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The Effects of Focal and Nonfocal Cues on the Neural Correlates of Prospective Memory: Insights From ERPs

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The present study is the first designed to investigate behavioral and event-related potential (ERP) correlates of the processes involved in focal and nonfocal prospective memory (PM) tasks. Focal tasks are those in which the features of the PM cue are easily extracted from the ongoing activity, whereas the process is more indirect in nonfocal tasks. Strategic monitoring was associated with a slowing of reaction times in ongoing trials and with frontal and parietal ERP modulations. These effects were greater in the nonfocal task, whereas they were smaller, or even absent for some individuals, in the focal task. This indicates that strategic monitoring is engaged to a greater extent in nonfocal tasks, whereas it is less extensively recruited, or not recruited at all by some individuals, in focal tasks. Indeed, the recognition of the PM cue might also occur automatically in focal tasks, as suggested by the FN400 increase in focal PM trials. Nonfocal tasks are supported by more controlled resources not only in retrieval, but also in postretrieval monitoring and coordinating processes. This was reflected in the enhancement of the prospective positivity and frontal slow wave observed in nonfocal PM trials. We interpreted these results as supporting the multiprocess view of PM.

Keywords: cue focality, delayed intentions, ERPs, prospective memory, strategic monitoring

Introduction

Prospective memory (PM) is defined as the ability to remember to perform an intended action at a particular moment in the future (Brandimonte et al. 1996). In a classical event-based PM paradigm, individuals are engaged in an ongoing activity and simultaneously have to remember to accomplish a previously encoded intention when a particular event (i.e. the PM cue associated with that intention) occurs (Einstein and McDaniel 1990).

Since in PM paradigms there are no explicit prompts that instigate the retrieval of intention, a central concern is to understand how an intended action is retrieved appropriately. Several theories have been proposed, ranging from those in which the retrieval is relatively automatic (Moscovitch 1994; McDaniel and Einstein 2000; McDaniel et al. 2004) to those in which the retrieval is mediated entirely by strategic monitoring (Burgess and Shallice 1997; Guynn 2003; Smith 2003; Smith and Bayen 2004). Strategic monitoring consists of a set of controlled attentional and memory processes that serve to monitor the environment for the occurrence of the PM cue and to compare the incoming stimuli with the representation of the PM cue stored in memory (Smith and Bayen 2004). Several studies measured the cost of adding a PM task on ongoing performance—labeled as "PM interference effect"—to infer the degree to which strategic monitoring processes are recruited (e.g. Marsh et al. 2003; Smith 2003; Hicks et al. 2005). Indeed, when these processes are engaged, they utilize resources intended for the ongoing task leading to a decline in performance, as indicated by the slowing of reaction times (RTs) and/or decrease in accuracy.

A theory that has gained increasing support in the PM literature is the multiprocess view (MPV; McDaniel and Einstein 2000, 2007; Einstein et al. 2005). According to this theory, the retrieval of intention can be supported either by automatic or by strategic processes depending on a variety of factors associated with the characteristics of both the PM and ongoing tasks (McDaniel and Einstein 2007).

Focality of the PM task represents a critical factor influencing the type of process recruited for PM retrieval (Einstein et al. 2005; McDaniel and Einstein 2007). Focal and nonfocal PM tasks differ in the extent to which the ongoing task encourages the processing of the PM cue features (see Einstein and McDaniel 2005, for representative examples of focal and nonfocal tasks). In focal PM tasks, the features of the PM cue are easily extracted from the processing of the information relevant for the ongoing task, whereas that does not occur in nonfocal PM tasks.

According to the MPV, retrieval of intention occurs spontaneously in focal PM tasks, whereas it relies on strategic monitoring in nonfocal PM tasks (Einstein and McDaniel 2005). Einstein et al. (2005) tested this prediction by comparing the PM interference effect (indicative of strategic monitoring) when a focal or a nonfocal PM cue was embedded in the ongoing activity. In this study, the PM interference effect was significant only for the nonfocal task, but not for the focal one. Importantly, PM performance remained high for the focal task, even though participants did not engage in monitoring processes. This pattern of results suggested that automatic retrieval processes underlie focal PM tasks, without the necessity of recruiting the resources-demanding strategic monitoring processes.

The focality of the PM cue plays a prominent role in PM since it was found to be a crucial determinant of the levels of accuracy in PM performance in general (Einstein et al. 2005; Meeks and Marsh 2010; Scullin, McDaniel, Einstein 2010; Scullin, McDaniel, Shelton, et al. 2010) and of the effects of aging or pathology in particular (McDaniel and Einstein 2007; Rendell et al. 2007; Kliegel et al. 2008; McDaniel et al. 2011; Uttl 2011).

Although there is currently an increasing interest in the study of the neural bases of PM (e.g. Reynolds et al. 2009; Bisiacchi et al. 2011; Burgess et al. 2011; Costa et al. 2011 for a review), little is known, however, about the neural correlates underlying cue focality. To our knowledge, only one study addressed this issue. Exploring the association between performance on focal and nonfocal PM tasks and gray matter volume, Gordon et al. (2011) observed a positive relationship between performance on the focal PM task and the volume of medial temporal regions, particularly of the hippocampus region, which is thought to support automatic retrieval (Moscovitch 1994; Konkel and Cohen 2009). In contrast, no significant structure–behavior relationships were found for the nonfocal PM task.

The current study, therefore, adopted the event-related potential (ERP) technique to investigate the effect of focal and nonfocal PM cues on the neural correlates of processes involved in prospective remembering. Moreover, the excellent temporal resolution of the ERPs allowed us to better clarify which processes are differentially recruited in focal and nonfocal PM tasks. Before presenting our study, we briefly review the literature on ERP correlates of PM.

Two main classes of ERPs are typically examined to investigate the neural correlates of PM: ERPs elicited by ongoing trials in PM sessions, and ERPs elicited by PM trials (i.e. trials in which the PM cue occurs).

The ERPs elicited by ongoing trials provide information on the electrophysiological correlates of strategic monitoring. These are usually explored by comparing the ERPs elicited by an ongoing task (e.g. a lexical decision task, or a categorization task) in PM sessions versus sessions without PM instructions (Chen et al. 2007; Knight et al. 2010; Czernochowski et al. 2012; Cona et al. 2012a). Strategic monitoring was shown to be associated with modulations of the ERPs that were expressed mainly over the frontal and parietal regions of the scalp (West et al. 2011; Czernochowski et al. 2012; Cona et al. 2012a, 2012b). More specifically, an early modulation was found at 130–140 ms after stimulus onset, after which a sustained modulation was found starting roughly at 200–300 ms and lasting for several hundred milliseconds (e.g. Knight et al. 2010; Czernochowski et al. 2012; Cona et al. 2012a, 2012b).

The second class encompasses the ERPs elicited in PM trials, which yield additional information on the specific phases of prospective remembering that lead individuals to accomplish an intention when they encounter the PM cue (see West 2011, for a review). The N300 is a negative deflection, greater for PM trials relative to ongoing trials, expressed between 300 and 500 ms after stimulus onset over the occipital–parietal sites of the scalp (West et al. 2001; West 2007), and related to the detection of the PM cue in the environment (e.g. West and Ross-Munroe 2002; West and Krompinger 2005; West 2007; see Cabeza et al. 2009; Ciaramelli et al. 2008, on the role of parietal cortex in memory search and detection).

The frontal positivity (or FN400) represents a positive deflection occurring between 300 and 500 ms after stimulus onset. It is greater for PM cues than for ongoing trials and is expressed over the midfrontal regions of the scalp (West 2007; 2011). The FN400 is considered to reflect the retrieval processes underlying stimulus recognition (Jenning and Jacoby 1993; Curran 1999; 2000) and has been associated with the retrospective components of PM supporting the recognition of PM cues (e.g. West and Krompinger 2005; West et al. 2006). The FN400 also has been linked to the process of switching between the ongoing and PM tasks (Bisiacchi et al. 2009).

The parietal positivity is a component that occurs over the parietal regions of the scalp roughly at 400 ms after the onset of the PM cue (West et al. 2001). This sustained positivity is the result of 3 distinct and separate components: The classical P3b, the recognition parietal old–new effect, and the prospective positivity (West and Wymbs 2004; West 2011). The recognition old–new effect appears between 400 and 800 ms poststimulus and reflects the retrieval of the intention from memory (West and Krompinger 2005). The prospective positivity emerged later, roughly at 600–700 ms, and is associated with postretrieval monitoring processes (West and Krompinger 2005; West 2007) and with coordination between PM and ongoing responses (Bisiacchi et al. 2009). Coupled with the parietal positivity, the frontal slow wave begins around 500 ms after stimulus onset (West et al. 2001, 2003). The frontal slow wave was shown to be sensitive to the number of intentions that are held in mind (West et al. 2003). Therefore, it is considered to reflect retrieval monitoring processes to evaluate the intentions recovered from memory when a PM cue is detected (Rösler et al. 1993; West et al. 2003).

The current study is the first designed to examine the influence of PM cue focality on the ERP correlates associated with processes supporting PM. We utilized a lexical decision task as the ongoing activity (see Fig. 1 for an illustration of the procedure). In the focal PM task, participants were required to respond when a particular word was encountered (e.g. "candle"), whereas in the nonfocal task, they responded when a word appeared that belonged to a previously presented category [e.g. "daisy" for the flower category; It is important to underline that "focal" and "nonfocal" are only labels to clarify that the ongoing task may encourage the processing of PM cue features with a greater or a lesser extent. Indeed, it should be better to conceptualize the dimension of PM cue focality not as a dichotomy, but rather along a continuum (see also Knight et al. 2011), thus distinguishing between more focal or less focal PM tasks.]. Indeed, carrying out intentions in response to categorical cues is considered representative of nonfocal PM tasks, and this procedure has been adopted in several studies (Marsh et al. 2003; Einstein et al. 2005; Meeks and Marsh 2010; Loft and Humphreys 2012).

Basing ourselves on the MPV (Einstein et al. 2005), we expected that PM cue focality would influence the ERP modulations associated with strategic monitoring, leading to more pronounced ERP modulations in nonfocal than in focal task.

We also explored the ERPs elicited in PM trials. This allowed us to highlight that processes are differentially engaged when a focal, or a nonfocal PM, cue is encountered. Indeed, although the MPV predicts that different processes are recruited to support PM depending on cue focality (McDaniel and Einstein 2000, 2007; Einstein et al. 2005), the nature of such processes is still poorly characterized. If focal and nonfocal PM tasks differ on the basis of perceptual and attentional processes for the detection of the PM cue, being more automatic in focal tasks (e.g. "pop out" detection) and more controlled in nonfocal tasks, then we should expect differences particularly in the ERP components related to cue detection, hence in the N300 (e.g. West et al. 2003; West and Krompinger 2005; West 2007). On the other hand, if differences reside in the memory processes that support the recognition of the PM cue (automatic retrieval vs. memory search, McDaniel et al. 1998; Breneiser and McDaniel 2006) and/or the retrieval of the intention (e.g. the automatic associative view, Moscovitch 1994; Einstein and McDaniel 1996), we should expect an effect of PM cue focality on the FN400 and/or parietal old–new effect, which are associated with the retrospective components of PM (West and Krompinger 2005). Finally, if differences occur in the later

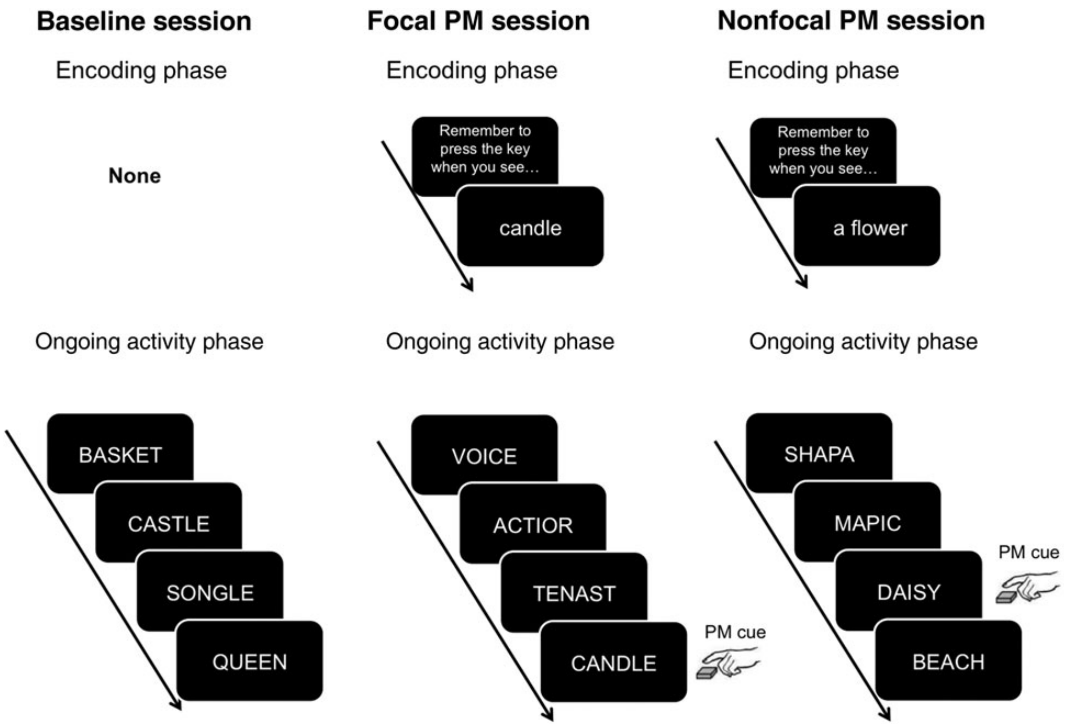

Figure 1. Illustration of a trial sequence for each type of session: Baseline, focal, and nonfocal PM sessions. In the PM sessions, each block was composed of an encoding phase and an ongoing activity phase. Periods of the blank screen (lasting 1600, 1800, or 2000 ms) were interspersed among the trials.

stages of PM, such as in the retrieval monitoring processes and task coordination, then several focality-related modulations should be observed in the prospective positivity and in the frontal slow wave (West et al. 2003; Bisiacchi et al. 2009; West 2011).

To better dissociate the effects of PM cue focality on the specific ERP components of PM, we used partial least squares (PLS) analysis (Lobaugh et al. 2001), which is a multivariate statistical technique able to identify differences in ERPs across experimental conditions.

Materials and Methods

Participants

Twenty-four individuals, recruited from the University of Toronto, between 19 and 30 years (M = 22.83; 19 females) took part in the study for financial compensation at the rate of $10/h. All participants were native English speakers and right-handed. They had normal, or corrected-to-normal, vision and no neurological pathologies. Informed consent was obtained from all participants in accordance with the guidelines of the Social Sciences and Humanities Research Ethics Board at the University of Toronto.

Materials

A total of 1260 stimuli, 693 of which were words and the others were pronounceable nonwords, were used in the present study. Word stimuli were selected from the CELEX database (Baayen et al. 1995) and could range from 4 to 9 letters in length. Nonword stimuli were created from the used words by changing one letter.

Sixty-six of the selected words were used as PM cues in focal (30 words) and nonfocal PM sessions (36 words). Moreover, in the nonfocal PM session, stimuli for PM cues had to be among the first 10 exemplars of 30 categories in the updated version of the Battig and Montague (1969) norms (Van Overschelde et al. 2004).

The psycholinguistic variables of words (mean frequency and mean length) were matched across the different experimental sessions (focal, nonfocal, and baseline sessions) and stimulus types (ongoing words vs. PM cues).

All stimuli were presented in white in the center of a black screen.

Procedure

The ongoing task was a lexical decision task. Half the participants had to respond, by pressing the "N" key with the right index finger if the string of letters was a word, and the "M" key with the right middle finger if the string of letters was a nonword. The opposite mapping was assigned to the other half of participants. All participants were asked to respond as quickly and as accurately as possible.

In the focal PM task, participants pressed the "C" key with the left index finger whenever a particular target word occurred (e.g. "candle"). In the nonfocal PM task, they pressed the "C" key whenever a word belonging to a given target category occurs, such as "daisy" for the target category "flower" (Fig. 1). For both PM sessions, participants were asked to quickly press the "C" key, immediately after making the decision for the ongoing task. RTs and accuracy were collected for both the ongoing and PM tasks.

The experiment was comprised of 3 sessions. In the "baseline" session, composed of 3 blocks of 20 trials each, participants were asked merely to perform the lexical decision task. In the PM sessions, focal and nonfocal PM tasks were embedded in the ongoing task. The order of the 3 sessions was counterbalanced across participants. Each of the PM sessions was divided in 30 blocks of 19 ongoing trials and 1 PM trial each. In 6 of the 30 blocks, the PM cue occurred twice, in order to prevent participants from no longer monitoring after the first occurrence of the PM cue. PM cues changed across the blocks of the PM session. Each block was preceded by an encoding phase, during which a PM word (in focal session) or a PM category (in nonfocal session) was presented on the center of the screen for 3000 ms. PM word stimuli during the encoding phase were presented in lowercase, whereas stimuli in the ongoing activity phase were shown in uppercase. The experimental design (i.e. the subdivision in blocks and the separation between an encoding and ongoing activity phases) was based on paradigms developed by West"'s studies (e.g. West and Krompinger 2005; West et al. 2007). At the end of each block, participants received feedback about their accuracy and response speed on the ongoing task. No feedback was given for the PM task.

On each trial, the stimulus remained on the screen until the response, followed by a blank that pseudorandomly lasted 1600, 1800, or 2000 ms.

Before the experimental sessions, participants practiced the lexical decision task for 12 trials and received feedback about speed and accuracy of their performance after each trial.

Both the behavioral and the ERP analyses focused on the word trials. As pointed out by several researchers within the PM field (e.g. Marsh et al. 2003; Smith 2010), nonword responses may be the result of extralexical processes (e.g. Grainger and Jacobs 1996), such as speed–accuracy trade offs, task demands, metacognitive variables, and other potential factors that were not controlled in this study. Moreover, metacognitive confounding effects on nonwords might be particularly likely in the present experiment given that the PM cue was never represented by a nonword.

Behavioral Analysis

To evaluate the effect of PM cue focality on the PM interference effect (i.e. the decline in ongoing performance due to the addition of the PM task), RTs and accuracy to ongoing words were analyzed by 2 separate ANOVAs, one for each condition, with Session (baseline vs. focal vs. nonfocal) as a within-subjects factor.

Furthermore, to investigate the effect of PM cue focality on the cue interference effect (i.e. the effect of encountering a PM cue on ongoing performance), RTs and accuracy in ongoing and PM words were analyzed by two 2×2 ANOVAs, with the Stimulus type (ongoing vs. PM) and Session (focal vs. nonfocal) as within-subjects factors. When the PM cue was presented twice within the same block, only the RTs and accuracy to the first occurrence were included in the analysis.

Post hoc analyses were performed by means of Newman–Keuls tests. The performance on PM task was analyzed in terms of both RTs (measured as latency from response to the lexical decision task) and accuracy, and compared the focal with the nonfocal session using paired *t*-tests. The effect size was quantified by means of η^2.

Electrophysiological Recording and Analysis

The electroencephalogram (EEG) was recorded by the advanced source analysis - advanced neuro technology system (Enschede, the Netherlands) from an array of 38 Ag/AgCl electrodes (Fp1, Fpz, Fp2, F7, F3, Fz, F4, F8, Fc5, Fc1, Fc2, Fc6, M1, T7, C3, Cz, C4, T8, M2, Cp5, Cp1, Cp2, Cp6, P7, P3, Pz, P4, P8, P0z, O1, Oz, O2, AF3, Af4, Po3, Po4, Po7, and Po8) mounted on an electrode cap (WaveGuard EEG Cap—ANT). Two pairs of bipolar electrodes were used to record vertical and horizontal eye movements. The EEG analog signal was amplified and digitized at a 512-Hz sample rate. Electrode impedances were maintained <10 kΩ during recording. The ground electrode was placed along the midline in front of Fz. The EEG was recorded in average reference. Data processing was performed with EEGLAB 9 (Delorme and Makeig 2004), running under Matlab environment (Version 7.4.0, MathWorks, Natick, MA, USA). The EEG data were band-passed filtered between 0.1 and 30 Hz and downsampled to 256 Hz. Epochs were locked on the presentation of the stimuli (i.e. the strings of letters). ERP analysis epochs included 200 ms of prestimulus baseline and 1500 ms of poststimulus activity as well as were corrected to the prestimulus baseline. Artifact correction was made by using the independent component analysis (ICA) toolbox in EEGLAB. The epoch rejection was performed with a cut-off of ±75 µV. After artifact rejection, the percentage of removed epochs was always <2.54% for each participant. Only epochs with correct responses on both the ongoing and PM tasks were analyzed.

ERPs were averaged for trials associated with ongoing words in baseline (M = 32; range: 29–34), focal (M = 272; 213–294), and nonfocal (M = 269; 244–287) sessions, as well as with focal PM (M = 33; 26–36) and nonfocal PM (M = 32; 27–36) words.

Partial Least Squares Analysis

PLS analysis is a multivariate data analysis technique that allows one to describe spatiotemporal relationships between neural activity and one cluster of independent variables, based on the groups and/or conditions of the experimental design (Lobaugh et al. 2001). Its primary advantage over other multivariate techniques used for EEG analysis, such as principal component analysis (PCA), or ICA, is that it enables one to identify simultaneously where the strongest experimental effects are expressed over the scalp and when they occur. PLS is the elective tool for our aims because it is able to identify the ERP effects specifically related to the experimental manipulations and to dissociate them from other possible confounding factors (e.g. semantic vs. lexical processing).

The term "partial least squares" refers to the computation of the optimal least squares fit to part of the correlation or covariance matrix of data (Lobaugh et al. 2001). In this experiment, the part is the "cross-block" correlation between the exogenous variables, namely the experimental conditions, and the dependent measures, which are the ERP amplitudes.

The ERP input data matrices for the PLS analyses contained subjects and conditions in the rows, and ERP amplitudes for all time points and channels, except for the 2 ocular electrodes, in the columns. Analysis was restricted to poststimulus interval, from 0 to 1500 ms. As a first step, the input data matrices were transformed by mean centering the columns of the ERP data matrix with respect to the grand mean. The averages of each condition were therefore expressed as deviations around zero. The matrix underwent singular value decomposition (SVD) to yield a set of latent variables (LVs). Each LV describes how strongly a certain pattern of experimental conditions (design scores) is expressed by each electrode at each time point (electrode saliences).

Specifically, 3 outputs were obtained from the SVD that allow one to understand and interpret the relationships between ERP amplitude and experimental conditions. The first was a vector of singular values, which represents the unweighted magnitude of each LV and is derived from calculating the proportion of the cross-block covariance matrix (i.e. the percentage of task-related variance) attributable to each LV. The second and third outputs contained the structure of the LVs and are orthogonal pairs of vectors (saliences) that are used to identify the temporal and spatial patterns of the LVs.

The significance of the LVs singular values was calculated using a permutation tests (1000 replications). Permutations consist in sampling without replacement to reassign the order of conditions for each subject. PLS is recalculated for each new permuted sample, and the number of times the permuted singular values exceeded the observed singular value in each LV is calculated as a probability. An LV was considered significant at $P < 0.05$. To prevent the effects of possible outliers, the stability of the ERP saliences in space and time was established through bootstrap resampling (200 replications) that provides a standard error. Bootstrap ratios >2.5 were chosen as the cut-off for stable nonzero saliences. The principal purpose of the bootstrap procedure is to identify those portions of the ERPs that reflect robust experimental effects across subjects. Matlab code to perform the PLS analyses can be downloaded from http://www.rotman-baycrest.on.ca/pls.

Two separate PLS analyses were conduced including data from all participants together. The first analysis considered the ERPs elicited by ongoing words and included 3 task conditions (baseline, focal, and nonfocal sessions). The second PLS analysis included ERPs belonging to 4 task conditions, obtained by crossing 2 Stimulus types, ongoing words versus PM words, × 2 Focality (focal vs. nonfocal cues) levels.

These 2 PLS analyses then were reconduced to distinguish between high-monitoring and low-monitoring participants. Participants were split into high- and low-monitoring groups based on a median split of the PM interference effect in the focal session, which resulted from the difference in the RTs on ongoing trials between the focal and baseline sessions.

Results and Comments

Behavioral Results

Performance on the Ongoing Task: the PM Interference Effect

In the ongoing task, RTs on ongoing words were influenced by the type of session, being fastest in the baseline, intermediate in the focal session, and slowest in the nonfocal session (Fig. 2*a*).

These observations were confirmed by the analysis of variance (ANOVA), which revealed the significant effect of Session ($F_{2,46} = 23.74$, $P < 0.01$, $\eta^2 = 0.50$). As can be seen in Figure 2*a*, RTs were slower in the nonfocal session (mean ± standard error: 661 ± 22 ms) than in both the focal (624 ± 18 ms) and baseline sessions (567 ± 13 ms), all $P < 0.01$. The RTs in the focal session were significantly slower when compared with those in the baseline session, $P < 0.01$.

Concerning the percentage of accuracy on the ongoing task, an ANOVA showed that the effect of Session approached significance ($F_{2,46} = 3.19$, $P = 0.050$, $\eta^2 = 0.12$). Post hoc analysis revealed that individuals were less accurate in the nonfocal session (94 ± 0.6%) when compared with the baseline session (96 ± 0.9%), $P < 0.05$. The percentage of accuracy did not differ significantly between the focal (95 ± 0.7%) and baseline sessions ($P > 0.05$).

Taken together, this pattern of results indicates that the PM interference effect was modulated by the focality of the PM cue and suggests that strategic monitoring is involved mainly for the detection of nonfocal relative to focal PM cues.

Performance on the Ongoing Task: the PM Cue Effect

To investigate the differential effect of focal and nonfocal PM cues occurrence on performance in the ongoing task, we compared trials containing the PM cue (i.e. PM trials) with word trials not containing the PM cue (i.e. ongoing trials), between the 2 PM sessions.

RTs were slower in the nonfocal with respect to the focal session, for both kinds of trials. Interestingly, RTs seemed to be faster for PM trials than for ongoing trials in the focal session, but not in the nonfocal session, where they resulted in equivalent RTs for the 2 types of trials (Fig. 2*b*).

The significance of the described pattern of data was confirmed by the 2 (Stimulus type: ongoing or PM) × 2 (Session: focal or nonfocal) ANOVA on RTs. Specifically, the analysis of RTs evidenced a significant effect of Session ($F_{1,23} = 14.87$, $P < 0.01$, $\eta^2 = 0.39$), with RTs being slower on nonfocal (665 ± 21 ms) than on focal trials (616 ± 16 ms). The Stimulus type × Session interaction was significant ($F_{1,23} = 5.53$, $P < 0.05$, $\eta^2 = 0.19$). Post hoc analysis indicated that RTs on focal PM trials (608 ± 16 ms) were significantly faster compared with that on focal ongoing trials (624 ± 18 ms; $P < 0.05$), whereas this difference was not significant in the nonfocal session (nonfocal PM trials: 668 ± 16 ms and nonfocal ongoing trials: 661 ± 22 ms, $P > 0.05$; Fig. 2*b*). The facilitation of RTs in focal PM trials might reflect the "intention superiority effect," which indicates the automatic activation of the representations of the focal PM cue and the associated intentions stored in memory (Goschke and Kuhl 1993; Marsh et al. 1998, 1999; Freeman and Ellis 2003). Interestingly, the intention superiority effect is absent when the PM cue is nonfocal, suggesting that other processes, presumably more controlled ones, act in this kind of trials. This pattern of results is also open to alternative accounts, as described in more detail in Discussion. The effect of Stimulus type was not significant ($F_{1,23} = 0.26$, $P > 0.05$, $\eta^2 = 0.01$).

As in the RT analysis, the percentage of accuracy in the ongoing task was examined by comparing PM and ongoing words in the 2 PM sessions. In general, accuracy in the ongoing task was higher in focal than in nonfocal sessions, and for PM than for ongoing trials. ANOVA confirmed this pattern. There were significant effects of Session ($F_{1,23} = 13.09$, $P < 0.01$, $\eta^2 = 0.36$), with percentage of accuracy being higher in the focal (97 ± 0.4%) than in the nonfocal (95 ± 0.5%) session, and of Stimulus type ($F_{1,23} = 15.75$, $P < 0.01$, $\eta^2 = 0.40$) indicating fewer errors on PM (97 ± 0.4%) than on ongoing trials (95 ± 0.6%) for both the focal and nonfocal sessions. The Stimulus type × Session interaction was not significant ($F_{1,23} = 0.39$, $P > 0.05$, $\eta^2 = 0.01$).

Performance on the PM Task

To examine the effect of PM cue focality on PM performance, RTs and the percentage of accuracy on the PM task were analyzed by comparing the 2 PM sessions (focal vs. nonfocal) by means of *t*-test analyses. Individuals were significantly slower in the nonfocal PM (314 ± 16 ms) than in the focal PM task (243 ± 13 ms) ($t_{(23)} = 6.62$, $P < 0.01$, $\eta^2 = 0.65$), but accuracy did

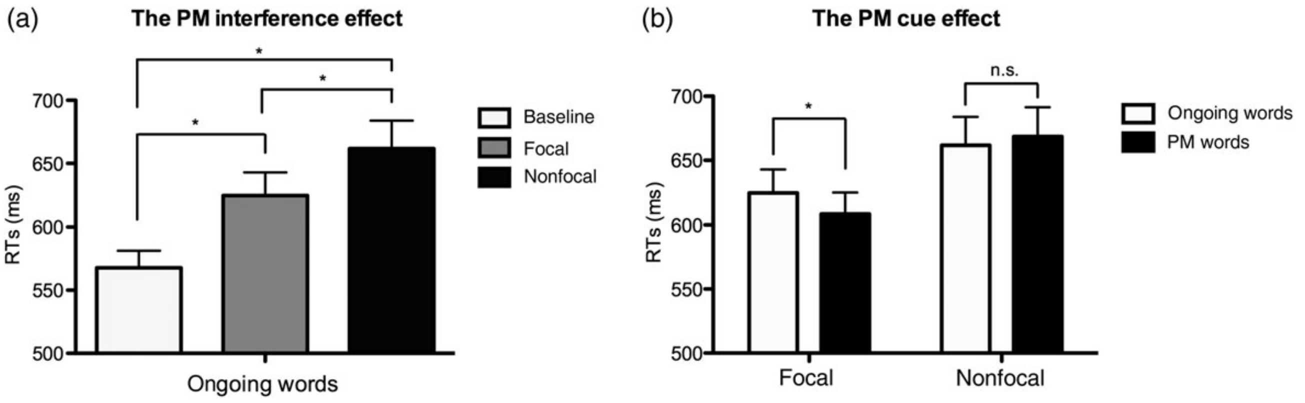

Figure 2. The effects of PM-related processes on ongoing performance. (*a*) The graph displays RTs to the ongoing words in the baseline, focal, and nonfocal sessions. (*b*) The graph displays RTs to the ongoing task for PM and ongoing words, in both the focal and nonfocal sessions. Asterisks indicate the presence of statistical significance ($P < 0.05$). The vertical bars indicate standard errors of the mean.

not differ significantly between the 2 PM tasks (nonfocal PM task: 91 ± 0.1% and focal PM task: 92 ± 0.1%). The slowing down of RTs in the nonfocal than in the focal task might be due to the requirement of more controlled processes when the PM cue is nonfocal. The equivalent percentage of accuracy confirms that the focal and nonfocal PM tasks adopted in this study were not different in terms of cue identification difficulty.

Electrophysiological Results

ERPs in the Ongoing Trials: an Index of Strategic Monitoring

We aimed to investigate the extent to which strategic monitoring was engaged in focal and nonfocal PM tasks, and in the corresponding ERP correlates. This was made possible by comparing, through a PLS analysis, the ERPs elicited by the ongoing trials in the 3 different experimental sessions: Baseline, focal, and nonfocal sessions.

The grand-averaged ERPs at select electrodes for word trials in baseline, focal, and nonfocal sessions are illustrated in Figure 3. Compared with the ERPs elicited by the ongoing words in the baseline session, the ERPs elicited by the ongoing words in the PM sessions were characterized by an increased positivity over parietal and centro-parietal regions and by an increased negativity over prefrontal and lateral frontal regions, both occurring in the time window between 200 and 400 ms. Afterwards, more sustained modulations of the ERPs in PM sessions were shown, starting from roughly 550 ms and lasting for several hundred milliseconds. As the previous ones, these modulations consisted of an increased negativity over prefrontal and lateral frontal regions, and a sustained enhanced positivity over centro-parietal, parietal, and occipital–parietal regions. All the modulations described above were expressed more in the nonfocal session relative to the focal session. Such considerations, driven by visual inspection, were also confirmed by the PLS analysis.

The PLS analysis revealed one significant LV ($P < 0.002$) that accounted for 82.08% of the cross-block covariance (Fig. 4). This LV reflected a contrast mainly between the baseline and

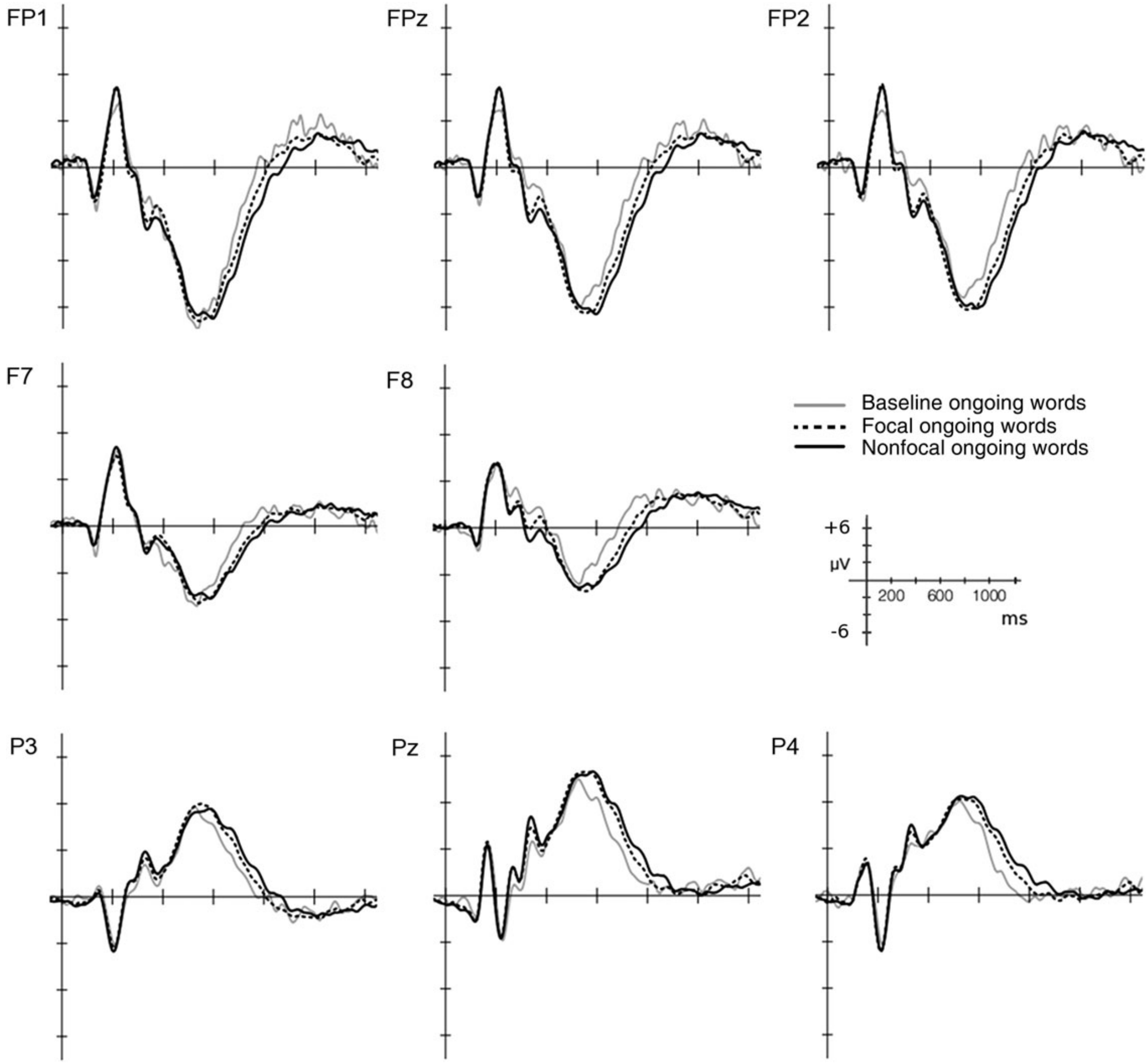

Figure 3. Grand-averaged ERPs elicited by ongoing words in the baseline session (gray line), the focal session (black dotted line), and the nonfocal session (black dashed line), at select electrodes.

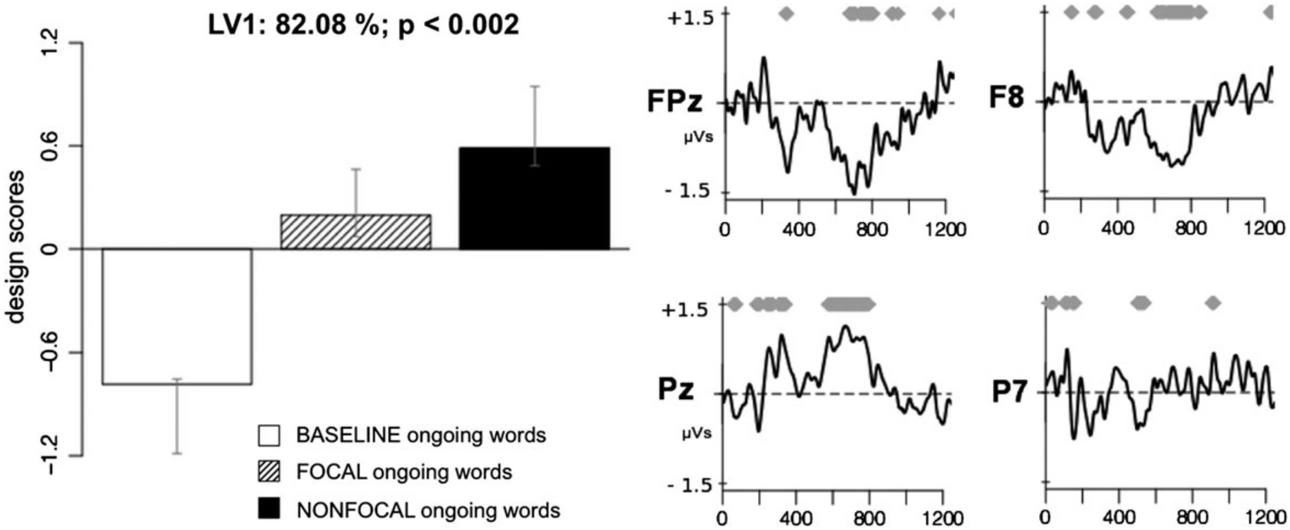

Figure 4. Design scores and electrode saliences for select electrodes (Fpz, F8, Pz, and P7) from the PLS analysis comparing the ERPs elicited by ongoing words in the baseline, focal, and nonfocal sessions. LV1 reveals a contrast that primarily distinguished between the baseline and nonfocal sessions and, only to a lesser extent, between the baseline and focal sessions. The dots above the salience waveforms indicate stable saliences.

nonfocal sessions and, only to a lesser extent, between the baseline and focal sessions. Indeed, the design scores for the focal session were substantially smaller compared with those for the other 2 sessions, indicating that the effect of focal session was weakly expressed in the ERP modulations captured by this LV. The electrode saliences associated with the LV revealed 3 main modulations (Fig. 4). The first was a phasic early modulation at 100 ms poststimulus over lateral parietal, parietal–occipital, and occipital sites. It reflected a faster and enhanced P1 in PM sessions relative to the baseline session. The second was a modulation that occurred in the time window between 160 and 370 ms, representing an increased positivity of the ERP components expressed over centro-parietal and parietal regions, and an enhanced negativity of the ERPs over prefrontal and lateral frontal regions (Fig. 3). The third modulation was represented by a sustained increased positivity over posterior sites (centro-parietal, parietal, and occipital–parietal sites) beginning at around 550 and lasting until 800 ms. Coupled with such positivity, an enhanced long-lasting negativity was observed over prefrontal and lateral frontal sites. As portrayed by the figures (Fig. 3), and confirmed by the differences in the design scores between the focal and nonfocal conditions (Fig. 4), the above-described modulations were more pronounced in the nonfocal session when compared with the focal session.

These results suggest that strategic monitoring was involved to accomplish both focal and nonfocal PM tasks, leading to several modulations of the ERPs in both the PM sessions. However, the degree of strategic monitoring required was modulated by the focality of the PM task and was noticeably higher for the nonfocal PM task, as revealed by the greater amplitude of the ERP modulations observed in this type of task.

ERPs Elicited by the PM Cues: Comparing Focal with Nonfocal Cues

A PLS analysis was conducted to investigate the effect of PM cue focality on the ERP correlates of the specific processes that compose prospective remembering. In this way, it was possible to clarify which processes are differentially recruited to accomplish the focal and nonfocal PM tasks.

When compared with the ERPs in ongoing words, the grand-averaged ERPs elicited by PM words were characterized by the typical modulations related to PM (Fig. 5), such as the N300 and parietal positivity components (West and Krompinger 2005; West et al. 2007; West 2011, for a review). More importantly, several differences in the ERPs were shown between focal and nonfocal PM trials (Figs 5 and 6). Specifically, the FN400 was higher in focal than in nonfocal PM trials (Fig. 6). On the other hand, when compared with focal PM trials, nonfocal PM trials showed an increased late sustained positivity over central and centro-parietal regions coupled with an increased late sustained negativity over lateral frontal regions. Such modulations began around 800 ms and lasted for several hundred milliseconds (Fig. 6). Finally, a long-lasting negativity over temporal regions distinguished PM trials from the ongoing trials and was more pronounced in nonfocal than in focal PM trials. A summary of the effects of cue focality on the ERP components elicited in PM tasks with the corresponding cognitive meaning is displayed in Table 1.

To test these observations, the PLS analysis included the ERPs elicited by both the PM and ongoing words of both the focal and nonfocal PM sessions. The permutation test revealed 2 significant LVs ($P < 0.0001$ and <0.039) that accounted for 80.94% and 15.38% of the cross-block covariance, respectively (Fig. 7). The first LV distinguished PM words from ongoing words, in both the 2 PM sessions (Fig. 7*a*). It reflected the ERP modulations specifically associated with prospective remembering, regardless of PM cue focality. The electrode saliences associated with this LV reflected the classical ERP components of PM, commonly evidenced in previous ERP studies: The N300 over parietal–occipital sites, the FN400 over frontal and fronto-central sites, the recognition old–new effect (time window: from 300 to 500 ms) over central and centro-parietal sites, and the prospective positivity component occurring from 600 to 1000–1200 ms poststimulus over centro-parietal, parietal, and parietal–occipital regions (Fig. 7*a*; e.g. West et al.

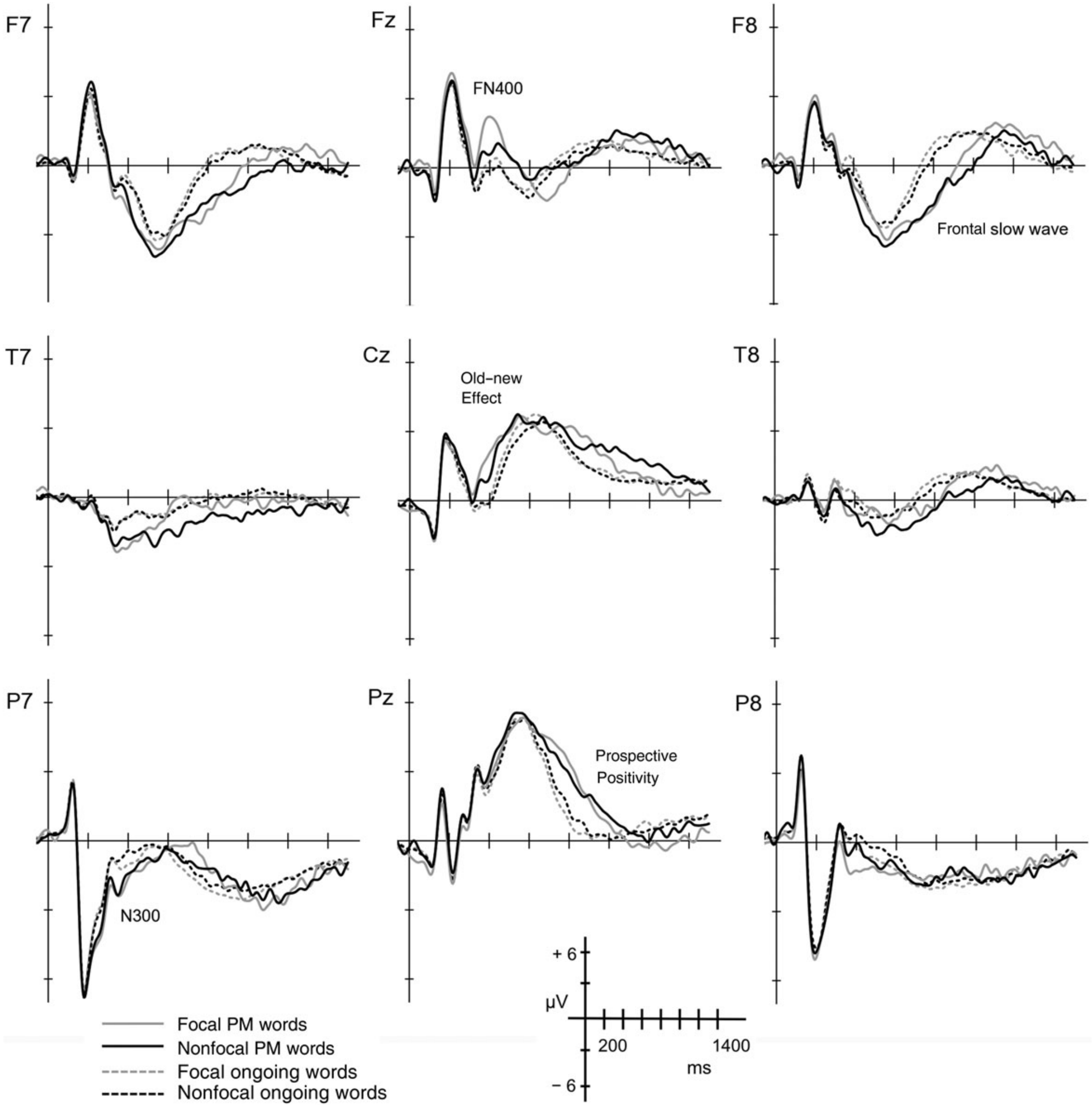

Figure 5. Grand-averaged ERPs elicited by ongoing words in the focal (gray dotted line) and nonfocal sessions (black dotted line), and by PM words in the focal (gray dashed line) and nonfocal sessions (black dashed line). The plots show the classical ERP components of PM.

2001; West and Krompinger 2005; West 2011). Moreover, coupled with the prospective positivity, an increased prefrontal and lateral frontal negativity (i.e. frontal slow wave, West et al. 2001, 2003) was shown roughly in the same time window. Finally, the electrode salience reflected an enhanced long-lasting negativity for PM trials with respect to the ongoing trials, starting at 300 ms and expressed over temporal sites. As can be seen in Figure 6, the ERP waveforms over temporal sites were similar among the different types of trial until 250 ms, but differentiated PM trials from ongoing trials after this time point.

The second LV specifically distinguished focal PM from nonfocal PM trials (Fig. 7*b*). The electrode saliences captured a modulation of a frontal positivity component, greater for focal PM trials relative to nonfocal PM trials, which reflected an enhancement of the FN400. Indeed, as classically shown for the FN400, this positive component occurred in the time window of 300–600 ms and was expressed over midline frontal regions (Figs 6 and 7*b*). Since the FN400 is associated with familiarity and automatic retrieval (Jenning and Jacoby 1993; Curran 2000), differences in this kind of component suggest that different retrieval processes subserve the recognition of the PM cue in focal and nonfocal PM tasks, with focal task being characterized by a more automatic retrieval process.

Furthermore, the electrode saliences revealed a long-lasting negativity over temporal regions, which was more negative in

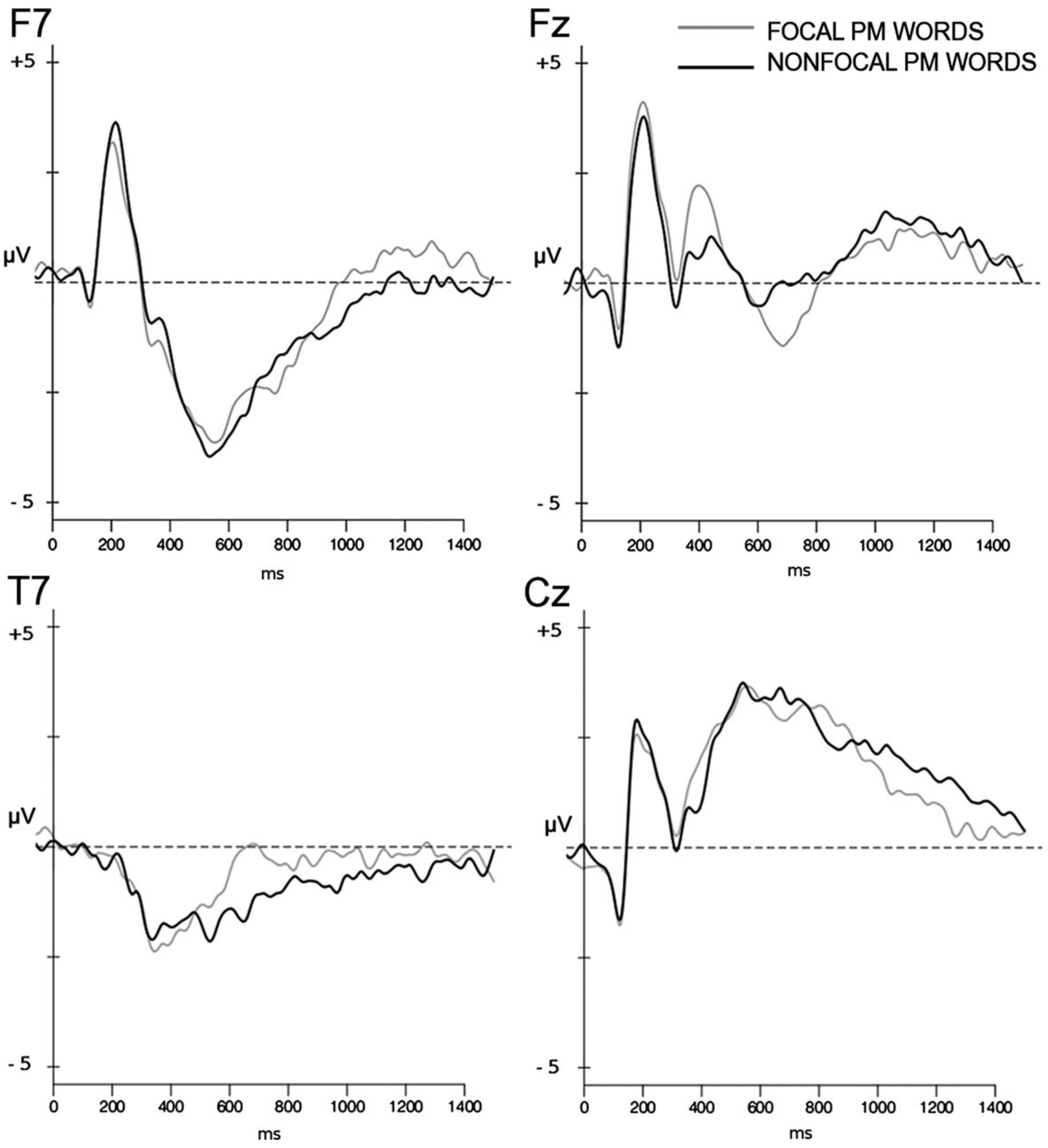

Figure 6. The figure highlights the ERP differences between focal (gray line) and nonfocal (black line) PM trials.

nonfocal than in focal PM trials at 460–500 ms until around 1000 ms. The electrode saliences of this second LV also evidenced that nonfocal PM trials were characterized by an enhancement of the late sustained central and centro-parietal positivity as well as of the negativity over lateral frontal regions, compared with focal PM trials. As shown in Figure 6, such modulations, beginning around 850–1000 ms and lasting until 1200–1500 ms, involved the later portions of the prospective positivity and the frontal slow wave, which are the components typically related to postretrieval monitoring and coordinating processes (West et al. 2001; West and Krompinger 2005; Bisiacchi et al. 2009). This result indicates that, when compared with the focal PM task, the nonfocal PM task required more resources for monitoring processes not only before the occurrence of the PM cue, but also after having made the PM response, in order to make sure that the stimulus was effectively the PM cue.

ERP Correlates of PM Processes: a Comparison Between High- and Low-Monitoring Participants

The second LV of the previous PLS analysis appears to differentiate the ERPs that are more linked to automatic retrieval

Table 1

Influence of PM cue focality on the ERP correlates of the PM processes

ERPs	Cognitive process	Influence of PM cue focality on ERPs?
Frontal and posterior sustained activity (in ongoing trials)	Strategic monitoring	✓
N300	Perceptual detection of PM cue	×
FN400	Automatic recognition of PM cue	✓
Old–new effect	Recollection processes	
Prospective positivity	Configuration and coordination of PM and ongoing actions	✓
Frontal slow wave	Retrieval monitoring processes	✓

Note: The effects of the PM cue focality on the main ERP components elicited in PM paradigms. The "✓" and "×"indicate, respectively, the presence and the absence of the effect of cue focality on each ERP. The middle column shows the cognitive processes that are typically considered to be associated with the ERP components.

(e.g. FN400) from the ERP correlates of processes that involve more strategic resources (e.g. prospective positivity— frontal slow wave).

Although appealing, the evidence of automatic processes in the focal PM task seems to conflict with the behavioral and ERP findings in the ongoing trials, which highlighted that a certain degree of strategic monitoring was implied even in this kind of PM task. Interindividual differences in monitoring, however, might clarify this potential contradiction (Einstein et al. 2005; Albiński et al. 2012; Savine et al. 2012). Indeed, it was recently argued that some individuals could be engaged in monitoring even if such a controlled process is not strictly necessary to perform it on focal PM tasks (Brewer et al. 2010; Einstein and McDaniel 2010; Scullin, McDaniel, Shelton, et al. 2010).

To test this hypothesis, we explored the ERPs elicited by the ongoing and PM words by distinguishing between high- and low-monitoring individuals. We divided participants into those who engaged in monitoring to accomplish the focal task (high-monitoring participants) and those who engaged in little or no monitoring (low-monitoring participants) on the basis of the PM interference effect observed in the focal session. High-monitoring participants showed a significant PM interference effect in the focal session (focal words–baseline words = 96.9 ± 14.0 ms; $t_{(11)} = 4.88$; $P < 0.01$; $\eta^2 = 0.68$). In contrast, the PM interference effect was not significant for the low-monitoring participants (focal words–baseline words = 16.9 ± 5.8 ms; $t_{(11)} = 2.04.8$; $P > 0.05$; $\eta^2 = 0.27$). Nevertheless, the accuracy on the focal PM task did not differ between the high-monitoring participants (92.9 ± 0.9%) and low-monitoring participants (92.0 ± 0.7%; $t_{(22)} = 0.25$; $P > 0.05$: $\eta^2 = 0.002$), providing evidence that strategic monitoring is not needed to perform the focal PM task.

A PLS analysis was run on the ERPs elicited by the ongoing words in the 3 sessions, including the participants divided into high- and low-monitoring. This analysis revealed one significant LV ($P < 0.002$), which accounted for 59.77% of the cross-block covariance (Fig. 8). In the high-monitoring group, this LV reflected a contrast not only between the baseline and nonfocal sessions, but also, to a lesser extent, between the baseline and focal sessions. On the other hand, in the low-monitoring group, this LV reflected a contrast only of the nonfocal session with the baseline session. Indeed, the design score for the focal session was close to zero, with the confidence interval bar intersecting the x-axis (Fig. 8). Therefore, in the low-monitoring group, the LV expressed the effect of monitoring on the ERPs only for the nonfocal, but not for the focal, session. The electrode saliences captured the ERP modulations associated with strategic monitoring: An increased sustained negativity over prefrontal and lateral frontal sites coupled with an enhanced positivity over parietal sites (as also evidenced in the previous PLS analysis on ongoing words).

Therefore, no evidence of strategic monitoring was found in the focal session in the low-monitoring group, either in terms of PM interference effect or in terms of ERP differences respect to the baseline session.

The PLS analysis contrasting PM and ongoing words among the PM sessions revealed 2 significant LVs ($P < 0.0001$ and <0.037), which accounted for 69.40% and 13.86% of the cross-block covariance, respectively. As the first LV of the previous PLS analysis of PM trials, also the first LV of the current analysis distinguished PM words from ongoing words, in both the 2 PM sessions. A similar pattern of results was expressed in the 2 groups, although the differences among the conditions were more accentuated in the low-monitoring group (Fig. 9). The second LV captured a difference between nonfocal and focal PM trials mostly in the low-monitoring group. In contrast, the magnitude of the design scores for focal and nonfocal PM trials was markedly attenuated in the high-monitoring group, indicating that the ERP differences between the 2 types of PM trials were less expressed in this group. Such attenuation of the ERP differences between focal and nonfocal PM trials might be due to the fact that high-monitoring participants recruited strategic processes in both the PM trials, even in the focal ones. Instead, in the low-monitoring group, the recruitment of partially different processes in focal and nonfocal PM trials would lead to greater differences between the corresponding design scores. The pattern of design scores and electrode saliences revealed an increase of the prospective positivity (over parietal and centro-parietal regions) and of the frontal slow wave (over lateral frontal regions) in nonfocal PM trials relative to focal trials. In contrast, there was an enhancement of the FN400 trials (over middle frontal and fronto-central sites) in focal PM trials relative to nonfocal PM trials (Fig. 9). Furthermore, the amplitudes of such ERPs were more pronounced in the low-monitoring group when compared with the high-monitoring group. This was supported by the different magnitude in the design scores between the 2 groups, with the low-monitoring group exhibiting a greater magnitude of the design scores for both the focal and nonfocal PM trials.

Collectively, these findings provide evidence of interindividual differences in monitoring to execute the focal task. Some of the participants recruited strategic monitoring to accomplish both the nonfocal and focal tasks, whereas other participants engaged in monitoring only in the nonfocal task, probably relying on spontaneous retrieval in the focal task.

Discussion

The present study was aimed at examining the effects of PM cue focality on the behavioral and electrophysiological correlates of PM. The investigation of the influence of PM cue focality on the ERPs elicited by ongoing trials permitted a better understanding of the extent to which strategic monitoring is involved in focal and nonfocal PM tasks, whereas the analysis of ERPs in PM trials provided new information regarding the other processes that differentially underlie the 2 PM tasks.

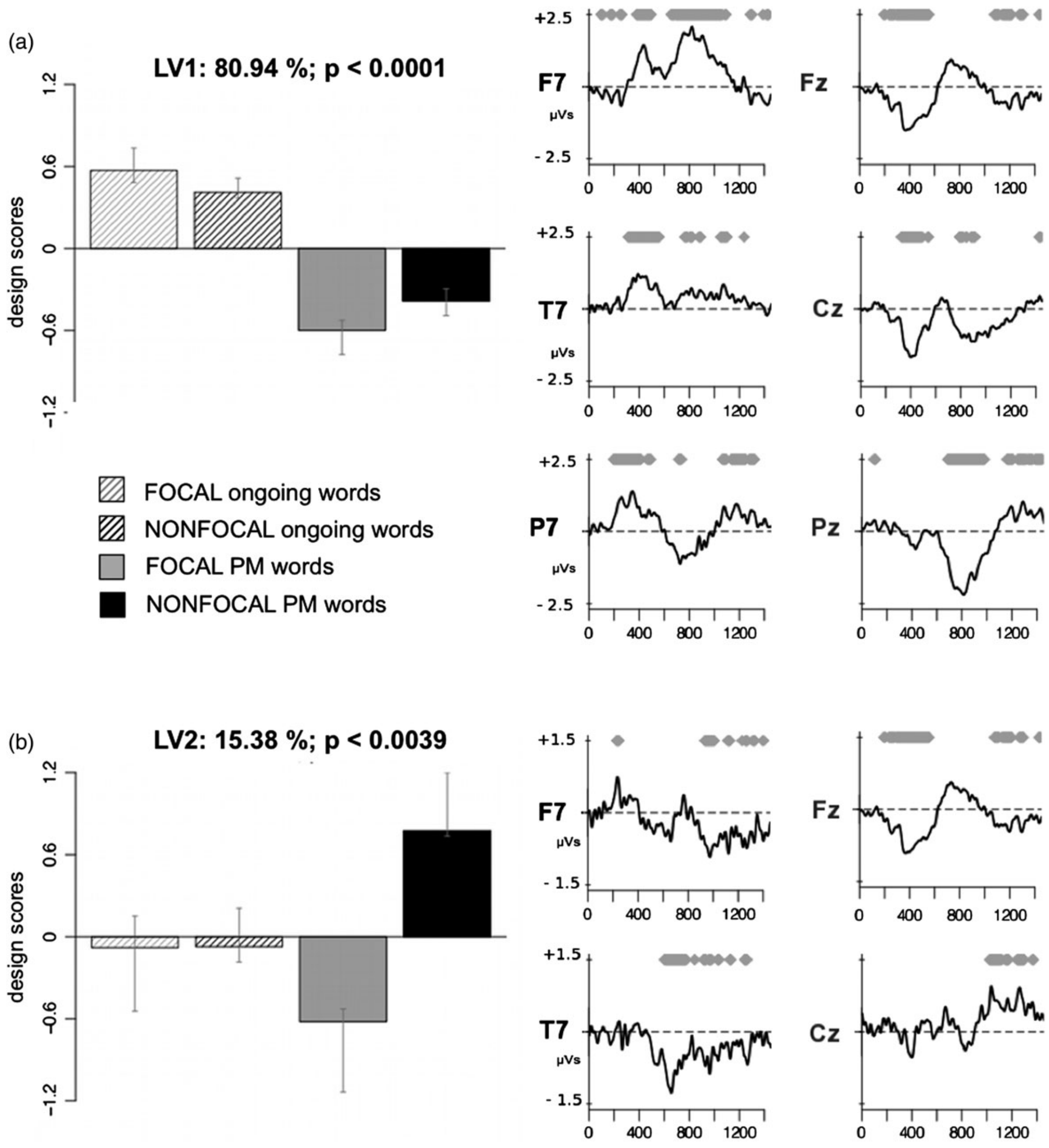

Figure 7. Design scores and electrode saliences for select electrodes from the PLS analysis that compares the ERPs elicited by ongoing and PM words on the focal and the nonfocal sessions. (*a*) LV1 distinguishes PM trials from the ongoing trials in both the sessions. (*b*) LV2 reveals a contrast specifically between focal and nonfocal PM trials. The dots above the salience waveforms indicate stable saliences.

An overview of the effects of PM cue focality on the ERPs with the corresponding cognitive meaning is displayed in Table 1.

Behavioral Correlates of Processes Involved in Focal and Nonfocal PM Tasks

According to the MPV, strategic monitoring is necessary to fulfill the prospective intentions when the PM cue is nonfocal, whereas it is less important, or even not required at all, when the PM cue is focal (Einstein et al. 2005; McDaniel and Einstein 2007; Scullin, McDaniel, Shelton, et al. 2010). Basing ourselves on this view, we expected to find a greater PM interference effect (indicative of strategic monitoring) in the nonfocal session when compared with the focal session. The behavioral data revealed a slowing in the speed of responses to the ongoing task when both the focal and nonfocal PM tasks were added to the ongoing activity. However, RTs were slower in the nonfocal session than in the focal session. Therefore, the

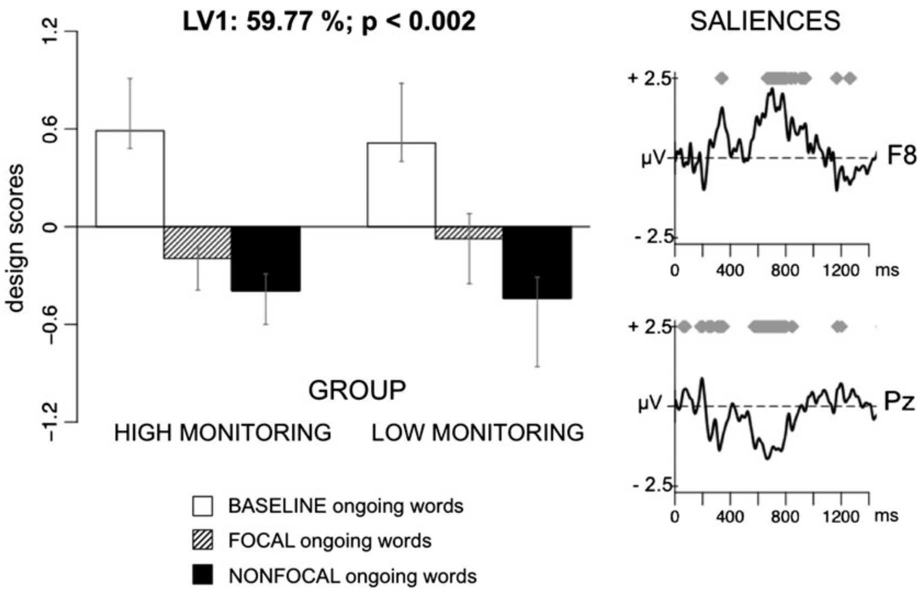

Figure 8. Design scores and electrode saliences at selected electrodes for the first LV from the PLS analysis contrasting the ERPs elicited by ongoing words in the baseline, focal and nonfocal sessions in the high- and low-monitoring groups. LV1 captures a contrast between the baseline and focal sessions only in the high-monitoring group, but not in the low-monitoring group. The electrode saliences reflect the frontal and parietal ERP modulations associated with strategic monitoring.

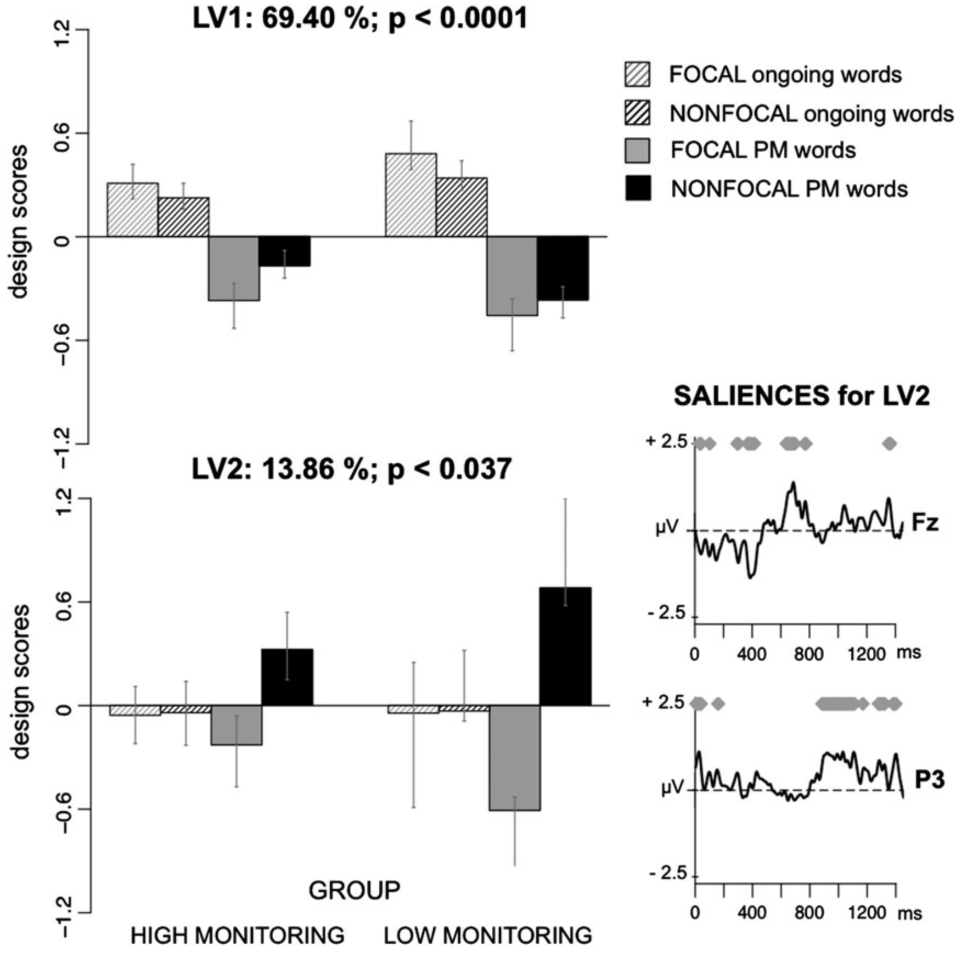

Figure 9. Design scores and electrode saliences at selected electrodes for the first and the second LVs from the PLS analysis contrasting the ERPs elicited by ongoing and PM words in the focal and nonfocal sessions in the high- and low-monitoring groups. LV1 reveals a contrast distinguishing between PM and ongoing words, in both the groups. LV2 reveals a contrast specifically between focal and nonfocal PM words. This difference was pronounced in the low-monitoring group, whereas it was more reduced in the high-monitoring group.

PM interference effect was shown for both the PM tasks, but was greater for nonfocal than for focal task (e.g. Marsh et al. 2003; Einstein et al. 2005; Scullin, McDaniel, Shelton, et al. 2010). In line with the MPV (Einstein et al. 2005), this pattern of results suggests that the degree of preparatory attention and memory resources required for strategic monitoring is influenced by PM cue focality and is higher when a nonfocal PM cue is expected.

The investigation of the ongoing performance when a PM cue is encountered (i.e. in PM trials) allowed us to clarify which processes differentially support both the focal and nonfocal PM tasks. Indeed, the slowing down of RTs on PM trials (i.e. labeled as the "cue interference effect"; Marsh et al. 2002, 2003) is interpreted as reflecting the engagement of processes related to PM, such as cue detection, cue verification, intention retrieval, and tasks coordination (Marsh et al. 2002, 2003; Knight et al. 2010). Some of these processes, not being automatic but controlled, would lead to a cost on the ongoing activity (Marsh et al. 2002, 2003). According to the MPV, prospective remembering is supported by more automatic processes (e.g. the spontaneous retrieval of intention) when the PM cue is focal, and by more controlled or strategic processes when the PM cue is nonfocal. If this is true, we should expect a smaller cue interference effect in focal, than in nonfocal, PM trials.

Interestingly, in focal PM trials, was there no cue interference effect, but rather a facilitation of RTs. Such a facilitation might reflect the "intention superiority effect," which refers to the decrease in RTs for information related to intentions in lexical decision and recognition memory tasks (Goschke and Kuhl 1993; Marsh et al. 1998, 1999; Freeman and Ellis 2003). In the present study, the intention superiority effect emerged in terms of RTs only on focal PM trials, and not on nonfocal PM trials, where RTs did not differ between PM and ongoing trials.

Consistent with the MPV, the absence of a cue interference effect—and even a facilitation of the RTs in focal PM trials—suggests that in certain situations, such as when the PM cue is focal, some of the processes mediating the realization of intentions can be automatic and hence did not lead to a cost on ongoing performance (Einstein et al. 2005; Uretzky and Gilboa 2010; Scullin, McDaniel, Einstein 2010; Scullin, McDaniel, Shelton, et al. 2010). Unlike the focal task, the nonfocal task might involve more controlled processes, as revealed by the absence of the intention superiority effect. The possibility that automatic retrieval of intention mediates focal tasks is also noted in a recent study (Uretzky and Gilboa 2010), which interpreted the intention superiority effect observed for PM cues as an index of the automatic activation of the intended action (see also Marsh et al. 1998).

An alternative explanation for the facilitation of the RTs in focal PM trials is that the representation of the PM word was more easily retrieved compared with the other words, since it was still active in working memory. Indeed, in each block, the same word was presented at least twice, at the encoding phase and during the ongoing activity, thus a word repetition effect might have contributed to such facilitation for the focal PM words. Nevertheless, if the PM cue was still active in working memory, this should lead to a rise in ongoing RTs of focal session compared with the ongoing RTs of the baseline in all the participants. Such slowing down of RTs, however, has been observed only in a subset of them. Hence, the behavioral measures alone do not seem sufficient to clearly establish which processes differ between focal and nonfocal PM tasks. On the other side, the investigation of the ERPs represents a helpful method to address this issue.

ERP Correlates of Strategic Monitoring in Focal and Nonfocal PM Tasks

As in the behavioral analyses, the electrophysiological analyses focused on the ERPs associated with both the ongoing and PM trials. A comparison of the ERPs on the ongoing words between the 3 different sessions was conducted to examine the effect of PM cue focality on the neural correlates of strategic monitoring. According to the MPV (McDaniel and Einstein 2000), if a greater recruitment of preparatory attention and memory resources is necessary for monitoring the presence of nonfocal PM cues, when compared with focal PM cues, then we should expect more pronounced ERP modulations related to strategic monitoring in the nonfocal session with respect to the focal session.

The addition of a PM task to the ongoing activity led to early phasic and later more sustained modulations of the ERPs in ongoing trials for both focal and nonfocal sessions. These modulations were similar to those observed in other studies that used PM cues that could be considered focal (West 2007; West et al. 2007; Cona et al. 2012a) and nonfocal (West et al. 2006, 2011; Chen et al. 2007; Knight et al. 2010; Czernochowski et al. 2012; Cona et al. 2012b). The current study, however, extends these findings since it showed that the amplitudes of such ERP modulations were influenced by PM cue focality, with nonfocal ongoing trials being characterized by greater amplitudes of the ERPs compared with nonfocal ongoing trials. This result is in line with the behavioral data, representing the electrophysiological counterpart of the higher PM interference effect observed in the nonfocal PM session with respect to the focal session. Therefore, it provides support for the hypothesis that greater recruitment of preparatory resources is needed for monitoring for the occurrence of nonfocal PM cues (Scullin, McDaniel, Shelton, et al. 2010).

However, in addition to the information provided by the PM interference effect, the investigation of the ERPs yielded a better characterization of the specific processes that are implicated in strategic monitoring. Indeed, the PLS analysis revealed that 3 main ERP modulations distinguished the ongoing words of the PM sessions—and mainly in the nonfocal condition—from the ongoing words of the baseline session.

An early transient modulation at 100 ms poststimulus was expressed over parietal–occipital and occipital sites and was represented by a speeded and enhanced P1 in the PM sessions with respect to the baseline session. As suggested by previous studies, the modulation of the earlier components might reflect the engagement of preparatory attention required to be in a "readiness mode," namely to be ready and prepared to respond to the PM cue (Cona et al. 2012a; see also Knight et al. 2010).

Afterwards, a more sustained modulation characterized the ERPs of the PM sessions in the time window between 160 and 370 ms and was expressed as an increased positivity of the ERPs that occurred over parietal and centro-parietal regions, accompanied by an enhanced negativity of the ERPs over prefrontal and lateral frontal regions. The amplitudes of the components occurring in this time window were lowest in the baseline, intermediate in the focal session, and highest in the nonfocal session. Previous studies considered the ERP modulations observed in similar time windows as evidence of the effects of attention allocated for strategic monitoring (e.g. Chen et al. 2007; Knight et al. 2010). Therefore, this pattern of results suggests that PM cue focality can effectively increase, along a continuum, the degree of preparatory attention needed for evaluating the presence of the PM cue.

The latest modulations that characterized the ERPs in PM sessions appeared at roughly 550 ms and were expressed as an enhancement of the slow waves occurring over posterior sites (which became more positive) as well as those occurring over prefrontal and lateral frontal sites (which became more negative). These slow waves were more pronounced in the nonfocal, than in the focal, PM session (Fig. 3). They might indicate that, in nonfocal PM tasks, a more effortful search in memory was needed to check the presence/absence of the PM cues in the environment. Indeed, it is important to note that strategic monitoring entails a memory search, required to compare whether the incoming stimulus matches with the representation of the PM cue stored in memory (Guynn 2003; Smith and Bayen 2004). Our interpretation of these modulations is supported by the results of the study by Rösler et al. (1993), who showed that similar slow waves were modulated by several aspects of monitoring and memory retrieval processes (see also Rugg 1995 and West et al. 2003).

Furthermore, as recently proposed in several studies, this long-lasting activity might also reflect another strategic monitoring process, termed retrieval mode (Guynn 2003, 2008), which is required to actively maintain intentions in memory (West et al. 2011; Czernochowski et al. 2012; Cona et al. 2012a, 2012b). However, future studies are needed to better clarify the functional significance of these ERP modulations with regard to the different processes composing strategic monitoring.

ERP Correlates of Processes Elicited by Focal and Nonfocal PM Cues

To our knowledge, this is the first study aimed at investigating the effect of PM cue focality on the ERP correlates of PM. We did not find any modulation of the N300 associated with the PM cue focality, suggesting that similar processes support the perceptual detection of the PM cues in focal and nonfocal PM tasks. Given that focal and nonfocal PM tasks are assumed to imply a different amount of strategic monitoring, then the absence of the modulation of the N300 as a function of PM cue focality seems to be in contrast to those findings that revealed an influence of strategic monitoring on this component (West 2007; West et al. 2007). It should be noted, however, that these experiments did not directly compare focal and nonfocal PM tasks, but instead they inferred this by analyzing the ERPs elicited by PM cues that were associated with an accomplished intention versus a missed intention.

On the other hand, the frontal FN400 was found to be substantially higher in focal, than in nonfocal, PM trials, revealing that different retrieval processes subserve the PM cue recognition in the 2 tasks (Einstein et al. 2005; Scullin, McDaniel, Shelton, et al. 2010). The FN400 has been interpreted to reflect the retrospective component of PM in several studies by West and Krompinger (2005) and West et al. (2006). Notably, it is considered to be associated with automatic memory and familiarity, and therefore, is commonly used as an index of automatic memory processes (e.g. Jenning and Jacoby 1993; Curran 2000; Wilckens et al. 2011). In this light, the higher FN400 in focal PM trials may indicate that, when a focal PM cue is encountered, individuals automatically activate the representation of the PM cue stored in memory and, likely, also the associated intention, as suggested by the presence of the intention superiority effect in these kinds of trials. This result extends the speculations drawn from other ERP studies (e.g. West 2007; West et al. 2007), according to which strategic monitoring would not be necessary for the recognition of focal PM cues (West 2011). On the other hand, nonfocal PM trials were characterized by a FN400 that was reduced with respect to the FN400 of focal PM trials, suggesting that the recognition of nonfocal PM cues is mediated by more controlled memory processes, such as memory search.

In a recent review of the ERP studies of PM, West (2011) discussed the N300 and the FN400 together, as a unique complex called “N300/frontal positivity.” Based on data from some of his studies (West et al. 2003, 2007), West noted that strategic monitoring influences the amplitude of this ERP complex for PM cues that could be labeled both focal and nonfocal. This claim, however, has yet to be tested directly. The present study is important because it highlights a dissociation between the N300 and the FN400 components, with only the FN400 being modulated by the focality of the PM cue.

One might argue that the differences observed in the FN400 amplitude between the 2 tasks were merely due to the fact that, on the focal session, but not on the nonfocal session, the PM cue was represented by the same word as that presented during the encoding phase. Although we cannot exclude the influence of a “repetition” factor, it is not likely that this was the unique factor that accounts for the differences in the FN400. (We also ran a further PLS analysis in which we excluded the epochs locked to PM cues that were presented a second time within the same block (6 PM trials). However, the results were not influenced by the removal of these epochs and they were almost identical to the results that included such epochs.) Indeed, we reduced the possible effect of perceptual repetition by presenting the PM cue in lowercase during the encoding phase and in uppercase during the ongoing activity phase. This manipulation reduces, but does not prevent, lexical priming. Nevertheless, if the repetition was the only factor responsible for the difference in the FN400 amplitude, then the LV reflecting such a difference should have distinguished the focal PM trials not only from the nonfocal PM trials, but also from all the other kinds of trials, such as the focal and nonfocal ongoing words since they were all presented only once during the experiment. Instead, the LV contrasted focal PM trials only with nonfocal PM trials, indicating that the ERP modulations expressed by this LV reflected the processes specifically related to prospective remembering.

In addition to the FN400, other ERP components were modulated by the focality of the PM cue. When compared with focal PM trials, nonfocal PM trials were characterized by a more negative slow wave occurring bilaterally over temporal regions. Unlike the FN400, it is more difficult to ascertain the functional significance of this slow wave. However, the first LV revealed that this temporal slow wave distinguished between PM and ongoing trials and was expressed roughly in the same time window as the FN400. Thus, it might be associated with the retrospective component of PM as well. Then, the more negative slow wave observed in the nonfocal PM task might confirm the involvement of controlled and effortful memory processes in this task, likely required for searching in memory for the representations of the PM cue and its associated intention.

Surprisingly, we did not find differences in the recognition old–new effect between focal and nonfocal PM trials. A possible explanation is the occurrence of the N400 that overlapped the old–new effect. Indeed, the N400 typically occurs over the same regions in central and parietal electrode sites, and in the same time window as the old–new effect (Kutas 1997, for a review), but with reverse polarity. The N400, mainly associated with semantic processing (Kutas and Hillyard 1980), should be greater for nonfocal PM cues relative to focal PM cues. Therefore, it might have masked possible differences in the old–new effect between the 2 PM tasks.

Finally, the later portions of the prospective positivity as well as of the frontal slow wave were more pronounced in nonfocal, than in focal, PM trials. These components were considered to reflect retrieval monitoring processes and task coordination processes (West and Krompinger 2005; Bisiacchi et al. 2009). Hence, this pattern of results indicates that nonfocal PM tasks require greater recruitment of controlled resources not only to monitor for the occurrence of the PM cue, but also to monitor the outcome of the retrieved intention. The greater prospective positivity observed for nonfocal PM trials may also indicate that, in this type of task, more effortful and demanding processes are required to coordinate the ongoing and PM responses (Bisiacchi et al. 2009).

Differences in the Neurocognitive Processes Underlying PM Between High- and Low-Monitoring Individuals

The results described above on PM trials suggest that partially different processes mediate prospective remembering based on PM cue focality: Nonfocal PM cues require more controlled and strategic processes to be detected, whereas focal PM cues seem to be recognized more automatically. Nevertheless, the behavioral and PLS analyses of ongoing trials indicated that a certain degree of strategic monitoring occurred even in the focal PM task.

One way to resolve this apparent contradiction in the data was to take into account individual differences in monitoring. Indeed, a possible explanation is that some participants did not monitor for PM cue detection in the focal session, whereas other ones were monitoring in this session, even though it was not strictly required to do so. In the ongoing trials of the focal session, the high-monitoring participants displayed a significant PM interference effect and showed ERP modulations reflective of strategic monitoring. In contrast, in the low-monitoring group, there was evidence neither of the PM interference effect, nor of the ERP modulations, related to monitoring. Therefore, behavioral and electrophysiological data converge in revealing individual differences in monitoring when a focal PM cue has to be detected. More specifically, the low-monitoring participants did not appear to monitor for the occurrence of the focal PM cues; hence they were more likely to rely on spontaneous retrieval to perform the focal PM task. Notably, the low-monitoring participants displayed the levels of accuracy on the focal PM task that were similar to those obtained by the high-monitoring participants, indicating that strategic monitoring seems not to be strictly necessary to perform the focal PM task (Scullin, McDaniel, Shelton, et al. 2010). On the other hand, in the ongoing trials of the nonfocal session, both the high- and low-monitoring participants showed the ERP modulations associated with strategic monitoring, as revealed by the similar magnitude of the design scores for this session in the 2 groups. Taken together, the findings on ongoing trials highlighted that all participants were engaged in monitoring to accomplish the nonfocal PM tasks. In contrast, only some participants recruited strategic monitoring in the focal task, since other ones tended to rely mainly on spontaneous retrieval to execute this kind of task.

This interpretation is supported by the results from the PLS analysis on PM trials. This analysis revealed that the ERPs elicited by focal PM trials were clearly differentiated from that by nonfocal PM trials in the low-monitoring participants, confirming the suggestion that they recruited partially different processes in the 2 PM tasks. By comparison, the dissociation of the ERPs between focal and nonfocal tasks observed in the high-monitoring group was less distinct. A possible explanation of this finding is that high-monitoring participants tended to allocate strategic resources to both the PM tasks, regardless of cue focality. Indeed, the second LV reflected a contrast between the ERPs related to automatic memory, as the FN400, which were more expressed in focal PM trials, and the ERPs related to strategic processes, as the prospective positivity and frontal slow wave, which were more expressed in nonfocal PM trials. This distinction was marked in the low-monitoring group, whereas it was attenuated in the high-monitoring group, suggesting that the latter group likely recruited strategic monitoring also to perform the focal PM task.

Although appealing, this hypothesis needs to be tested further. Indeed, it is important to note that PM cue focality is not the only factor able to modulate the extent to which strategic monitoring is recruited. Other factors, such as the importance given to the PM tasks or the percentage of PM trials (Einstein et al. 2005; Loft and Yeo 2007; Smith et al. 2007; Loft et al. 2008), could have contributed to the behavioral and ERP effects of strategic monitoring observed in the present study. We should note that ideally, focal trials occur even more rarely than they do in our experiment, and that under such conditions it is possible that no monitoring would be evident in any individual. Given the constraints of conducting ERP studies in which many signals need to be averaged, we needed to increase the stimuli in the focal condition. It is encouraging that, even under these less-than ideal conditions, a subset of individuals not given to monitoring showed the predicted "automatic" effect both behaviorally and electrophysiologically. Lastly, as in previous studies, individual differences were also shown to have a substantial impact on PM processes (Einstein et al. 2005; Albiński et al. 2012; Savine et al. 2012).

Conclusions

The present study showed that the involvement in strategic monitoring varied as a function of the type of PM cue focality and the individual's approach to the PM task. Strategic monitoring was engaged by all participants in the nonfocal task, whereas it was evident in some participants, but not in others, for the execution of the focal task. These findings support the most updated versions of the MPV, showing that whereas monitoring is necessary for the recognition of nonfocal PM cues, it may be engaged, but not needed, for the detection of focal cues (i.e. Brewer et al. 2010; Scullin, McDaniel, Shelton, et al. 2010).

In addition, the investigation of the RTs and the ERPs in PM trials provided converging support for the MPV (McDaniel and Einstein 2000), indicating that different retrieval processes subserve PM depending on cue focality. Indeed, focal PM cues seem to be recognized more automatically compared with nonfocal PM cues, an effect that is especially marked in low-monitoring individuals. This conclusion is based on the observation that encountering a focal PM cue (relative to a nonfocal cue) led to a higher FN400 and to a facilitation on RTs in ongoing trials.

In addition, the slower return to baseline of the prospective positivity and of the frontal slow wave in nonfocal PM trials indicates that nonfocal PM tasks, when compared with focal ones, are supported by more effortful postretrieval monitoring and task coordination processes, consistently with the MPV. Thus, by using behavioral and electrophysiological evidence, the present study extends the MPV, since it showed that focal and nonfocal tasks differ not only in the kind of monitoring and retrieval process required, but also in other PM components, such as postretrieval monitoring.

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