Electrophysiological correlates of proactive interference in the 'Recent Probes' verbal working memory task☆

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ABSTRACT

Using event-related potentials (ERPs), the present study examined the temporal dynamics of proactive interference in working memory using a recent probes task. Participants memorized and retained a target set of four letters over a short retention interval. They then responded to a recognition probe by judging whether it was from the memory set. ERP waveforms elicited by positive probes compared to those from negative probes showed positive shifts in a fronto-central early N2 component and a parietal late positive component (LPC). The LPC was identified as the electrophysiological signature of proactive interference, as it differentiated between two types of negative probes defined based on whether they were recently encountered. These results indicate that the proactive interference we observed arises from a mismatch between familiarity and contextual information during recognition memory. When considered together with related studies in the literature, the results also suggest that there are different forms of proactive interference associated with different neural correlates.

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1. Introduction

Much modern research in cognitive psychology and cognitive neuroscience has been devoted to working memory, which is considered to be the crucial interface between long-term knowledge representations and perception (Baddeley & Hitch, 1974; Jonides et al., 2008). A prominent feature of working memory is that only information pertinent to present task demands should be maintained and used but not irrelevant or outdated information, even though they may have been relevant moments before (Bjork, 1978; Roth & Courtney, 2007). Consequently, an important research topic is to understand how proactive interference (PI) arises when information that was once maintained in working memory interferes with current processing and how such interference is resolved.

Whereas classical PI research relied primarily on measures of recall accuracy, Monsell (1978) introduced a 'Recent Probes' paradigm based on the Sternberg item-recognition task (1966), allowing the examination of PI with response times. In this paradigm, participants hold a small set of target items in memory over a short retention interval and then make a *yes* (positive) or *no* (negative) decision to a recognition probe. Critically, a probe can be drawn from the target set of the immediately preceding trials, making it a 'Recent probe'. In contrast, a 'Non-recent probe' has not been encountered recently. Accurate *no* decisions have been found to be significantly slower to Recent Negative probes than to Non-recent Negative probes, indicating a PI effect that memory for items recently encountered interferes with current item-recognition (Monsell, 1978). Starting from the work of Jonides, Smith, Marshuetz, and Koeppe (1998), researchers have adopted this paradigm in a number of brain imaging studies to identify brain structures associated with PI resolution in working memory, such as left inferior frontal gyrus (Badre & Wagner, 2005; Bunge, Ochsner, Desmond, Glover, & Gabrieli, 2001; D'Esposito, Postle, Jonides, & Smith, 1999; Mecklinger, Weber, Gunter, & Engle, 2003; Yi, Driesen, & Leung, 2009).

To complement these PET and fMRI localization studies for a full elucidation of the mechanisms of proactive interference, more research is needed to reveal the corresponding temporal dynamics. In the present study, we applied event-related potentials (ERPs), a cognitive neuroscience technique that excels in temporal resolution to the recent probes verbal working memory task. Specifically, we compared ERP responses elicited by Recent Negative probes with those elicited by Non-recent Negative probes to identify ERPs

that differ between these two conditions, namely, the electro-physiological signature of PI. Previously, there were only three related ERP studies (Du et al., 2008; Tays, Dywan, Mathewson, & Segalowitz, 2008; Tays, Dywan, & Segalowitz, 2009).

The Du et al. (2008) study adopted a working memory paradigm involving directed forgetting that Zhang, Leung, and Johnson (2003) introduced. In this paradigm, participants held in memory an initial set of letters and were then cued to ignore some of the letters and to remember the rest as the final target set for probe recognition. As in the recent probes tasks, the critical comparison between Recent Negative probes drawn from the ignored subset and Non-recent Negative probes drawn from letters not shown in the present trial has revealed reliable behavioral PI effects in several studies adopting this paradigm (Nee, Jonides, & Berman, 2007; Yi et al., 2009; Zhang et al., 2003).

Using ERP, Du et al. (2008) observed a fronto-central negative component peaking around 300 ms post-probe-onset whose amplitude was significantly smaller for the Recent Negative probes than for the Non-recent Negative ones. They interpreted this finding as an N2 effect indexing the resolution of proactive interference induced by familiarity. This interpretation was reasonable in the sense that their N2 resembles an FN400 component that is often thought to index familiarity in recognition memory (Curran, 2000; Mecklinger, 2000). It becomes questionable, however, in light of more recent evidence indicating that FN400 may be associated not with familiarity but rather with conceptual priming (for reviews, see Paller, Voss, & Boehm, 2007; Voss & Paller, 2008), or processes downstream from those responsible for computing familiarity information (Tsivilis, Otten, & Rugg, 2001). Regardless of its interpretation, the observation in Du et al. that N2 is sensitive to recency manipulation suggests a possible prediction for the present study. Assuming that the PI effects found in different research paradigms are associated with the same neural signature, one would predict the same ERP component to differ across the two Negative conditions in the present recent probes task involving a similar recency manipulation. That is, a smaller N2 would be expected for the Recent Negative condition compared to the Non-recent Negative condition.

Alternatively, one could predict PI effects to be associated with later ERP components, in light of a biased-competition model of proactive interference as discussed in Jonides and Nee (2006). The model was initially proposed by Desimone and Duncan (1995) to explain the mechanism of visual selective attention and later developed by Kan and Thompson-Schill (2004) to also explain conceptual selection. By this model, proactive interference is resolved in the same evaluation process that distinguishes between positive and negative probe items, and the decision of whether a probe belongs to the current target set is based on competition between two types of memory codes, familiarity and contextual information. For the recent probes task, the Recent Negative probes, which have a higher level of familiarity due to their recent appearance in the preceding trials, are more likely to prompt a *yes* response than Non-recent Negative probes. To overcome this inappropriate response tendency, the decision-making process must be controlled and biased to rely more on the correct contextual information.

According to this model, the recency manipulation in the present study should modulate ERP components associated with a processing stage in which both familiarity and contextual information are available and can thus interact with each other for the proposed competition. The late positive component (LPC) seems to be such a candidate, as it is known to index both familiarity and episodic retrieval in long-term memory recognition (Voss & Paller, 2008; Voss & Paller, 2009). There are reasons to assume that this is true in short-term memory as well. First, at a general level, short- and long-term memories have been argued to be in fact the same system (for review, see Jonides et al., 2008).

Second, there are both theoretical models and empirical evidence suggesting that familiarity and episodic recollection as dual processes for long-term recognition (e.g., Yonelinas, 1994) are also at work in short-term memory recognition (Crites, Delgado, Devine, & Lozano, 2000; Crites, Devine, Lozano, & Moreno, 1998; Danker et al., 2008; McElree & Dosher, 1989; Oberauer, 2008; Öztekin & McElree, 2007). Therefore, if it is assumed that LPC in short-term memory is like its counterpart in long-term memory in indexing both familiarity and episodic retrieval of contextual information, the Jonides and Nee model (2006) would predict the LPC to be modulated by recency manipulation in the present study, reflecting the competition between familiarity and contextual information.

Thus, we designed an experiment to induce proactive interference with a recent probes task and to identify the ERPs associated with the interference effect. Based on the literature, the analysis emphasized the early N2 component and the late positive component.

2. Method

2.1. Participants

Nineteen college students (10 males, 9 females, age range from 20 to 26 years, mean ± SD = 22.9 ± 1.9 years) participated in this study. All were right-handed with normal or corrected-to-normal vision, and none reported any history of neurological or psychiatric disorders. Written informed consent was obtained from each participant in accordance with guidelines of the Institute of Psychology, Chinese Academy of Sciences, Beijing. Data from one participant were discarded due to excessive eye blinks and artifacts.

2.2. Stimuli and procedure

Participants were seated in a dimly lit and sound-attenuated room and asked to relax and to minimize unnecessary motions as much as possible throughout the experimental session. All visual stimuli were in black color against a white background and presented on a computer monitor about one meter away. The design and procedure were the same as that in Jonides et al. (1998). As illustrated in Fig. 1, each trial started with a warning screen shown for about 500 ms (range 450–550 ms), followed by a target set of four letters shown for 1000 ms. After a jittered delay interval (mean duration 2000 ms, range 1900–2100 ms), a probe letter was shown for 1000 ms. The probe was then replaced by a fixation cross presented for 1000 ms (range 950–1050 ms) before the next trial started. All letters were drawn from a pool of 21 consonants and presented in upper case except the probe, which was in lower case. Participants were told to press either a left or right key immediately after they decided whether the probe was in the target set. Both response speed and accuracy were emphasized. The response and key mappings were counterbalanced across-subjects.

As in Jonides et al. (1998), for all test trials, the current target set (e.g., the second trial in Fig. 1) consisted of two letters drawn from the target set of the immediately preceding trial (e.g., 'F' and 'R'), and two letters *not* present in the target sets of the two preceding trials (e.g., 'B' and 'M'). The four types of trials derived from manipulating response type (Positive vs. Negative) and lag (Recent vs. Non-recent) were equally represented and randomly intermixed in each block.

All participants completed one practice block and five test blocks. Each test block contained 66 trials, evenly divided into three independent segments of 22 trials. The first two trials in each segment were filler trials and not included in the data analysis.

2.3. Recording system and data analysis

EEGs were recorded from the scalp by 64 nonpolarizable Ag/AgCl sintered electrodes in preconfigured caps using the Neuroscan EEG system with a sampling rate of 1000 Hz. The electrode sites followed the extended 10–20 convention with the AFz electrode used as the ground. Both horizontal and vertical EOGs were recorded for offline data analysis. The impedance in all electrodes was less than 5 kΩ. The recordings were referenced to a vertex electrode and were later re-referenced to the mean of both mastoids.

For the behavioral data, mean response time (RT) and error rate were analyzed using repeated-measures ANOVAs. The RT analysis included only the behaviorally correct trials. For the EEG data, visual inspection and artifact rejection were performed offline, including only the correct trials. Epochs were segmented from 200 ms before to 1500 ms after probe onset, with baseline correction performed using mean amplitudes of the pre-probe period. Eye movement artifacts were removed using regression-based weighting coefficients (Semlitsch, Anderer, Schuster, & Presslich, 1986). Epochs with amplitudes exceeding ±80 μV in any channel were excluded with an automated procedure. The bandwidth filter ranged from
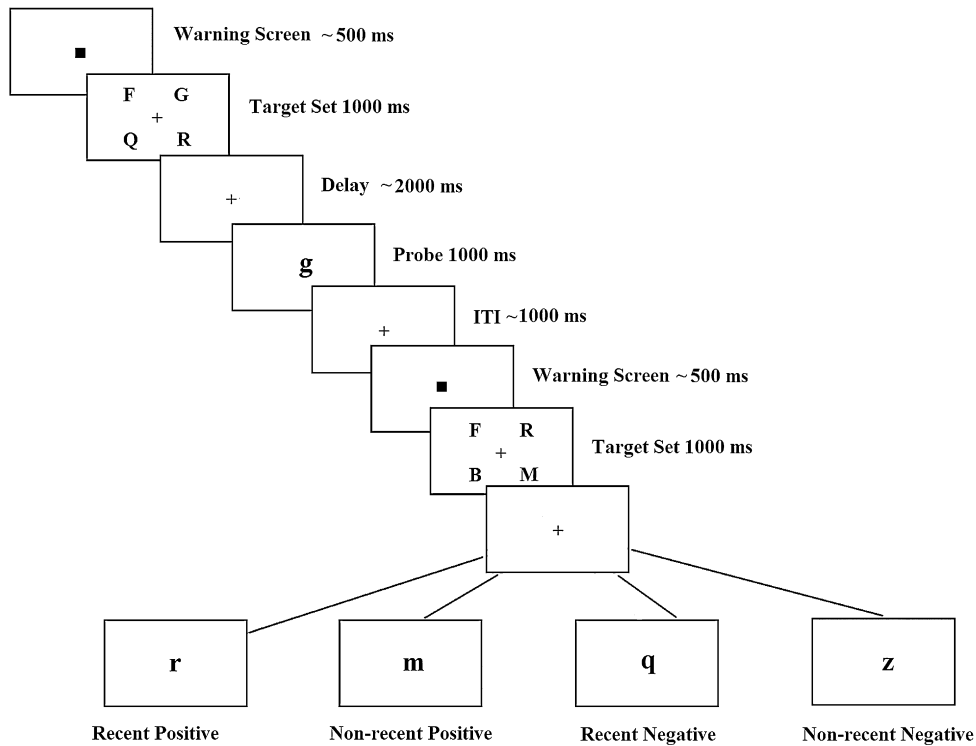
Fig. 1. A schematic illustration of the trial structure and the different experimental conditions is shown. Each trial displayed a warning screen and then a four-letter target set. Participants responded to a probe letter by judging whether it was in the target set of the current trial. In the Recent Positive condition, the probe, e.g., 'r', was in the target sets of both the current and the immediately preceding trial; in the Non-recent Positive condition, the probe, e.g., 'm', was in the current target set but not the preceding one; in the Recent Negative condition, the probe, e.g., 'q', was in the preceding target set but not the current one; and in the Non-recent Negative condition, the probe, e.g., 'z', was in neither the present nor the preceding target set.

0.05 to 40 Hz. Event-related potentials locked to probe onsets were computed by averaging epochs separately for each of the four types of trials.

3. Results

3.1. Behavioral data

Although our design distinguished between Recent Positive and Non-recent Positive conditions as in Jonides et al. (1998), the first-pass analysis did not reveal any significant differences between these two trial types for either the behavioral data (mean RT: 676 ms vs. 668 ms, mean error rate: 11.1% vs. 13.4%) or the EEG data. For simplicity, the two positive conditions were merged in the following analysis.

Table 1 shows the behavioral results for all three conditions. An ANOVA of the response times revealed a significant main effect for trial type, $F(2, 34) = 18.7$, $p < 0.0001$. Post hoc comparisons indicated that RT in the Recent Negative condition was significantly longer than in both the Positive and the Non-recent Negative conditions ($p < 0.0001$), and that the latter two did not differ significantly from each other ($t(17) = 0.7$, $p = 0.5$). For error rates, the main effect of trial type was also significant, $F(2, 34) = 32.9$, $p < 0.0001$. Participants made significantly more errors in the Positive condition than in the

Recent Negative condition (12.3% vs. 8.7%, $p < 0.01$), and more errors in the Recent Negative condition than in the Non-recent Negative condition (8.7% vs. 4.1%, $p < 0.0001$).

3.2. EEG data

As shown in Fig. 2, for most of the electrode sites, grand average potentials computed for 18 participants revealed a sequence of positive and negative deflections that we identified as N1, P2, N2, and LPC components. While the earlier components (including N1, P2 and N2) were more prominent over frontal and fronto-central areas, the LPC was more prominent over central to parieto-central areas. Repeated-measures ANOVAs with Greenhouse–Geisser correction were performed on the amplitudes and latencies of all components. N1 and P2 were not found to be modulated by trial type and therefore are not discussed below.

By visual inspection, N2 was identified as the maximum negative peak in the 250–350 ms period of the epoch, and LPC was identified as the maximum positive peak in the 400–600 ms period. Peaks were identified individually for each participant, with a time window defined centering on each peak. The window was narrower for N2 (80 ms) than for LPC (120 ms) due to their waveform shapes. Peak times provided the latency measures and waveform averages within time windows provided the mean amplitude measures.

3.3. N2

A three-way repeated-measures ANOVA was conducted on N2 amplitudes with trial type, electrode position (frontal: FZ, F1, F2; fronto-central: FCZ, FC1, FC2), and laterality (midline, left side, and

Table 1

Mean response times and error rates for the three experimental conditions ($N = 18$).

	Positive	Recent Negative	Non-recent Negative
	M ± SE	M ± SE	M ± SE
RT (ms)	672 ± 19	728 ± 18	679 ± 17
Error Rate (%)	12.3 ± 1.2	9.2 ± 1.0	4.1 ± 0.6
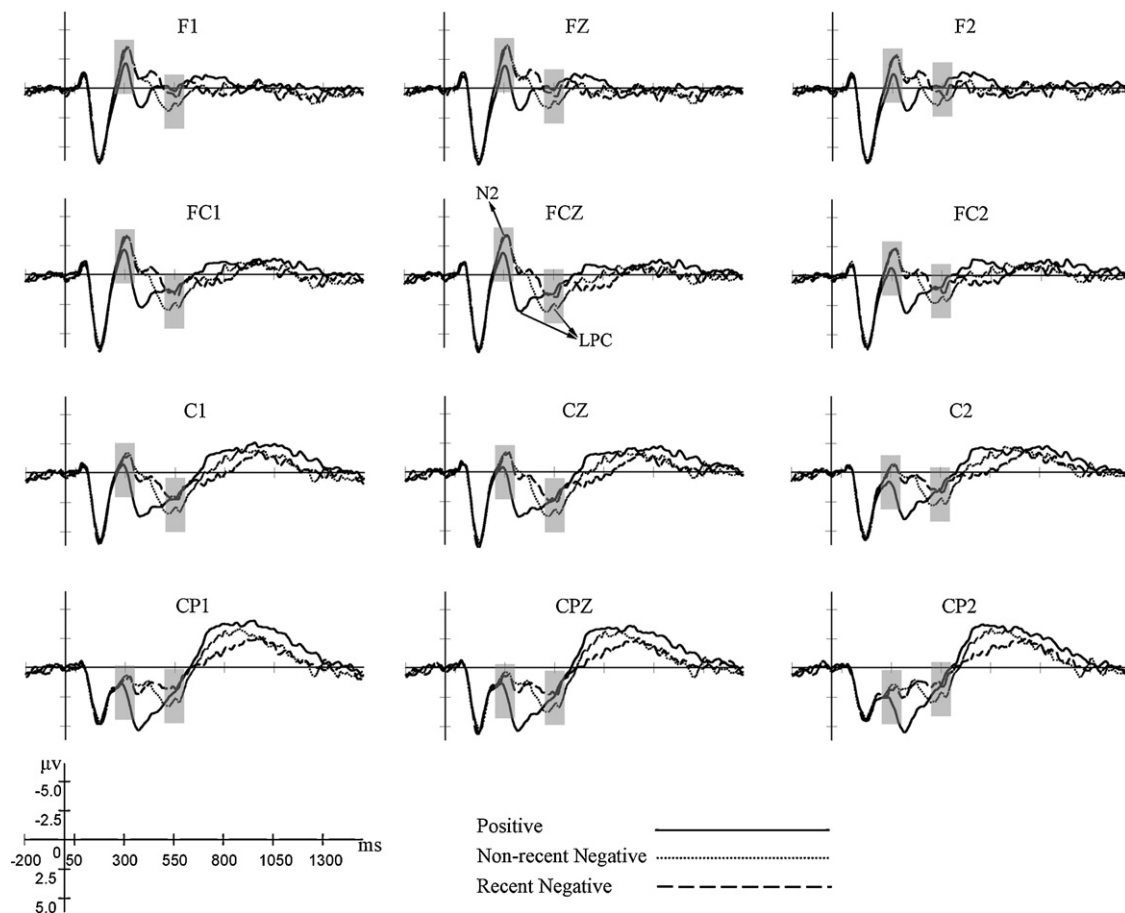
Fig. 2. Grand averaged ERP waveforms time-locked to probe onset for the three experimental conditions at 12 representative electrodes in the frontal and parietal areas, with arrows at FCZ showing the peaks being compared. Gray bars indicate time windows used for producing Fig. 3.

right side) as factors. The main effects were significant for trial type $F(2, 34) = 12.0$, $p < 0.0001$, and laterality $F(2, 34) = 31.1$, $p < 0.0001$. The interaction between trial type and electrode position was also significant $F(2, 34) = 3.4$, $p < 0.05$. Post hoc analyses showed significantly larger negative shifts of N2 in both of the Negative conditions when compared to the Positive condition (Recent Negative: $-3.9 \mu V$ vs. $-2.5 \mu V$, $t(17) = 4.1$, $p < 0.001$; Non-recent Negative: $-3.9 \mu V$ vs. $-2.5 \mu V$, $t(17) = 4.4$, $p < 0.0001$). There was no significant difference between the two Negative conditions ($t(17) = 0.2$, $p = 0.8$). Difference waves were computed for the *Positive minus Negative* comparison (pooling over the Recent and Non-recent Negative conditions). Mean amplitudes of the difference waves in the N2 time window (250–350 ms) were then entered into one-sample t-tests to produce a scalp topography illustrating the effects of response type (Fig. 3a). The one-way ANOVA on N2 latencies did not reveal any significant effect for trial type ($F < 1$).

3.4. LPC

A three-way repeated-measures ANOVA was conducted on LPC amplitudes with trial type, electrode position (central: CZ, C1, C2; parieto-central: CPZ, CP1, CP2), and laterality (midline, left side, and right side) as factors. There were significant effects for trial type, $F(2, 34) = 8.8$, $p < 0.001$, electrode position, $F(1, 17) = 11.3$, $p < 0.05$, and for their interaction, $F(2, 34) = 8.6$, $p < 0.001$. The amplitude was significantly smaller for the Recent Negative condition than for both the Positive condition (3.8 μV vs. 5.0 μV, $t(17) = 3.4$, $p < 0.05$) and the Non-recent Negative condition (3.8 μV vs. 4.7 μV, $t(17) = 3.0$, $p < 0.05$), with no significant differences between the latter two con-

ditions ($t(17) = 1.3$, $p = 0.2$). For the effect of electrode position, LPC amplitude was larger in the parieto-central area than in the central area (4.9 μV vs. 4.0 μV, $t(17) = 3.4$, $p < 0.05$). Difference waves were computed for the *Recent Negative minus Non-recent Negative* comparison. Mean amplitudes of the difference waves in the LPC time window (500–600 ms) were then entered into one-sample t-tests to produce a scalp topography illustrating the effects of recency (Fig. 3b).

LPC latencies were analyzed with a one-way ANOVA, which revealed a significant effect of trial type, $F(2, 34) = 11.5$, $p < 0.001$. LPC latency was significantly shorter for the Positive condition (412 ms) than for the two Negative conditions (Non-recent Negative: 483 ms, $t(17) = 4.2$, $p < 0.005$; Recent Negative: 472 ms, $t(17) = 3.8$, $p < 0.005$). LPC latency was not different between the two Negative conditions ($t(17) = 0.7$, $p = 0.5$).

4. Discussion

The behavioral results showed significantly faster responses in the positive condition than in the negative condition[1], replicating

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[1] *Note*: the result that error rates were higher in the positive trials than in the negative trials was previously observed in Du et al. (2008) but not in Zhou et al. (2004), although both used a Sternberg task similar to the present task. One possibility is that the Du et al. (2008) study and the present study, but not the Zhou et al. (2008) study, were on proactive interference and involved lure probe items. Participants may have developed a negative response bias to guard against errors in trials with lure probes, which resulted in more misses than false alarms. This bias, however, should not affect our results of the critical comparison between the two types of negative trials.
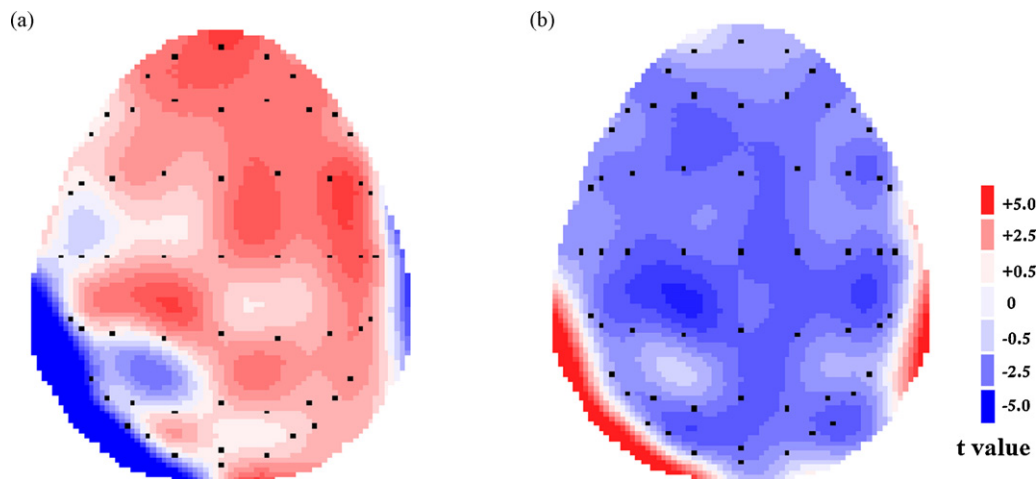
Fig. 3. Scalp distributions plotted based on one-sample *t*-tests of mean amplitudes for: (a) the *Positive minus Negative* difference waves in the N2 time window (250–350 ms, the left gray bar at CZ in Fig. 2) showing effects of response type (the two Negative conditions were pooled) and (b) the *Recent Negative minus Non-recent Negative* difference waves in the LPC time window (500–600 ms, the right gray bar at CZ in Fig. 2) showing effects of recency.

the typical finding in the Sternberg task (Sternberg, 1966). Recent Negative trials were significantly slower and less accurate than the Non-recent Negative trials, replicating the PI effect found in previous studies using the recent probes tasks (Jonides et al., 1998; Nee et al., 2007). Two ERP components were elicited by the probe, an early N2 with a fronto-central distribution and a late positivity (LPC) with a parietal distribution. Compared to the negative condition, the positive condition was associated with reduced N2 amplitude, enhanced LPC amplitude, and shortened LPC latency. LPC amplitude was smaller for the Recent Negative condition compared to the Non-recent Negative condition, but the two conditions did not differ in N2. As the most critical finding, the last result showed that the recency manipulation modulated LPC but not N2. We consequently identified LPC as the neural correlate of proactive interference in the present study.

In the following, we will first describe how we conceptualize the N2 and LPC effects that differentiated between the positive and negative responses, and then discuss the theoretical implications for associating PI with LPC, followed by a comparison with other ERP studies on PI in working memory. In the end, we will describe related PI research in long-term memory to indicate a potential extension of the present research.

The N2 and LPC differences between the recognition of positive and negative responses are highly robust findings, as they have been observed in previous studies employing the Sternberg paradigm (Danker et al., 2008; Du et al., 2008; Kramer, Strayer, & Buckley, 1991; Zhou, Zhang, Tan, & Han, 2004). In long-term memory, there are two well-known effects associated with the recognition of old items as compared to new items, the FN400 effect occurring between 300 and 500 ms, and the parietal old-new effect occurring between 500 and 800 ms (for review, see Rugg & Curran, 2007). Danker et al. (2008) recently proposed that the N2 and LPC effects in short-term memory may correspond to the FN400 and the parietal old/new effects in long-term memory respectively, as they responded to task manipulations in similar ways. While this proposal needs to be further established with more empirical evidence, it is tentatively adopted in the present study as a reasonable assumption. Consequently, we associate our N2 effect with conceptual priming and our LPC effect with familiarity and episodic recollection, according to popular interpretations of FN400 and the parietal old/new effect (see Section 1).

In light of this conceptualization, the identification of LPC as the neural correlate of PI in the present study supports the notion that PI is associated with a processing stage wherein both famil-

iarity and contextual information are available. This confirms the prediction from the biased-competition model of PI (Jonides & Nee, 2006). According to this model, when evaluating available evidence for probes in the Positive and the Non-Recent Negative trials for a *yes*/*no* decision, context and familiarity codes match with each other. A probe in positive trials has high level of familiarity and strong associations with the present trial's context, both indicating evidence in favor of its being recently seen and prompting a *yes* response. A probe in Non-Recent Negative trials has low level of familiarity and weak contextual associations, both indicating evidence in favor of its not being recently seen and prompting a *no* response. However, in the case of Recent Negative trials, familiarity level is high providing evidence in favor a *yes* response, whereas recollection based on contextual information provides evidence in favor of a *no* response. This mismatch between the two types of information should initiate additional control processes to bias decision-making to rely more on the correct contextual information instead of the misleading familiarity information. This will delay decision-making and produce performance decrements in these trials. Such performance decrements may be accompanied by reduced confidence during recognition, which has been associated in some studies with reduced amplitude of the parietal old/new effects (Curran, 2004; Curran, Debuse, Woroch, & Hirshman, 2006; Woodruff, Hayama, & Rugg, 2006). For example, Woodruff et al. (2006) found that less confident old items tend to have more negative-going ERPs than confident old and new items.

Different from the present study, the recency manipulation was found to modulate the frontal N2 in Du et al. (2008). One possibility is that their PI effect may not result from familiarity but rather from directed forgetting task requirements. When explicitly instructed to forget a set of items (To-Be-Forgotten, or TBF items) within each trial, their participants may have suppressed the mental representations associated with these items, making them less accessible (Ullsperger, Mecklinger, & Müller, 2000). This could incur a processing delay when these items appeared later as probes in the Recent Negative condition, compared to the Non-recent Negative control probes. In comparison to such within-trial manipulation, the present task showed cross-trial interference from previous trial items that were not explicitly relevant to the current trial.

Under our earlier assumption that identifies N2 with FN400, the N2 effect in Du et al. (2008) may alternatively reflect conceptual priming due to representation of the TBF items. As the TBF items were part of the study set and only removed from active memory

maintenance later in a trial, they would produce conceptual priming when they re-appeared as probes just as the positive probes do. Such a priming effect would, however, be less than that from the positive probes that were maintained throughout the trial. This matches with the finding in Du et al. (2008) that N2 in the Recent Negative condition did not differ as much as the Positive condition did from the Non-recent Negative condition (with the difference taken to indicate conceptual priming).

In the present study, the Positive condition but not the Recent Negative condition showed a N2 effect compared to the Non-recent Negative condition. Given both conditions involved repetition (i.e., probes in Positive trials repeated a study item in the current trial, and probes in Recent Negative trials repeated a study item in a previous trial), one needs to explain why conceptual priming was found in one condition but not the other. We suggest that within-trial repetition effects (i.e., in the Positive condition) may be stronger, possibly because they occur over a shorter temporal interval, compared with cross-trial repetition effects (i.e., in the Recent Negative condition). This difference may be amplified in the present task that, like many other working memory tasks, involved the overuse of a small set of items across a large number of trials (Tays et al., 2009). Such overuse may have driven the conceptual representations of all items in the set to a highly active state during the experimental session. Cross-trial repetitions may not be able to significantly enhance the representations to produce noticeable conceptual priming, compared to within-trial repetitions.

Task differences may also account for the different results between the present study and that from Tays et al. (2008, 2009) who associated PI with a frontal N450 component known to index response conflict and inhibitory processes (Rebai, Bernard, & Lannou, 1997; West & Alain, 1999). Though using the recent probes task as we did, Tays et al. (2008, 2009) included a condition where the same probe would occur in two consecutive trials ($n - 1$ and n) requiring a positive response in the former but a negative response in the latter, thus producing response conflict in trial n. Furthermore, in 3/4 of their negative trials, the probe in trial n was taken from items in trial $n - 1$. Therefore, awareness that items from previous trials may reappear and thus interfere with current response may have prompted their participants to be cautious with all items that were not in the present target set but looked familiar. Thus, they may have withheld responses until they were certain. Hence, the same inhibitory N450 was elicited for trials involving response conflict as well as trials involving proactive interference.

There are only two electrophysiological studies of PI in long-term memory. In Uhl, Franzen, Serles, Lindinger, and Deecke (1990), participants first learned one list of words pairs. They then learned another list consisting of either new pairs or pairs rearranged from those in the first list. Cued recall of the rearranged pairs was less accurate compared to the new pairs, demonstrating a proactive interference. The authors observed negative DC shifts and larger P3 during acquisition associated with the PI effect. They interpreted these results to indicate enhanced neural processing for controlling interference. Also using a paired-associate learning task, Rößner, Rockstroh, Cohen, Wagner, and Elbert (1999) observed PI-related ERP effects, including larger early and late positive components during acquisition and more negative late slow waves during cued recall. It would be difficult to compare these studies with the present one, given the many task differences between them. More studies are needed to examine the neural correlates of PI in both short-term and long-term memories, preferably using similar paradigms. To this end, one possibility in future research is to extend the present paradigm to include recency intervals ranging from seconds to minutes. Such research would not only provide insights into proactive interference but also constitute a new approach to understanding the relationship between the two memory systems.

5. Conclusion

The present study examined the neural correlates of PI in working memory using ERPs. ERP waveforms associated with memory recognition were found to distinguish between positive and negative probes in an early N2 component and the LPC. The LPC but not the N2 component differentiated between two types of negative probes defined based on whether they were recently encountered, and was therefore identified as the electrophysiological signature of proactive interference. When considered together with related studies in the literature, our results suggest that PIs observed in different experimental tasks are associated with different neural correlates. This indicates the necessity of ERP studies on proactive interference to reveal its temporal dynamics and to complement studies using behavioral and fMRI methodologies.

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