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Masked repetition priming hinders subsequent recollection but not familiarity: A behavioral and event-related potential study

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Abstract The present study used the masked repetition priming paradigm in the study phase and the R/K paradigm in the test phase to investigate whether repetition priming can hinder recognition memory and which recognition process (familiarity or recollection) is hindered. Event-related potentials (ERPs) in the study and test phase were recorded to explore the temporal course of how repetition priming hinders subsequent recognition memory and which old/new effect (FN400 or LPC) is affected. Converging behavioral and ERP results indicated that masked repetition priming hindered subsequent recollection but not familiarity. The analysis of ERP priming effects in the study phase indicated that primed words were associated with less negative N400 and less positive LPC compared to unprimed words. The analysis of the priming effect as a function of subsequent memory revealed that only the LPC priming effect was predictive of priming effect on subsequent memory, which suggested that the "prediction-error" account might be a possible explanation of how repetition priming affects subsequent recognition memory.

Keywords Masked repetition priming · Familiarity · Recollection · N400 · LPC

The relationship between repetition priming and recognition memory is a long-lasting hotspot in the field of memory research. Repetition priming, one kind of implicit memory, is reflected by increased processing fluency, for example, more accurate and faster responses to previously encountered items compared to new items with no reference to conscious recall (Richardson-Klavehn & Bjork, 1988; Schacter & Buckner, 1998). Recognition memory (i.e., explicit memory) refers to the conscious retrieval of previous events. According to dual-process models of recognition memory, recognition memory is supported by two distinct processes: familiarity and recollection. Recollection refers to the recognition experience accompanied by recall of the context or other relevant information associated with prior events, whereas familiarity refers to the recognition experience without recall of any context or other relevant information (Mandler, 1980; Yonelinas, 2002).

Research on the relationship between repetition priming and recognition memory has mainly focused on whether they reflect different memory systems, for example, multisystem theories posit that repetition priming and recognition memory are independent and reflect different memory systems (e.g., Squire, 2004; Tulving & Schacter, 1990), whereas, single-system theories posit that the two forms of memory depend on the same memory system (e.g., Berry, Shanks, & Henson, 2008). However, little work has been conducted to investigate when and how these two forms of memory can interact with each other.

In a pioneering functional magnetic resonance imaging (fMRI) study, Wagner, Maril, and Schacter (2000) let participants perform the same semantic task after a long lag (25-hour) or a short lag (3-minute) in the incidental reencoding phase. They found that words repeated after a short lag were

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associated with greater behavioral (reduced reaction times; RTs) and neural priming effect (reduced brain activities in the left inferior prefrontal cortex; LIPC) but worse subsequent recognition memory compared to those repeated after a long lag. In addition, they found a negative relationship between behavioral and neural priming and subsequent high-confidence recognition memory for words repeated after a long lag. These results provided the first evidence that repetition priming can interact with recognition memory by hindering episodic encoding (Wagner et al., 2000). However, Stark, Gordon, and Stark (2008) proposed that the results in Wagner et al. (2000) might, in fact, reflect opposing effect of task demands (i.e., lag and task consistency) on priming and recognition memory (e.g., long lag results in improved recognition memory but less priming compared to short lag) but not the effect of priming on episodic encoding. Their study cast doubt on the view that repetition priming can interact with recognition memory. Therefore, experiments that can mitigate the influence of task demands are needed to investigate whether repetition priming can "truly" interact with recognition memory.

Masked repetition priming paradigm is a good candidate for this purpose. In a typical masked repetition priming experiment, a masked prime item, which is either the same (primed item) or unrelated to the target item (unprimed item), is briefly presented before the target item. The processing fluency of the primed item is increased (e.g., faster responses) compared to unprimed item even though participants were unaware of the presentation of the prime item (e.g., Jacoby & Whitehouse, 1989; Woollams, Taylor, Karayanidis, & Henson, 2008). As primed and unprimed words are presented in the same incidental encoding task, the contamination of lag and task consistency can be mitigated. Therefore, the masked repetition priming paradigm was used in this study to investigate whether repetition priming can indeed interact with recognition memory.

Although the study of Wagner et al. (2000) suggested that brain activities at LIPC might be responsible for priming effect on subsequent recognition memory, the temporal course of how repetition priming impairs subsequent memory remains unknown. It can help to examine whether this effect results from early perceptual or conceptual processing, from late elaborative encoding activities, or from both by investigating the temporal course of how repetition priming impairs subsequent recognition memory. Event-related potential (ERP), which is an advantage of high temporal resolution, is suitable to investigate this. Therefore, ERPs during the study phase were recorded in the present study to explore the temporal course of how repetition priming impairs subsequent recognition memory.

ERP has been used widely to investigate the neural correlates of masked priming effect using lexical decision tasks (e.g., Misra & Holcomb, 2003; Vergara-Martínez, Gómez, Jiménez, & Perea, 2014). Studies using the masked repetition priming paradigm have found that an earlier priming effect around the latency of P200, which was supposed to be associated with earlier perceptual processing, and a later priming effect around the latency of N400, which was assumed to be related to lexical and conceptual-level processing, were associated with masked repetition priming effects (e.g., Holcomb & Grainger, 2006; Misra & Holcomb, 2003; Woollams et al., 2008). Significant later priming effects (e.g., late positive potential; LPC) were rarely reported in masked repetition priming studies. Most studies did not include late time windows in their analysis (e.g., Eddy & Holcomb, 2010; Holcomb & Grainger, 2009). Studies that did include the later time window rarely obtained significant priming effect during this time window (e.g., Holcomb, Reder, Misra, & Grainger, 2005; Misra & Holcomb, 2003).

However, ERP studies investigating encoding activities suggested that episode-encoding activities were associated with late ERP components (e.g., LPC). It was found that ERPs of subsequently remembered items are more positive than subsequently forgotten items from 400 ms poststimulus onset to 800 ms, which is referred to as DM effect (difference due to subsequent memory effect; Paller, Kutas, Shimamura, & Squire, 1987; Paller & Wagner, 2002). Although some studies reported differences between ERPs in subsequently remembered and forgotten items in earlier time windows (e.g., 300 ms–500 ms), these effects were supposed to reflect other processing (e.g., semantic processing) during encoding and might not be predictive of subsequent memory (e.g., Cansino, Trejo-Morales, & Hernandez-Ramos, 2010; Kuo, Liu, Ting, & Chan, 2012). Because encoding activities and priming effects are associated with temporally different ERP components, we can find out processing at which level (e.g., early perceptual or late encoding processing) was related to a priming effect on subsequent memory by investigating the priming effects in the encoding phase.

The analysis of ERP priming effects in the encoding phase also might help to test possible accounts of how repetition priming affects subsequent memory. Wagner et al. (2000) proposed that repetition priming hinders subsequent recognition by reducing encoding variability. In their view, repetition priming decreases the variability and increases the scarcity of the semantic features encoded into the memory traces by increasing the probability that the same task-relevant stimulus features are processed. Besides this "semantic" account, a "predictive coding" account also could explain the effect of repetition priming on subsequent memory. In this view, repetition priming is assumed as a decrease in prediction error for primed items or an increase in prediction error for unprimed items (Friston, 2005; Summerfield, Trittschuh, Monti, Mesulam, & Egner, 2008; Summerfield, Wyart, Johnen, & De Gardelle, 2011). Prediction error of unprimed items can enhance episodic encoding as it triggers attentional resources, which results in improved subsequent memory (for a similar argument, see Henson & Gagnepain, 2010). The "semantic" account would predict that ERPs associated with semantic processing should be interacted with subsequent recognition memory, whereas, the prediction-error view would predict that ERPs associated with prediction error should be interacted with subsequent recognition memory.

As mentioned in the beginning, recognition memory is supported by two distinct processes: familiarity and recollection. It is important to see whether repetition priming affects subsequent recollection and familiarity to the same extent. The present study utilized remember/know (R/ K) paradigm in the test phase (Tulving, 1985; for a review, see Migo, Mayes, & Montaldi, 2012), which is one of the most widely used paradigms to distinguish familiarity and recollection process, to examine the specific effect of repetition priming on subsequent familiarity, and recollection. In addition, ERP can also help to determine which recognition memory process is affected by repetition priming at the encoding phase. Prior studies of recognition memory have found that spatio-temporally different ERP old/new effects, in which more positive ERPs are associated with correct old responses compared to correct rejections (CRs), are associated with familiarity and recollection: the FN400 old/new effect, which is frontal-central distributed around 300 ms to 500 ms poststimulus onset, is correlated to familiarity (although some researchers posited that FN400 is correlated to conceptual priming rather than familiarity recently; e.g., Paller, Voss, & Boehm, 2007), and the LPC old/new effect, which is central-parietal distributed around 500 ms to 800 ms poststimulus onset, is correlated to recollection (e.g., Curran, 2000; Rugg et al., 1998; for a review, see Rugg & Curran, 2007). Therefore, which recognition memory process is impaired by repetition priming in the encoding phase can be determined by investigating the FN400 and LPC associated with primed and unprimed (in the encoding phase) words in the test phase.

In sum, this study aimed to investigate whether repetition priming can indeed interact with recognition memory by hindering episodic encoding, while mitigating the contamination of task demands by using masked repetition priming paradigm and to explore the temporal course of how repetition priming impairs subsequent recognition memory by using ERP. In addition, the R/K paradigm and ERP were utilized in the test phase to determine which recognition memory process (familiarity or recollection) was affected by repetition priming.

Method

Participants

Twenty-three students (17 females, 22[±3] years old, all right handed) participated in this experiment. All participants had normal (or corrected to normal) vision and no neurological illness. Data of three participants were not included in analysis because of too much muscle artifacts and electrode drift (>25 % trials). All participants signed an informed consent and got paid for their participation. This research was approved by the Human Research Ethics Committee of Capital Normal University.

Stimuli

Four hundred two-character Chinese words, half living and half nonliving, mean total strokes: 16 (6–34), mean word frequency: 34 (5–99) occurrence per million (Liu et al., 1990) were used as stimuli. The old/new and priming/unpriming status of the word sets were counterbalanced across participants. An additional 28 words were used in filler and practice trials.

Procedure

There was an incidental study phase and a test phase (consisting of two test blocks) in this experiment. Participants were asked to perform a "living/nonliving" judgment task in the study phase. Participants took a practice test, which consisted of 20 words to become familiar with the procedure of the living/nonliving judgment task before the formal study block. Two hundred words (half living and half nonliving) were presented in the study block. Another four filler words (two at the beginning and two at the end) were presented to avoid primacy and recency effects. Each word was preceded by a briefly, masked prime, which was either the same (*primed words*, 50 %) or unrelated (an unrelated word of the same prime status, *unprimed words*, 50 %) to the target word. On contrast to typical priming task, response accuracy was emphasized whereas response speed was not encouraged in this experiment to improve subsequent memory performance by increasing semantic and elaborative processing of the words.

Participants were told about the surprise memory test and instructions about R/K responses immediately after the study phase. A practice test, which consisted of 10 words (six from the practice block and four new words), was performed before the test phase to make sure participants understood the R/K instructions correctly. Two hundred words (half studied and half unstudied) were presented in each test block. Participants were asked to indicate whether they had seen the word in the study phase or not by responding old (seen) or new (not seen). If they responded old, they were prompted to report whether they recollected the word (R judgment) or just felt the word was familiar (K judgment). The label *familiar* but not *know* was used in this experiment to minimize colloquial biases associated with "knowing'," as posited by Taylor and Henson (2012), but the label K was used in this paper to follow the literature. Participants were asked to respond R if they could recall any specific information associated with the test word in the study phase (e.g., they could recall their feeling when they saw the word or they could recall what the word looked like in the screen in the study phase) and to respond K if they could not recall any such information. Stimulus presentation and response collection were performed using Presentation (Neurobehavioral Systems, Inc.).

The schematic of trial procedure in the study and test phases is shown in Fig. 1. Stimuli were presented in white against black background on the center of a CRT computer screen (refresh rate 85 Hz) positioned approximately 70 cm in front of the participant. In the study phase, each trial began with a fixation cross, which was presented randomly between 1,506 and 2,000 ms. Then, a 306-ms forward mask was presented, followed by a 35-ms prime word, and then a 70-ms backward mask was presented. The target word was presented immediately after the backward mask for 1,506 ms. In the test phase, each test trial began with a fixation cross, which was presented randomly between 1,506 and 2,000 ms, followed by the test word, which was presented for 506 ms, then a 2,000-ms blank screen was presented, during which participants made the old/new judgment; if participants made an “old” judgment, the prompt “remember or familiar” (in Chinese) was presented until participants made the R/K judgment, and the next trial began immediately after participants' response. If they responded “new” or failed to respond within 2,000 ms, the next trial was presented. Response assignments were counterbalanced across living/nonliving, old/new, and R/K responses.

Participants were not told about the presentation of masked prime words during the experiment. They were told that the presentation of the flickering symbols was used to obtain a baseline measure of EEG. In the interview about the awareness of the masked prime word after the experiment, 6 of the 20 participants reported that they were aware that something was presented during the flickering symbols, and three of them reported that they knew it was word and could identified the word in some trials. The remaining reported that they could not identify what was presented or they knew it was word but could not identify the word in most of the trials.

EEG recording and data analysis

The EEGs were recorded with 64 Ag/AgCl electrodes positioned in a nylon electrode cap by Neuroscan system. Electrode impedance was kept below 5 kΩ. The EEGs were recorded with a band pass of 0.05 to 40 Hz (0.05–30 Hz filtered offline), and sampled at a rate of 500 Hz. All channels were referred to the left mastoid electrode (rereferenced to averaged mastoids in offline analysis). Electrodes were placed above and below the center of left eye and on the canthi of the eyes to record vertical and horizontal electro-oculograms. Ocular artifacts were corrected by the method from Semlitsch, Anderer, Schuster, and Presslich (1986). EEGs were segmented into epochs from 100 ms prior to stimulus onset to 900 ms after stimulus onset (with the prior 100 ms served as baseline correction). To save more trials for analysis of the priming effect as a function of subsequent memory (R, K, Miss), robust averaging, which as embodied in SPM12 software, was used for averaging (Litvak et al., 2011; Wager,

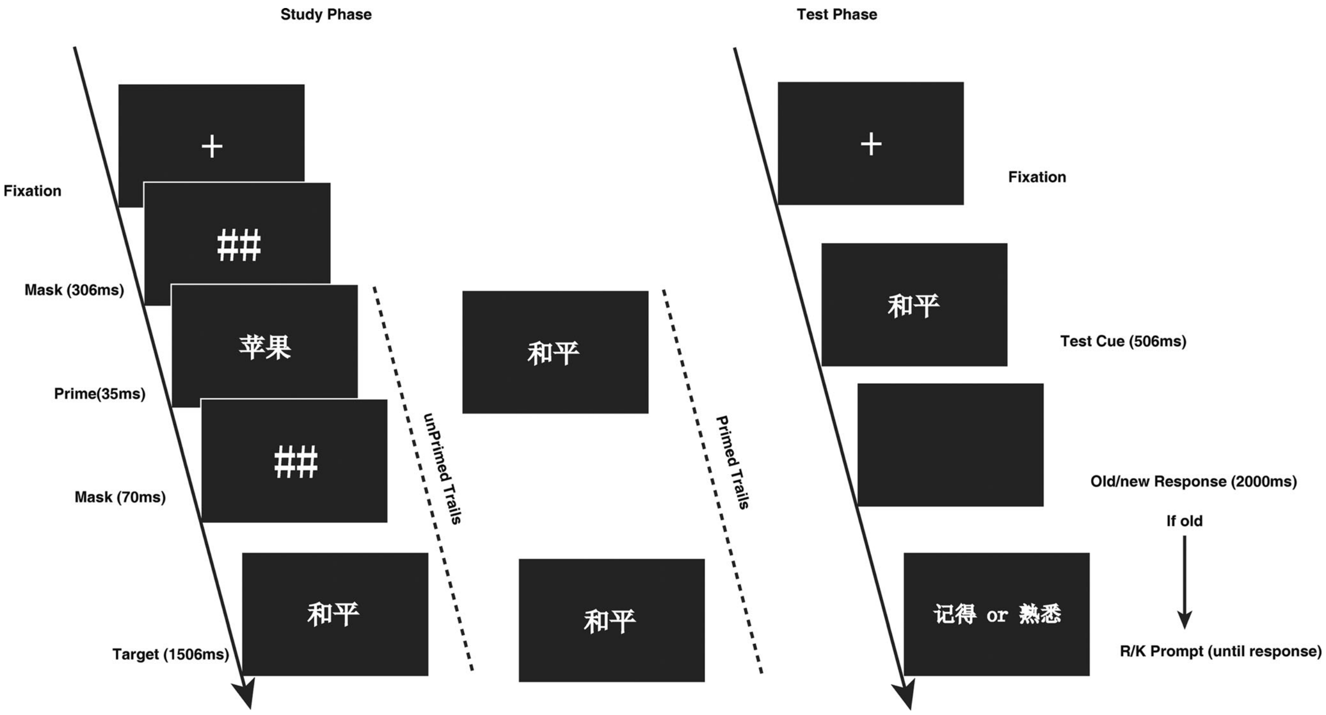

Fig. 1 Schematic of trial procedure in study and test phase

Keller, Lacey, & Jonides, 2005). A low-pass filter (30 HZ) was applied after robust averaging because it might induce some high-frequency noise. Three midline electrode clusters were selected in the analysis of the ERPs. The clusters were frontal: F1, FZ, and F2; central: C1, CZ, and C2; parietal: P1, PZ, and P2. Statistical comparisons were performed using a repeated-measures ANOVA (criterion $p = .05$). Greenhouse–Geisser correction was used where appropriate (however, uncorrected freedom was reported with a corrected p value in the results part). Bonferroni correction was utilized in post hoc comparisons.

Results

Behavioral data

Study phase

In order to investigate whether masked priming affected the performance of subjects in the study phase, a paired t test was conducted on RTs and accuracy of the living/nonliving judgment task to primed and unprimed words. The paired t test on RTs revealed that participants responded faster to primed words than unprimed words, 644 (±68) ms versus 676 (±60) ms, $t(19) = 5.163$, $p < 0.001$, which indicated that processing of primed words was facilitated compared to unprimed words even though response speed was not encouraged in the present study. However, the paired t test on accuracy revealed no difference between the accuracy to primed and unprimed words, 0.96 (±0.02) versus 0.97 (±0.02), $t(19) = 0.691$, $p = .498$, which might result from a ceiling effect because the task was relatively easy in the study phase.

Test phase

The mean proportions of each response type to studied and unstudied words are depicted in Table 1. Overall accuracy (Pr, calculated as the proportion of hits minus the proportion of false alarms, collapsed across primed and unprimed words; Snodgrass & Corwin, 1988) was 0.31 (±0.12) for R judgments and 0.17(±0.11)for K judgment. The Pr values of R and K responses were both significantly greater than zero, $t(19) = 12.036$, $p < .001$, and $t(19) = 7.282$, $p < .001$, respectively. These results indicated that R and K judgments were above chance level in the present study.

Table 1 Mean proportions (in percentage, with standard deviation in brackets) of each response type to studied (primed and unprimed in the study phase) and unstudied words

Study status	Priming status	Remember	Know	New
Studied	Primed	34(12)	31(13)	35(15)
	Unprimed	38(11)	30(12)	32(14)
Unstudied		4(4)	14(6)	82(8)

To investigate the effect of repetition priming on subsequent memory, a two-way ANOVA, which involved priming status (primed/unprimed in the study phase), and response type (R/K), was conducted on proportions of R and K responses to studied words. It revealed a marginally significant main effect of priming status and a significant two-way interaction, $F(1, 19) = 3.907$, $p = .063$, and $F(1, 19) = 4.67$, $p = .044$, respectively. Separate paired t tests on R and K responses indicated that the proportion of R responses was significantly greater for unprimed than for primed words, $t(19) = 2.992$, $p = .007$, whereas the proportion of K responses was not significantly different between primed and unprimed words, $t(19) = 0.696$, $p = .495$. These results indicated that repetition priming impaired subsequent recollection but not familiarity.

ERP data

Study phase

Overall priming effects A time window of 300 ms to 500 ms, which is consistent with the latency of N400, and a time window of 500 ms to 700 ms, which is consistent with the latency of LPC, were taken to index the priming effect in the formal analysis according to former studies (e.g., Holcomb et al., 2005; Lucas, Taylor, Henson, & Paller, 2012).[1] To investigate the overall priming effects, a two-way ANOVA, involving priming status (primed/unprimed) and electrode cluster (frontal/central/parietal), was conducted on ERPs to primed and unprimed words. Grand-averaged ERP waveforms for primed and unprimed words and the topographic maps of the overall priming effect (ERPs to primed words minus ERPs to unprimed words) between 300 ms and 500 ms and 500 ms and 700 ms are shown in Fig. 2.

300 ms–500 ms The two-way ANOVA, involving priming status (primed/unprimed) and electrode cluster (frontal/central/parietal), conducted on ERPs to primed and unprimed words revealed a significant main effect of priming status and a significant two-way interaction, $F(1, 19) = 15.943$, $p < .001$, and $F(2, 38) = 7.263$, $p = .006$, respectively. Although the priming effect was greater at the central and parietal electrode clusters compared to the frontal electrode cluster (frontal: 1.1; central: 1.75; parietal: 1.65), amplitudes of ERPs to

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[1] Analysis, in which a time-window was chosen from time-point analysis was reported in the supplementary file. The results of time-point analysis were similar to the results in the main part.

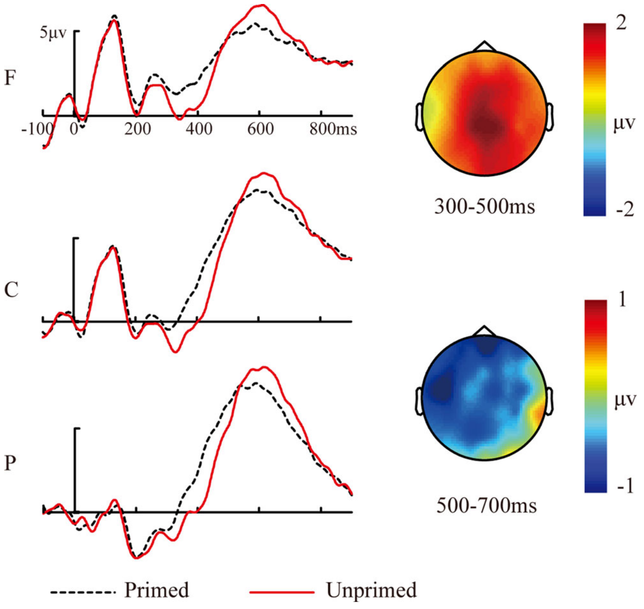

Fig. 2 Grand-averaged ERP waveforms for primed and unprimed words and the topographic maps for the overall priming effect (ERPs to primed words minus ERPs to unprimed words) between 300 ms and 500 ms and 500 ms and 700 ms in the study phase. F: frontal electrode cluster; C: central electrode cluster; P: parietal electrode cluster

primed words were less negative than unprimed words at all three electrode clusters, frontal: $t(19) = 3.139$, $p = .005$; central: $t(19) = 4.307$, $p < .001$; parietal: $t(19) = 4.022$, $p = .001$. These results indicated that the priming effect during 300 ms to 500 ms was central-parietal maximum distributed.

500 ms–700 ms The two-way ANOVA, involving priming status (primed/unprimed) and electrode cluster (frontal/central/parietal), conducted on ERPs to primed and unprimed words revealed a marginally significant main effect of priming status, $F(1, 19) = 3.849$, $p = .06$, and no significant two-way interaction effect, $F(2, 38) = 0.63$, $p = .494$. These results suggested that amplitudes of ERPs to unprimed words were marginally more positive than primed words.

Repetition priming effects as a function of subsequent memory In order to investigate which repetition priming effect is related to the priming effect on subsequent memory, ERPs to primed and unprimed words were averaged as a function of subsequent memory (R/K/Miss). If the ERP priming effect is related to the priming effect on subsequent memory, there should be an interaction between subsequent memory and priming status. Thus, a three-way ANOVA, involving subsequent memory (R/K/Miss), priming status (primed/unprimed), and electrode cluster (frontal/central/parietal) was conducted on ERPs to primed and unprimed words as a function of subsequent memory. Data of four subjects were excluded in this analysis for less than 15 artifact-free trials in any condition. The ERP waveforms for primed and unprimed words as a function of subsequent memory are shown in Fig. 3.

300 ms–500 ms The three-way ANOVA, involving subsequent memory (R/K/Miss), priming status (primed/unprimed), and electrode cluster (frontal/central/parietal) conducted on ERPs to primed and unprimed words as a function of subsequent memory, revealed a significant main effect of subsequent memory, $F(2, 30) = 3.592$, $p = .046$, and a significant main effect of priming status, $F(1, 15) = 24.292$, $p < .001$. None of the three-way or other two-way interaction effects were significant (all $ps > .1$). These results suggested that the priming effect during 300 ms to 500 ms was similar across words with subsequently R, K, and Miss responses, which indicated that this priming effect was not predictive of subsequent memory.

500 ms–700 ms The three-way ANOVA, involving subsequent memory (R/K/Miss), priming status (primed/unprimed), and electrode cluster (frontal/central/parietal) conducted on ERPs to primed and unprimed words as a function of subsequent memory, revealed a significant main effect of subsequent memory and a two-way interaction between subsequent memory and priming status, $F(2, 30) = 6.722$, $p = .005$, and $F(2, 30) = 3.465$, $p = .048$. ERPs to words with subsequent R responses were more positive for unprimed than primed trials, $t(15) = 3.103$, $p = .007$, whereas ERPs for words with subsequent K and Miss responses were not different between primed and unprimed trials, $t(15) = 1.009$, $p = .329$, and $t(15) = 0.334$, $p = .743$, respectively. None of the three-way or other two-way interaction effects were significant (all $ps > .1$). These results suggested that the priming effect (ERPs to unprimed word minus ERPs to primed words) during 500 ms to 700 ms was greater for subsequently recollected words than subsequently known and missed words, which indicated that this priming effect was predictive of subsequent recollection based recognition memory.

Test phase

Basic memory effects In order to investigate the basic memory effects (FN400 and LPC old/new effects), ERP responses were collapsed across primed and unprimed (in the study phase) words to compare ERPs for R hits, K hits, and CRs. Neural activity for familiarity was examined by contrasting K hits with CRs, while neural activity for recollection was examined by contrasting R hits with K hits. Thus these contrasts were of particular interest in the following analysis: A time window of 300 ms to 500 ms and a time window of 500 ms to 800 ms were taken to indexed FN400 and LPC old/new effects, respectively, based on previous studies (e.g., Rugg et al., 1998; Woollams et al., 2008).[2] A two-way ANOVA,

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[2] Analysis, in which a time window was chosen from time-point analysis was reported in the supplementary file.

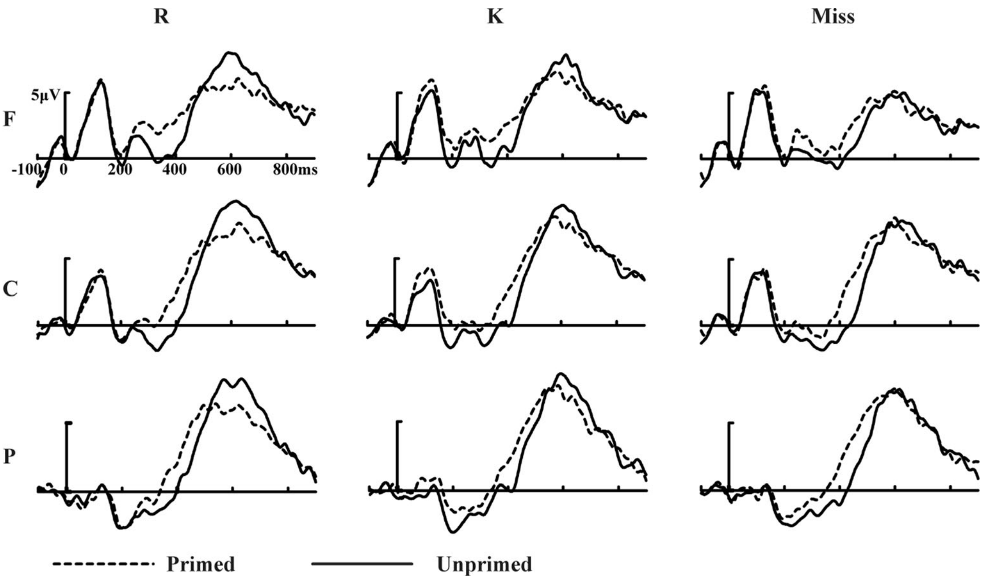

Fig. 3 Grand-averaged ERP waveforms for primed and unprimed words as a function of subsequent memory (R/K/Miss) in the study phase. F: frontal electrode cluster; C: central electrode cluster; P: parietal electrode cluster

involving response type (R/K/CR) and electrode cluster (frontal/central/parietal) was conducted separately for each time interval. Grand-averaged ERP waveforms for R hits, K hits, and CRs, and topographic maps of FN400 and LPC old/new effects, are shown in Fig. 4.

300 ms–500 ms The two-way ANOVA, involving response type (R/K/CR) and electrode cluster (frontal/central/parietal), revealed a significant main effect of response type and no significant interaction effect, *F*(2, 38) = 7.325, *p* = .003, and *F*(4, 76) = 1.82, *p* = .172, respectively. The post hoc comparison of the main effect of response type indicated that amplitudes of ERPs to R hits were less negative than CRs (*p* = .002) but were not different from K hits (*p* = .879). In order to examine the ERPs associated with familiarity specifically, a separate two-way ANOVAs, involving response type (K/CR) and electrode cluster (frontal/central/parietal), were

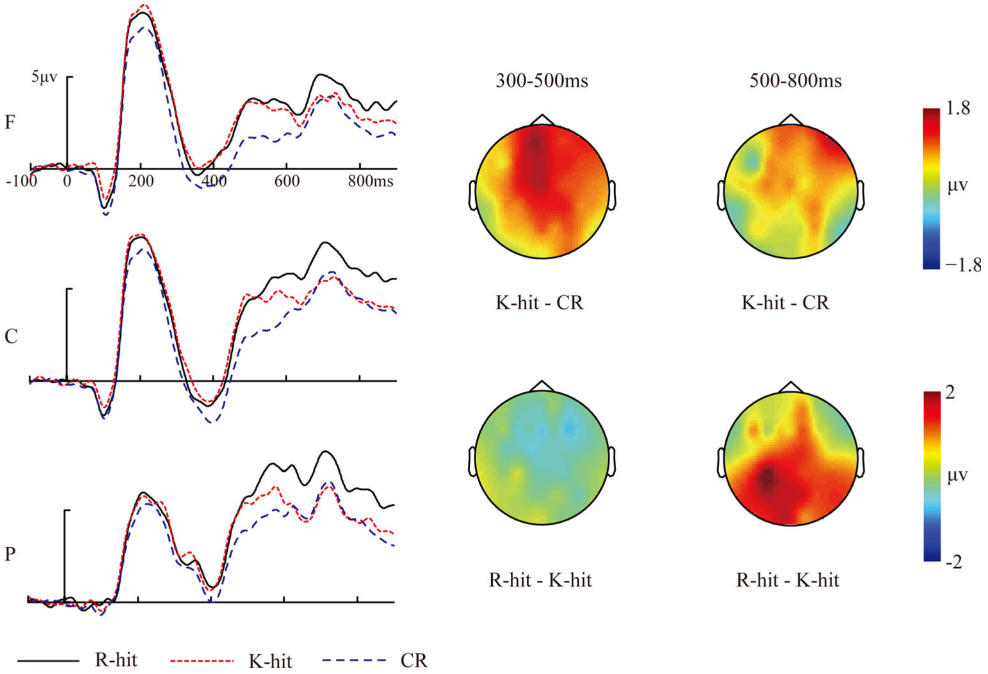

Fig. 4 Grand-averaged ERP waveforms for R hits, K hits, and CRs, and topographic maps of FN400 ("K-hits – CRs" at 300 ms–500 ms) and LPC ("R-hits – K-hits" at 500 ms–800 ms) old/new effects in the test phase. F: frontal electrode cluster; C: central electrode cluster; P: parietal electrode cluster

conducted on ERPs to K hits and CRs, which revealed a significant main effect of response type and a marginally significant two-way interaction, *F*(1, 19) = 17.229, *p* = .001, and *F*(2, 38) = 3.976, *p* = .049. Amplitudes of ERPs to K hits were less negative than CRs at all three electrode clusters, frontal: *t*(19) = 4.168, *p* = .001; central: *t*(19) = 4.427, *p* < .001; parietal: *t*(19) = 2.732, *p* = .013. These results indicated that the FN400 old/new effect between K hits and CRs was frontal-central maximum, which was consistent with previous researches.

500 ms −800 ms The two-way ANOVA , involving response type (R/K/CR) and electrode cluster (frontal/central/parietal), revealed a significant main effect of response type and a significant interaction effect, (*F*(2, 38) =5.922, *p* = .007, and *F*(4, 76) = 2.56, *p* = .071. The main effect of response type was significant at all three electrode clusters (all *p*s < .05). Post hoc comparisons indicated that amplitudes of ERPs to R hits were more positive than CRs at all three electrode clusters, frontal: *p* = .03; central: *p* = .004; parietal: *p* = .004, whereas amplitudes of ERPs to K hits were not different from CRs at all three electrode clusters, frontal: *p* = .296; central: *p* = .689; parietal: *p* = .986. In order to examine the ERPs associated with recollection specifically, a separate two-way ANOVAs, involving response type (R/K) and electrode cluster (frontal/central/parietal), were conducted on ERPs to R and K hits, which revealed a significant main effect of response type and a significant two-way interaction, *F*(1, 19) = 4.067, *p* = .058, and *F*(2, 38) = 4.275, *p* = .039. Amplitudes of ERPs to R hits were more positive than K hits at central and parietal electrode clusters, central: *t*(19) = 2.185, *p* = .042; parietal: *t*(19) = 2.516, *p* = .021, but not at frontal electrode cluster, *t*(19) = 1.013, *p* = .324. These results indicated that the LPC old/new effect between R hits and K hits was central-parietal maximum, which was consistent with previous researches.

Effect of repetition priming (in the study phase) on old/new effects The previous analyses revealed that even though the difference between both R versus CR and K versus CR is significant over the FN400, there is no difference between R and K responses, which suggested that the FN400 old/new effect reflected familiarity and the LPC old/new effect reflected recollection (e.g., Woollams et al., 2008). Therefore, which recognition memory process was affected by repetition priming can be tested by investigating which type of old/new effect was affected by repetition priming. As there was no primed or unprimed condition for unstudied words, analysis was conducted on ERP responses to words that were correctly identified as old (R or K hits) to examine which old/new effect was affected by repetition priming in the study phase. A three-way ANOVA, involving priming status (primed/unprimed in the study phase), response (R/K), and electrode cluster (frontal/central/parietal) was conducted on ERPs to primed and unprimed old hits during 300 ms to500 ms (FN400) and 500 ms to 800 ms (LPC) separately. Data of three subjects were excluded in this analysis for less than 15 artifact-free trials at any condition. Grand-averaged ERP waveforms for primed and unprimed old hits are shown in Fig. 5.

For the FN400, none of the main effect of priming status or two-way or three-way interaction effects involving priming status were significant (all *p*s > .1). For the LPC, the main effect of priming status was significant, *F*(1, 16) = 8.785, *p* = .009. The two-way interaction effect between response and priming status was not significant, *F*(1, 16) = 0.065, *p* = .801. These results suggested that repetition priming in the study phase only affected the LPC old/new effect, which indexes recollection.

In summary, the results of ERP data in the test phase were consistent with the behavioral results that repetition priming impaired subsequent recollection but not familiarity.

Discussion

Both the behavior and ERP results indicated that subsequent recollection but not familiarity was impaired by masked repetition priming in the study phase. These results provided stronger evidence for the view that repetition priming can interact with recognition memory by hindering new episodic encoding (Wagner et al., 2000) because the contamination of lag and task consistency was mitigated using a masked repetition priming paradigm. Furthermore, the present study explored the temporal course of how repetition priming affects subsequent recognition memory by analyzing ERPs associated with primed and unprimed words in the study phase.

Priming effect on behavioral and ERP responses in the test phase

Although the results of the present study supported the results of Wagner et al. (2000), they seemed to be contrary to studies that reported perceptual priming can enhance episodic encoding and increase subsequent recollection but not familiarity (Gagnepain, Lebreton, Desgranges, & Eustache, 2008; Gagnepain et al., 2011). They proposed that perceptual priming enhanced the integration of the item and its context (a noisy background sound) by “freeing up” attention from item processing, which increased subsequent recollection. However, there was no such context in the present study and in Wagner et al. In addition, the tasks of Gagnepain et al. (2008) and Gagnepain et al. (2011) emphasized on perceptual processing, whereas the present study and Wagner et al. involved more conceptual processing. We speculated that how priming affects episodic encoding might depend on the experimental context. When the task emphasizes perceptual processing and there was background associated with the items,

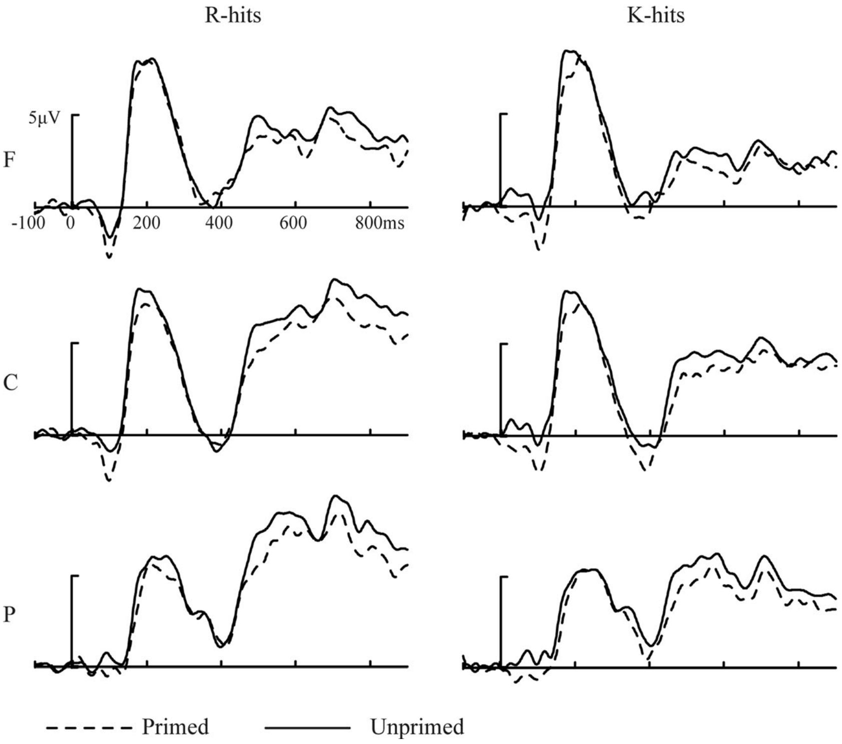

Fig. 5 Grand-averaged ERP waveforms for R and K hits as a function of prime status in the test phase. F: frontal electrode cluster; P: parietal electrode cluster. C: central electrode cluster

(perceptual) priming should facilitate subsequent memory by enhancing the integration of items and its context. However, when the task emphasizes conceptual processing and there was no such context, priming impaired subsequent memory by facilitating item processing and reducing encoding activities.

We should also mention that Turk-Browne, Yi, and Chun (2006) investigated the relationship between repetition priming and recognition memory. However, they presented all the items twice in the encoding phase and compared the repetition priming effect between subsequently remembered and forgotten items in their study, and they aimed to investigate whether implicit and explicit memory share neural mechanisms in encoding phase. These differences do not justify comparing the results of this study to the present study. However, these departures indicated that further studies are needed to investigate the factors that manipulate how priming affects episodic encoding.

Behavioral and ERP priming effects in the study phase

The RTs for primed words were faster than unprimed words, which implied that the processing of primed words was facilitated compared to unprimed words. The analysis of ERP data in the study phase revealed that an early negativity between 300 ms and 500 ms, and a late positivity between 500 ms and 700 ms were associated with priming effect. The amplitudes of ERPs to primed words were less negative than unprimed words during 300 ms and 500 ms and less positive than unprimed words during 500 ms and 700 ms. In addition, the 300-ms to 500-ms priming effect was similar across words with subsequent R, K, and Miss responses, whereas the 500-ms to 700-ms priming effect was greater for words with subsequent R responses, which suggested that the 500-ms to 700-ms priming effect but not the 300-ms to500-ms priming effect was related to the priming effect on subsequent recollection responses.

The latency of the early negativity is similar to N400, which reflects lexical and semantic (conceptual) processing of meaningful stimuli (Kutas & Federmeier, 2011). Less negative N400 reflects facilitated processing or accessing to lexical or conceptual information of target items. The N400 priming effect in the masked repetition priming paradigm might reflect more facilitated lexical-level than conceptual-level processing because it is assumed that more lexical- and prelexical-level presentations were activated than were conceptual level presentations by masked repetition priming (Holcomb et al., 2005; Lucas et al., 2012). However, conceptual-level processing should also be facilitated by masked priming because some studies found that masked semantic priming also elicited a significant N400 effect (e.g., Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002; but see Brown & Hagoort, 1993). Thus, the N400 priming effect in the present study might reflect more efficient lexical- and conceptual-level processing for primed words.

The latency of the late positivity is similar to LPC. As mentioned in the introduction, the LPC priming effect had rarely been reported in prior studies using a masked repetition priming paradigm. There are some procedure differences between these studies and the present study, which might cause the observation of an LPC priming effect in our study. The duration of a target word in most previous studies (e.g., 500 ms) was shorter than the present study (1,506 ms), and response speed was often encouraged in those studies. The short duration of target word and emphasis on response speed might interfere with the late ERP component. Another reason is that most previous studies did not take the subsequent memory performance into consideration. The results of this study indicated that the LPC effect was only significant for words with subsequent R responses, which suggested that encoding quality might affect the magnitude of the LPC priming effect. Further studies are needed to explore the factors that affects the LPC masked priming effect.

The LPC effect is usually obtained in recognition memory tasks or unmasked priming tasks and is supposed to be related to conscious recollection processing (e.g., Schnyer, Allen, & Forster, 1997). However, the LPC effect in the present study should not be elicited by conscious recollection of the masked prime word. First, most participants reported that they were not aware of the masked prime word. Second, the short duration of the prime words (35 ms) was not sufficient to form episodic trace, as suggested by a prior study in which no episodic memory was formed for the masked primes (Schnyer et al., 1997). In addition, the topographic distribution of the LPC old/new effect, which reflects conscious recollection, is central-parietal distributed (Rugg & Curran, 2007). However, the LPC priming effect in the present study is widely distributed in the scalp (mainly distributed in frontal and parietal regions). Therefore, the LPC effect in the present study should not reflect conscious recollection.

We speculate that the LPC effect in the present study reflects brain activities associated with episodic encoding. As mentioned in the introduction, previous studies have found that DM effect was associated with ERPs from 400 ms post-stimulus onset to 800 ms (e.g., Paller et al., 1987; for a review, see Friedman & Johnson, 2000; Paller & Wagner, 2002). The time window of the LPC priming effect in the present study is similar to the time window of the DM effect. And the topographic distribution of the LPC priming effect in the present study was also similar to the DM effect in prior studies, which is widely distributed in the scalp (mainly distributed in frontal and parietal regions). Therefore, the LPC priming effect might reflect more episodic encoding activities for unprimed words compared to primed words.

It was assumed that ERPs during this time window reflect encoding activities that can distinguish subsequent recollection from familiarity (Paller & Wagner, 2002) because previous studies have found that ERPs for items with subsequent recollection-based recognition (e.g., correct source recognition) were more positive than subsequently missed items, whereas ERPs for items associated with subsequent familiarity-based recognition (e.g., incorrect source recognition) were not different from subsequently missed items during this time window (e.g., Cansino et al., 2010; Mangels, Picton, & Craik, 2001). The DM effect during this time window is assumed to reflect the process of registering information into declarative memory, which is performed by the medial temporal lobe (MTL. Mangels et al., 2001). The frontal and parietal distributed DM effect during this time window might reflect the involvement of frontal lobe and MTL in episodic encoding, which is consistent with results of fMRI or positron emission tomography (PET) studies (Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; Cansino et al., 2010). Therefore, more positive ERPs of unprimed words might reflect more episodic encoding activities for unprimed words compared to primed words, which results in more R responses to unprimed words but not K responses in the test phase.

How repetition priming hinders subsequent recognition memory

As mentioned in the introduction, the semantic account proposed that priming hinders subsequent recognition memory because priming decreases the variability of the semantic features encoded into the memory, which would predict that ERPs associated with semantic processing (i.e., N400) should be predictive of the priming effect on subsequent memory. The analysis of the priming effect as a function of subsequent memory suggested that the LPC priming effect but not the N400 priming effect was predictive of the priming effect on subsequent R responses. This analysis indicated that more efficient lexical and semantic processing, reflected by the N400 priming effect, is not directly related to the priming effect on subsequent R responses. Therefore, the results of the present study might not support the semantic account.

We speculated that the results of the present study might support the prediction-error account. Although we interpreted the LPC priming effect as a reflection of encoding activities, the LPC priming effect might also be related to prediction error. First, prediction error can trigger attentional resources, which would enhance the encoding of unprimed words, which resulted in more positive LPC. Second, some recent ERP studies investigating the effect of prediction in language comprehension found that late positivity (LPC), around 500 ms after stimulus onset, which was similar to the LPC effect in the present study, might be related to the cost associated with unpredicted items (Federmeier, Wlotko, Ochoa-Dewald, & Kutas, 2007). These findings suggested that brain activities associated with the cost of prediction error might also contribute to the LPC priming effect in the present study. These interpretations indicated that the prediction-error account might be a possible explanation for the priming effect on subsequent memory.

Potential caveat

One potential caveat of this study is that masked repetition priming might not reflect the same underlying processes as unmasked repetition priming (Forster, Mohan, Hector, Kinoshita, & Lupker, 2003; Gomez, Perea, & Ratcliff, 2013), although some researchers have posited that masked and unmasked repetition priming reflect the same essential process (Bodner & Masson, 2001; Masson & Bodner, 2003). We used the masked repetition priming paradigm in the present study to mitigate the contamination of lag and task consistency, which is hard to realize by the unmasked repetition priming paradigm. Another advantage of the masked repetition priming paradigm is that it can mitigate the contamination of incidental explicit memory processing for the repeated words in unmasked repetition priming.

Although the present study suggested that more fluently processed items were associated with worse subsequent recognition memory, we do not imply that there is a straight relationship between processing fluency and episodic encoding. Multiple manipulations can affect processing fluency, and there are multiple levels of processing fluency (for s review, see Alter & Oppenheimer, 2009). It is still not clear fluency of which processing level (e.g., perceptual fluency, conceptual fluency) can affect episodic encoding. In addition, some studies found that increased processing fluency in the encoding phase had no effect on subsequent memory (Kornell, Rhodes, Castel, & Tauber, 2011) or even promoted subsequent memory (Koriat, 2008). Further studies are needed to examine the relationship between processing fluency and episodic encoding, and the factors that modulate the relationship between processing fluency and episodic encoding.

Conclusion

In summary, the present study provided stronger evidence for the hypothesis that repetition priming can interact with recognition memory (Wagner et al., 2000). The analysis of ERPs during the study phase suggested that the N400 priming effect, which is related to lexical or semantic processing, was not predictive of priming effect on subsequent memory, whereas the LPC priming effect, which might be related to the cost of prediction error or encoding activities, was predictive of priming effect on subsequent memory. These results indicated that repetition priming and recognition memory do not work totally independently. Prediction error of unprimed words would trigger attentional resources and enhance encoding activities, which results in better recollection-based recognition memory.

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