perceptually distinctive prospective memory cues with brain-sources in posterior areas, whereas the N400 may be an indicator of conceptual cue recognition with brain sources in mid-central and frontal areas.

Prospective Positivity. Conceptual and perceptual PM-task ERPs

Brain sources contributing to monitoring effect at the scalp
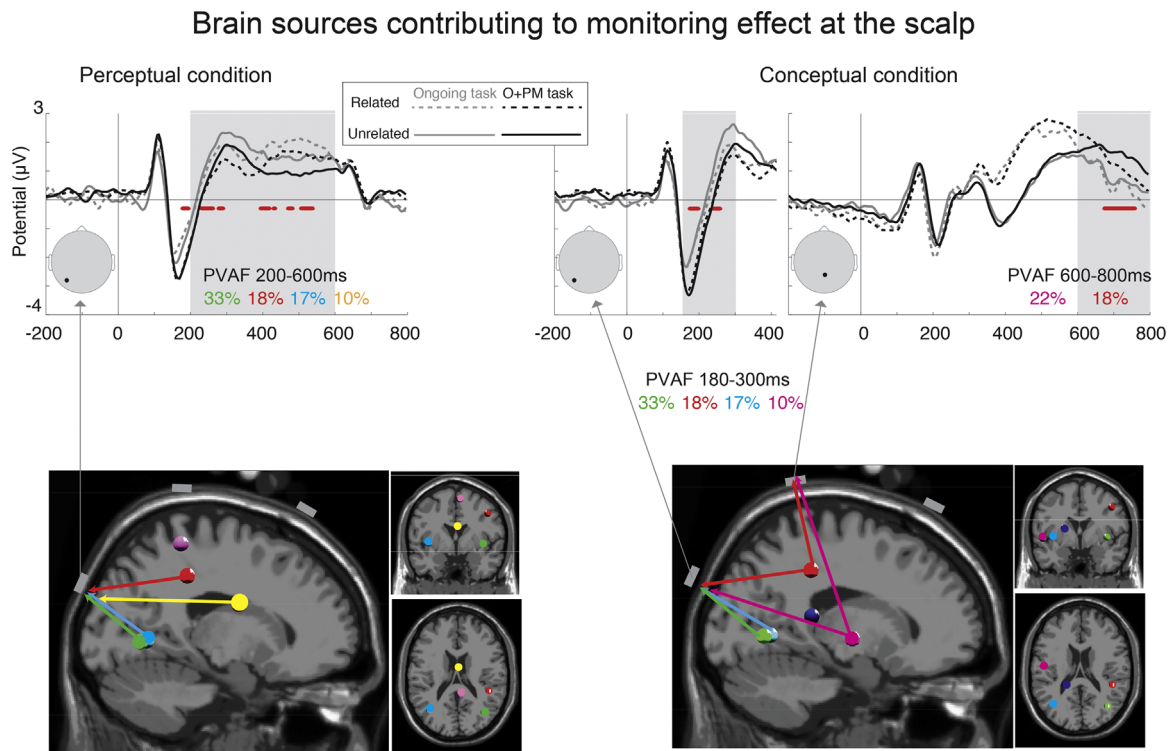
Fig. 4. Brain sources that contribute to the statistical effect observed at the scalp. (Top panel) Scalp ERPs, shaded areas indicate time windows used to calculate the contribution of IC clusters to the statistical difference. (Bottom panel) Dipole locations of brain IC clusters whose projections explained the statistical difference shown at the scalp. PVAF values and cluster locations are shown in the same colours. Scalp maps of the dipoles are shown in the same colour code in Fig. 3.

each contained a positive slow wave over parietal and frontal scalp regions (Fig. 5B). The prospective positivities shown here differ between perpetual and conceptual PM-tasks. In the perceptual PM-task the prospective positivity is stronger over the parietal scalp site, with a statistical difference starting at 400 ms approximately. In the conceptual PM-task, the parietal positivity clearly differs between related and unrelated words from about 600 ms over the frontal scalp site. Different brain sources contributed to the slow-wave positivities in each condition (Fig. 6). We calculated the PVAF in smaller time windows (400–600 and 600–800 ms) to explore how the brain clusters contributed to the significant prospective positivity. In the conceptual PM-task, the positive slow-wave was mainly produced by the frontal-midline IC cluster (Fig. 6; yellow IC cluster, 61% PVAF between 600–8000 ms) located in or near the anterior cingulate cortex (Table 2), with contribution from the left frontal cluster (15%PVAF located close or in BA 9) and from the left occipital cluster in a lesser extent (7% PVAF). The frontal-midline IC cluster also contributed to the positivity observed in the perceptual PM-task (33% PVAF between 400–600 ms and 21% PVAF between 600–800 ms). However, for the perceptual prospective positivity, the main contributions came from the superior parietal, right parietal and right middle frontal IC clusters (Fig. 6; pink, red and purple IC clusters respectively). Thus, the slow-wave potential or prospective positivity observed at parietal and frontal scalp locations have different contributing brain sources depending on the type of PM-task. In summary, although conceptual and perceptual PM-task ERPs showed similar-appearing scalp-channel positivities, they had different contributing brain sources; fronto-parietal for the perceptual PM-task and frontal for the conceptual PM-task, with only the frontal midline cluster, with a source located in or close to the anterior cingulate cortex, common to both PM tasks.

4. Discussion

In the present study we used ERPs and brain-source analysis to investigate whether ERP components, previously associated with PM task performance, reflect particular mechanisms associated with perceptual PM-tasks or general mechanisms associated with PM-task processing. We examined perceptual and conceptual PM-tasks across three phases of the PM-task process: monitoring for PM cues, cue detection and realisation of delayed intentions. The ICA source-decomposition approach we applied allowed us to identify brain sources that underlie differences observed at the scalp channel level, contributing to understanding similarities and differences between different types of prospective memory tasks beyond ERPs. Additionally, we used point-by-point statistics (instead of comparing average ERP amplitudes), an exploratory approach that allows us to identify where in the time course of the stimulus processing the differences were greater, without prior assumptions.

4.1. Behavioural and neural correlates of monitoring: contribution to theories in prospective memory

Our results are consistent with the PM literature and support our hypotheses for monitoring; we found an enhanced occipital negativity (N200) associated with monitoring for perceptual PM cues (Knight et al., 2010; West, 2007; West et al., 2006). Higher ERP amplitudes over occipital areas have been interpreted as a sign of top-down attentional modulation (Knight et al., 2010). If we interpret the enhanced N200 as a result of modulation of brain activity facilitating processing of perceptual features, we would expect to find this enhanced negativity associated only with the perceptual PM-task condition. However, it seems that this early top-down attentional modulation is not only associated with processing of perceptual features, as the conceptual PM-task condition also showed this early sign of monitoring. The left
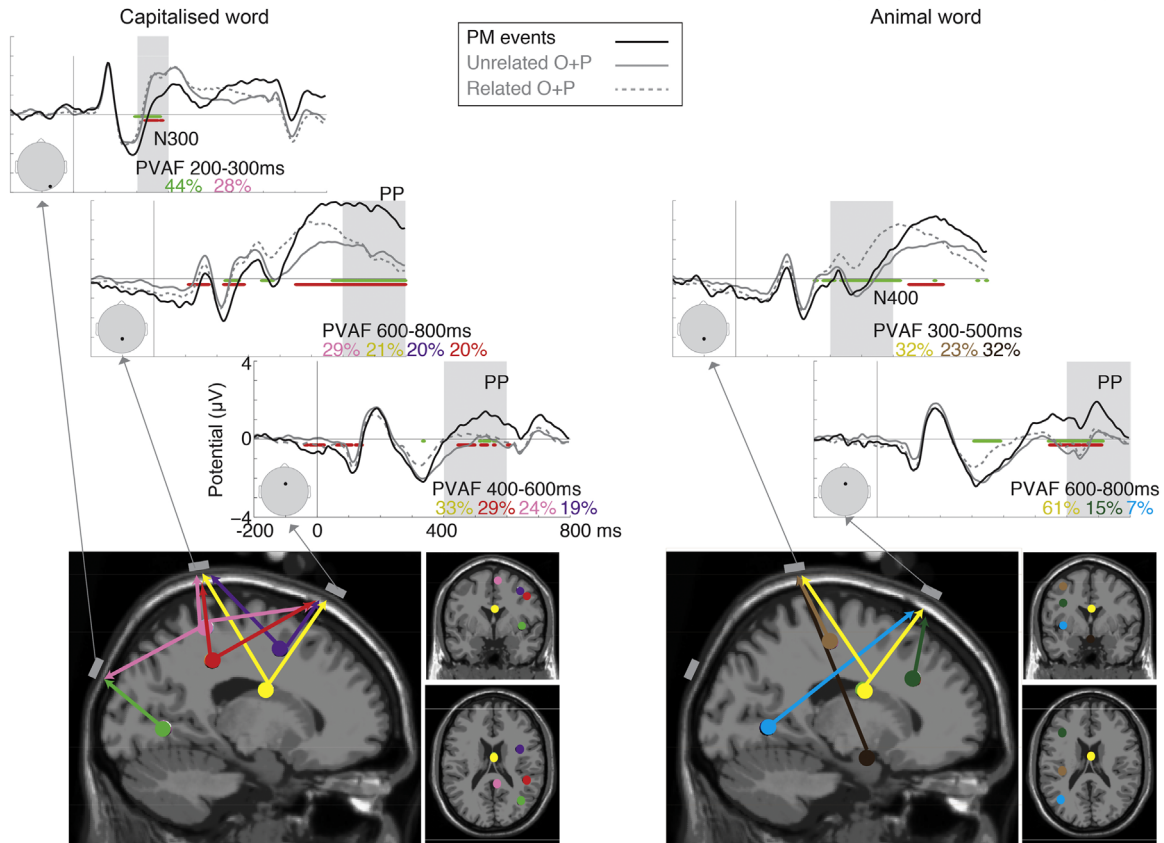
Prospective memory effect
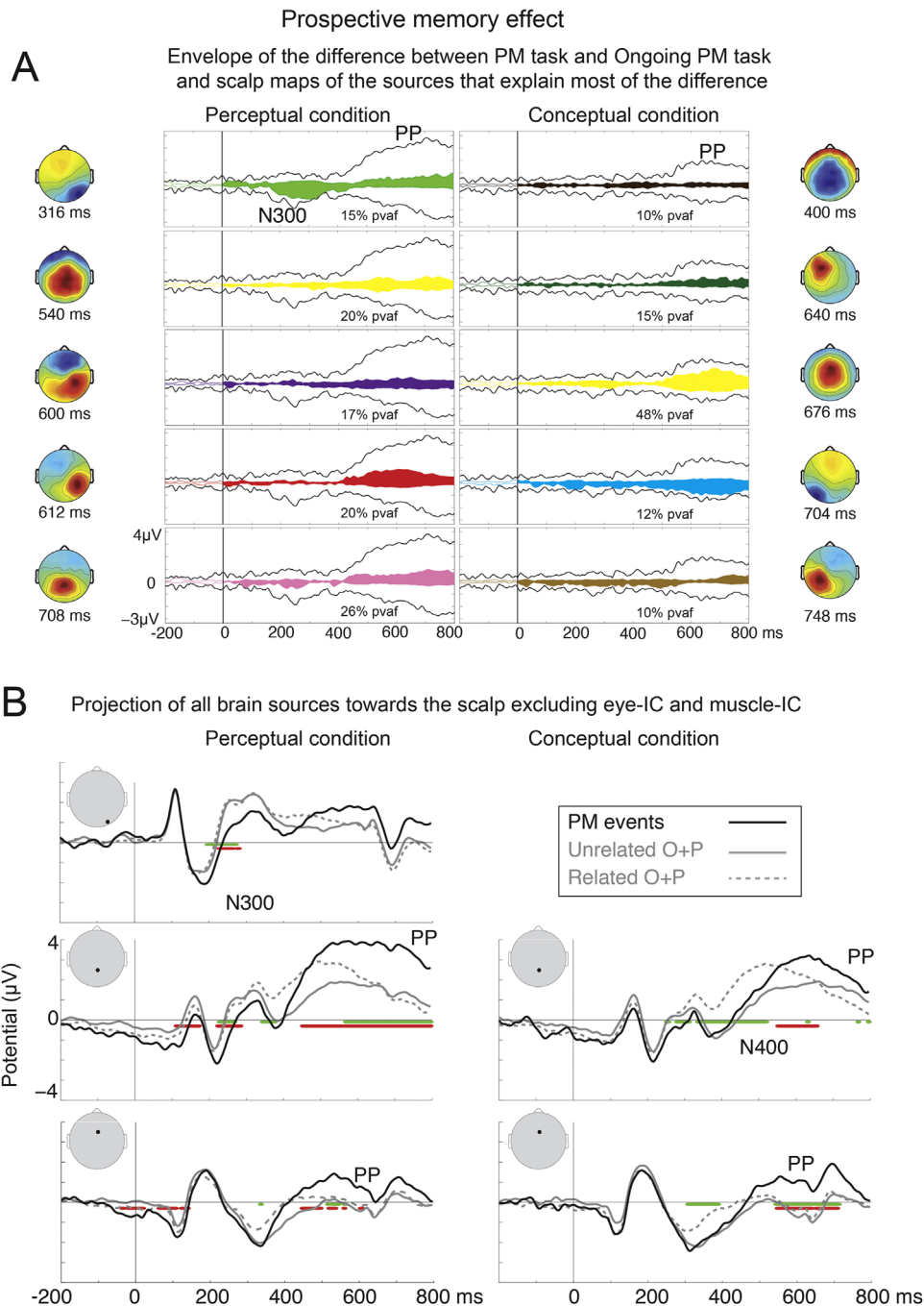
Fig. 5. Prospective memory effect. (A) Envelope of the difference ERP indicating the five IC clusters with highest PVAF values within the whole ERP time window (0–800 ms). Outer (black) envelope traces correspond to most positive and negative channel values at each epoch latency. Inner (colour) traces show the contribution of each IC cluster to the difference ERP. Scalp maps show the mean scalp projection of IC cluster activity at the latency at which it contributes most strongly to the ERP difference. Only the frontal mid-line IC cluster is common to both PM-tasks (yellow cluster). (B) Artifact-cleaned ERPs at three scalp sites above occipital (E85), parietal (E62) and frontal (E6) cortex: these sensor locations are indicated on the cartoon heads in the top-left corner of each ERP panel. A permutation-based *t*-test was applied to the data at each latency in the time window (−200 ms to 800 ms), corrected for multiple comparisons using FDR (p < 0.01). Red horizontal bars: Unrelated words versus PM-task cues. Green bars: Related words versus PM-task cues. PP stands for prospective positivity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

occipital IC cluster that contributed the most to this difference was located in or near to the caudal portion of the left fusiform gyrus (Table 2). A positron emission tomography (PET) study has shown that this area is activated during semantic categorisation (Thioux et al., 2005). Thus PM-task cue recognition based on the meaning rather than the physical characteristics of the cue word may be the reason for eliciting greater N200 over the occipital region. These results can be interpreted as a neural correlate of a Retrieval Mode or "active maintenance of the intention" (Guynn, 2003, 2008),

which allows recognition of a PM-task cue. This Retrieval Mode has been proposed to operate by a more or less continuous modulation of brain activity, to facilitate processing of stimuli that may be relevant for the performance of a future intention (Guynn, 2003, 2008; Knight et al., 2010; Reynolds et al., 2009). One contradiction with the theory proposed by Guynn (2003) is that it assumes that monitoring relies on limited cognitive resources and the performance on the ongoing task will be impaired when the Retrieval Mode is active. However, our perceptual PM-task

Fig. 6. Brain sources that contribute to the prospective memory statistical effect observed at the scalp. (Top panel) Scalp ERPs, shaded areas indicate time windows used to calculate the contribution of IC clusters to the statistical difference. (Bottom panel) Colour-coded PVAF values and centroid of equivalent dipole locations whose projections explained the statistical difference shown at the scalp. Coloured arrows indicate contributions of IC clusters to the selected scalp channels. Note that different scalp locations represent a mixed contribution of the same neural generators. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

paradigm showed no behavioural signs of active monitoring. Thus we suggest that the Retrieval Mode may operate without incurring a behavioural cost, supporting the Preparatory Attentional and Memory Processes (PAM) theory (Smith and Bayen, 2004), which states that some degree of strategically allocated attention is always necessary to perform a PM task. The conceptual PM task did show behavioural evidence of PM-task monitoring, with slower responses for the unrelated items in the 'Ongoing+PM task' condition. The reaction time slowing may reflect the implementation of a specific PM monitoring strategy, different from the Retrieval Mode, probably corresponding to Target Checking (Guynn, 2003), to identify specific features that differentiated a PM cue from an ongoing task unrelated word. Note that conceptual PM-cues (animal words) were also unrelated words, whereas related words could never be a PM-cue. Responses for unrelated words were delayed by about 40 ms (from 752 to 791 ms). Accordingly, the EEG analysis revealed that Unrelated words during the 'On-going+PM task' condition, showed a long-lasting positivity significantly different from the unrelated words during the 'Ongoing-only task' condition around the 700 ms in the parietal scalp channel (Fig. 3), with its source in the right parietal and left temporal IC clusters (Fig. 4). It is probable that this late effect corresponds to a neural correlate of strategic monitoring (Target checking) associated only with the conceptual PM-task, further research will be needed to support this result for example, by examining different types of conceptual PM tasks.

The implementation of strategic monitoring or other cognitive resources required to perform a PM task can vary depending on specific features of the ongoing and PM tasks implemented. In our study, the conceptual PM task (detecting animal words) is similar to the main focus of the ongoing task (checking semantic categories), whereas the perceptual PM task (detecting capitalised letters) is not the main focus of the ongoing task. Thus our conceptual and perceptual PM tasks can be classified as *focal* and *non-focal* tasks respectively (Hicks et al., 2005; Marsh et al., 2003). It has been found that focal PM tasks are easier to perform than non-focal tasks (Einstein et al., 2005; Hicks et al., 2005). Accordingly, Cousens et al. (2015) obtained greater accuracy for conceptual PM tasks (focal) compared to perceptual tasks (non-focal) embedded in a conceptual ongoing task. Although their experimental paradigm was similar to the one used in our study, our results show the opposite. We found that the perceptual (non-focal) PM task was better performed than the conceptual (focal) PM task. It may have been that the similarity between the conceptual PM and ongoing tasks made it more difficult to inhibit the ongoing task response than for the perceptual PM task (our ongoing task was a 1-back categorisation task that required continuous attentional engagement, whereas Cousens et al.'s ongoing task was discrete). This shows the complex nature of PM tasks, and supports the idea that the cognitive demand required to successfully respond to PM tasks is a multifactorial process (Marsh et al., 2003; Scullin et al., 2013).

4.2. ERP markers of cue detection in PM tasks

As hypothesised, ERP markers for cue detection were specific to

the type of PM cue. Mechanisms associated with perceptual PM cues were implemented at a relatively early stage of stimulus processing (N300) and were associated with occipital and parietal brain sources. The right-occipital cluster, with centroid in or near the caudal portion of the fusiform gyrus (Table 2), explained most of the N300 effect (44% PVAF). The centro-parietal cluster (28% PVAF) also contributed to the significant difference (Fig. 6) - this cluster has its centroid in or near the superior parietal cortex (Table 2), part of the dorsal attentional network (Corbetta and Shulman, 2002). The superior parietal cortex is associated with top-down attentional modulations and it is probably responsible for modulation observed over sensory areas (Shomstein, 2012), represented by the right-occipital cluster in our study. In contrast, conceptual cue detection was associated with an N400-like waveform with a source in the ACC. The detection of the conceptual cue occurred later in the temporal processing of the events (see Table 1) and was not associated with early perceptual features of the word, but with later stages of processing involving extraction of word meaning. These results are consistent with previous findings (West, 2011; Wilson et al., 2013). Cousens et al. (2015), in their comparison between perceptual and conceptual PM-tasks, also described the N300 for the perceptual PM-task cues, but they did not observe the N400 for detection of conceptual PM-task cues. This difference may be explained by the fact that Cousens et al. collapsed the ERPs of the two types of ongoing task response and compared the resulting ERP with the ERP of PM-cues. In contrast, we compared the PM cue with related and unrelated words of the ongoing task separately, the N400 for conceptual PM-cues was evident only when the PM-task events were compared against the related ongoing task events.

4.3. ERP markers of realisation of delayed intentions in PM tasks

In line with the PM literature, the Prospective Positivity was observed in both perceptual and conceptual PM-tasks. As originally hypothesised, the brain source analysis showed that different combination of brain clusters contributed to the Prospective Positivity depending on whether the PM task required the identification of a perceptual or conceptual PM-task cue. However, we also found a brain source (located in the ACC) common to perceptual and conceptual PM-tasks. The Prospective Positivity has been previously described as a general marker of PM associated with post-retrieval processes (Cousens et al., 2015; West, 2011). We concur with this idea and complement it by suggesting that the Prospective Positivity reflects general post-retrieval processes that arise from a mixture of components specific to the PM-task implemented, plus neurocognitive processes that transcend the particular PM-task.

The different neural generators found in each of the PM tasks can be attributed to particular aspects of the tasks. In the perceptual condition, the main contributing clusters that explained most of the Prospective Positivity effect observed after 400 ms in parietal and frontal regions, were the right-parietal cluster (whose location, BA40, is part of the temporo parietal junction, TPJ) and the centro-parietal cluster (superior parietal cortex). The TPJ may have a general post-perceptual function supporting contextual updating triggered by external stimuli (for a review see Geng and Vossel, 2013). This idea is concordant with the perceptual PM task, where the presence of an event relevant to the task (the upper case letter) would indicate the need to make a context-appropriate response (Downar et al., 2002; Geng and Mangun, 2011) different from the ongoing task responses. Additionally, the TPJ has also been indicated as one of the possible neural sources of the P300 (Geng and Vossel, 2013), a component that may be contributing to the perceptual positivity in perceptual PM tasks (Kok, 2001; West et al., 2006; West and Wymbs, 2004). In turn, the superior parietal cortex (also a neural generator of the Perceptual Positivity in our

study) is involved in enhancing processing of stimulus features (top-down attentional modulations) that are relevant for the performance of the task (Corbetta and Shulman, 2002). Thus, in our study the superior parietal cortex may be modulating activity in the TPJ to facilitate identification of perceptual PM task cues. As a result, the presence of a capitalised letter would capture attention, with the subsequent shift of task setting from the ongoing task to the PM task. The right middle frontal cluster (purple dipole, Fig. 6) also contributes to the Prospective Positivity, showing that the sustained positivity observed over the parietal and frontal sites also had a motor component (PM responses were given with the left hand). This motor IC cluster was not observed for the conceptual PM-task condition, which does not exclude its participation completely, but it does indicate that its contribution, if any, it is not as relevant as the other IC clusters found. In summary, the contribution from the parietal cluster to the prospective positivity may reflect detection of the perceptual PM cue (P3b component) and updating of the task setting, results in line with the finding described by West (2011).

On the other hand, the Prospective Positivity in the conceptual PM-task originated mainly in the frontal-midline IC cluster and it may signal the retrieval of the correct response or some sort of response conflict, given that the realisation of the delayed intention in the conceptual condition required inhibiting responses given for unrelated items of the ongoing task and switch task set towards a PM task response. The participation of the ACC (the main contributing cluster in this condition) is fundamental in these types of tasks which require a strong component of goal-directed behaviour (Cohen et al., 2000). The left frontal cluster (BA9), part of the dorsolateral prefrontal cortex, also contributed to the Prospective positivity in the conceptual condition, activity in this area has also been related to high order cognitive functions such as planning. Thus, we propose that the contribution of midline and left frontal clusters in the prospective positivity of the conceptual task reflect updating of the task setting based on goal-directed processed, unlike the perceptual condition where parietal clusters are more relevant and the updating of task set seems to be based on perceptual processes (maybe cue driven processes rather than goal-directed processes).

Finally, our results showed that the ACC is also present in the perceptual PM-task, to a lesser extent compared to the conceptual PM-task, but its involvement in both PM-tasks led us to think that it represents a component of the Prospective Positivity that transcend specific forms of PM-task. A great variety of tasks show involvement of the ACC, and these tasks usually require; response monitoring (Gehring and Knight, 2000; Sheth et al., 2012), working memory load (Onton et al., 2005) and executive control of attention (Carter et al., 1999; MacDonald et al., 2000). The participation of the ACC in this wide variety of cognitive functions has given it the reputation of a regulator of attention and behaviour in complex cognitive tasks, and this may be the reason why it is present in both PM tasks. We propose as an initial account that the involvement of the ACC may be associated to task set configuration, one of the neurocognitive processes that may be underlying the prospective positivity (West, 2011). The implementation of a new task set configuration is a neurocognitive component common to both PM paradigms, it occurs early in the perceptual PM task, given that the detection of the PM cue is based on perceptual processes. By contrast, in the conceptual PM task occurs later, after the categorisation of the word. More research would be needed to disentangle the role of the ACC in other types of PM-tasks, for example, using the dual-task (respond to the ongoing task first, followed by a PM task response) or switch approach (inhibit the response for the ongoing task and give a PM task response instead) described by Bisiacchi et al. (2009) or exploring other types of PM tasks such as time-based PM-tasks.

4.4. Limitations of the study

To study neural correlates of monitoring in PM we have used a traditional experimental design (Brewer et al., 2010; Cona et al., 2012; Czernochowski et al., 2012; Guynn, 2003, 2008; Knight et al., 2010; Marsh et al., 2003; Smith, 2003, 2010; Smith et al., 2007; West et al., 2006; West et al., 2007), assuming that the difference between 'Ongoing+PM task' and 'Ongoing-only task' conditions reflects neurocognitive processes associated with the addition of a PM component to the task. This may raise concerns regarding whether the results can be attributed to the PM task performance or to other non-specific factors. As PM tasks are defined as being embedded in an ongoing task, it is not possible to examine a PM task in the absence of an ongoing task. However, use of a within-subject factorial design, in which exactly the same ongoing task is performed under two conditions, is designed to ensure as much as possible that the only difference between the conditions is the requirement for prospective remembering.

We have argued that the results of the ERP and brain source analysis that are common to both types of PM-tasks represent mechanisms that transcend the specific type of PM task performed, whereas results that are shown by only one of the PM tasks represent mechanisms associated with the particular type of PM task used. However, one possible issue is whether the differences between the conceptual and perceptual tasks that we observed arose not from the conceptual/perceptual distinction, but from specific interactions of these tasks with the ongoing task. A specific interaction could result from the fact that both the ongoing task and the conceptual PM task (a focal task) require semantic processing of words. On the other hand, for the perceptual PM task the distinction between upper/lower case is not relevant for making a semantic decision in the ongoing task (non-focal task). According to the detailed brain source analysis we have implemented in our study, we propose that some results may be more associated with perceptual/conceptual distinction: as is the case of the N300 and the N400 associated with the detection of perceptual and conceptual PM cues respectively. Whereas other results may be related to specific interaction between the PM task and the ongoing task: as is the case of the different neurocognitive processes and brain sources contributing to the prospective positivity in perceptual and conceptual PM tasks. Nevertheless, the extent to which the results obtained here transcend specific interactions with the ongoing task could be addressed in future studies, for example, embedding the PM tasks in a perceptual ongoing task or comparing non-focal conceptual with non-focal perceptual PM tasks.

We acknowledge the lack of a counterbalanced condition in relation to hand used to give PM responses (participants always used the left hand to give a PM response), which may explain the involvement of a motor component in the Prospective Positivity of the perceptual PM-task. In this case, the motor component was not the only one and more importantly, not the main component of the prospective positivity (as the brain source analysis revealed), but future experimental designs should consider counterbalancing the stimulus-response mapping.

While using source-resolved analysis reduces some of the limitations of traditional ERP analysis, other limitations remain. Furthermore, some cautions in interpreting the results presented here must be considered taking into account that we applied new methods to the analysis of our data. Testing and visualising grand-mean ERPs, as we have done here, need not imply that all trials in the experiment, all-IC cluster activities, and all subjects' data show the same effects. More detailed trial-by-trial and subject-by-subject analysis may reveal more information about brain mechanisms underlying PM in this experiment. In addition, we have used an ICA source-decomposition approach applied to a high-density EEG recordings (128 channels) to identify brain sources that underlie differences observed at the scalp channel level. Decomposing a high number of channels typically produces a large number of ICs that contribute to a small extent to the data variance, and furthermore do not have scalp maps compatible with a compact source located in brain cortex. For this reason a high number of non-physiologically plausible ICs were excluded, restricting the data analysis to ICs that are compatible with a plausibly localised cortical source. Another issue is that in our study participants contributed between 18 and 64 ICs, which were then formed into twenty IC clusters. Some of the clusters had no contribution from some participants, while for other clusters some participants contributed more than one IC, representing a possible limitation to interpretation of our results. However, subject uniformity traditionally assumed in grand-average ERP research is not necessarily accurate – indeed some participants exhibit any given ERP effect more than others (though these differences are only rarely explored in the ERP literature). Here, the statistical analysis was performed on the scalp channels, as in traditional ERP studies, instead of at cluster levels (we only report scalp ERP and we do not show IC-cluster ERPs), thus we did not address the 'missing participant' problem in the statistical analysis. Finally, there is still a margin of error in the localisation of centroid IC clusters. To increase spatial resolution of the data better head models should be used for dipole fitting (Akalin Acar and Makeig, 2013), thus also the brain localisation results should be taken with caution.

5. Conclusion: commonalities and differences between perceptual and conceptual PM-tasks

In conclusion, our results showed that: (1) Top-down attentional mechanisms modulate processing of ongoing-task events in perceptual and conceptual PM tasks, even in the absence of behavioural signs of PM monitoring cost, and PM-task monitoring involves attentional modulation at different levels of stimulus processing (e.g., cue recognition for both types of PM-tasks and response monitoring for the unrelated words of the conceptual PM-task). (2) The brain regions most involved in PM-task performance may depend on the characteristics of the prospective memory cue. (3) Finally, ERP markers associated with PM cue detection (N300 and N400), rather than reflecting processes general to PM-task performance, reflect particular mechanisms implemented according the nature of the PM-task. ERP markers associated with realisation of delayed intentions (Prospective Positivity), even when looking similar at scalp level, represent a combination of components specific to the PM-task, plus neurocognitive processes that transcend the particular PM-task performed.

Acknowledgements

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