RESEARCH ARTICLE

Influence of lag length on repetition priming in emotional stimuli: ERP evidence

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Background: Previous studies have demonstrated both behavioral and neural evidence for the potential mediations of lag length and pre-existing memory representation on repetition priming. However, such mediations on emotional stimuli have not been described.

Methods: The current experiment intended to disentangle lag length from pre-existing memory representation. A lexical decision task was performed, in which different emotional characters (either normal or transposed) were re-presented either immediately or delayed.

Results: In immediate repetition, one early and two late (ie, N400 and late positive complex) repetition-related event-related potential (ERP) effects were elicited, but these were not sensitive to pre-existing memory representation. The delayed repetition case merely observed the N400.

Conclusion: These results suggest that the repetition-related priming effect is neutrally sensitive to lag length. Emotional information potentially exerts early and later influences in the processing underlying stimuli memory.

KEYWORDS

emotional valence, lag length, late positive complex, N400, pre-existing memory representation, repetition priming

1 | INTRODUCTION

It is well-known that priming is the subsequently unconscious or unintentional retrieval of information related to previous experiences.¹ Repetition priming, one type of priming, refers to the facilitation in the processing of a repeatedly presented stimulus (ie, higher accuracy in identifying the stimulus and faster response for it).²⁻⁸

Studies on neural mechanisms, such as event-related potential (ERP) studies, have found at least two deflections to repeated stimuli: the early N400 component and the late positive complex (LPC).^{9,10} The N400, with maximal negativity in the centroparietal region, peaking at approximately 400-ms poststimulus onset, has been considered to reflect semantic-related processing.¹¹ The LPC, a parietal positivity that peaks at approximately 600 ms, has been taken as an index of memory retrieval.¹²

Previous research has demonstrated that the lag length between twice-presented (ie, unprimed and primed) trials, pre-existing memory representation, and the emotional valence of stimuli are potentially influential in generating a repetition priming effect.^{4,6,7,13,14} For instance, Swick and Knight¹⁴ confirmed that the repetition priming effect in words decreased from immediate repetition, in which no item was intervened when a stimulus was re-presented, to delayed repetition, in which 1-3 or 9-19 items were intervened. Henson et al⁴ found a greater effect for shorter lag cases (with 1-2 stimuli sandwiched, and the lag was close to 4.8 seconds) than for longer lag cases (at least 40 stimuli were intervened, and the lag was >96.0 seconds). Gordon et al¹³ provided similar evidence in possible and impossible figures.

Electrophysiological and hemodynamic measures confirm the similar mediation. The ERP study conducted by Henson et al⁴ revealed that the magnitudes of two repetition-related effects (distributed in 150-300 ms and 400-600 ms, respectively) significantly

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decreased as the lag length increased. The authors claimed that the short lag processing might be mediated by the attributes of transient neural activity associated with iconic memory traces, while the long-lag processing was held to reflect long-lasting synaptic changes that might be associated with longer perceptual memory. Besides, the N250r, a component that typically peaks at approximately 250 ms postfamous/familiar face onset in immediate repetition and indexes the access of stored structural representations, was attenuated when 2-4 different faces were intervened,¹⁵ and disappeared when the intervals became longer, such as intervals of over 3 minutes, 5-16 minutes, or beyond 15 minutes.^{3,6,16,17}

Another important factor for repetition priming effect is the pre-existing memory representation. For instance, the effect was greater for words vs pseudo-words,⁸ famous vs unfamiliar faces,^{6,7,17,18} meaningful vs meaningless symbols,⁵ and possible vs impossible figures.¹³ These findings suggest a greater repetition priming effect for stimuli with pre-existing memory representations over those without.

The repetition-related neural activity is also the consequence of the pre-existing memory representation. For instance, the study conducted by Swick and Knight¹⁴ revealed that repetition-related waveforms were hemispherically different between words and non-words. Similarly, the N250r and N400 were much greater for pre-experimentally famous/familiar faces and experimentally learned faces, compared to unfamiliar faces, reflecting that these variations are based purely upon whether a face holds a status of pre-existing memory representation.^{6,7,19-25}

Apart from the lag length and pre-existing memory representation, studies have also demonstrated robust sensitivity of repetition priming to the emotional valence of stimuli, but the results are not exactly the same. Thomas and LaBar²⁶ found that the priming effect was greater for higher emotional aroused words vs lower and neutral emotional aroused words. Positive targets exhibited a reliable effect, while negative targets had no effect.²⁷ Furthermore, the effect was reliable for neutral images, but not for negative stimuli.²⁸ In contrast, others do not show such modulation: negative and neutral nouns together with faces elicited similar repetition priming effects.^{29,30}

The study has demonstrated that the repetition-related waveforms vary according to the affective content of stimuli. Using an incidental repetition paradigm with fearful, happy, and neutral unknown faces in an electroencephalography-magnetoencephalography (EEG-MEG) study, Morel et al³¹ found a very early repetition effect at approximately 40-50 ms over posterior regions for neutral faces, and then the N170/M170 for both neutral and emotional faces, which is followed by a late M300 component selective to fearful faces. They argued that the early MEG effect was more likely related to the discriminative visual processing of facial expressions, while the late MEG effect was the consequence of a higher arousing or threatening value of fearfulness relative to happy and neutral stimuli. An ERP study conducted by Méndez-Bértolo et al³⁰ revealed that repeated negative words, instead of neutral words, reduced the P120 but enhanced the N170, while the later N400 and P300 (generally indexes memory-related processes) did not differ between these two types of words, suggesting a word's negative content

might capture attention that possibly interfered at the early semantic processing.

Overall, the above reviewed literature concerning emotional stimuli can be summarized as follows: (a) the repetition-related neural activity, such as its time-course and scalp distribution, is sensitive to the attributes of stimulus emotional valence; while (b) it remains unclear during which stage will an influence happen. Conflicts between previous studies may be explained from the perspective of the lag length between unprimed and primed trials. There were 21-105 intervening items (within 1-7 minutes) in the study conducted by Morel et al³¹ but no intervening item in the study conducted by Méndez-Bértolo et al.³⁰ An alternative account is that the stimuli hold different pre-existing memory representations. The faces in the former study were all unknown to participants, while the words in the latter study had been exposed pre-experimentally. As such, it is hard to determine whether differences in these ERP effects are in fact driven by lag length, or instead by the pre-existing memory representation.

To summarize, with the lag length and pre-existing memory representation serving as two potential mediators, no study has disentangled these two in repetition priming for emotional stimuli. Based on this, the current study attempted to elucidate the behavioral and scalp distribution differences simultaneously. For this sense, a lexical decision task was performed by participants, which had the advantage of making emotional processing irrelevant. This could prevent the possible top-down attentive biases to emotional aspects, as suggested in a previous study.³⁰ In the task, stimulus re-presentation was either immediate or delayed, and six types of stimuli representing two relevant factors were compared: pre-existing memory representation (two levels: normal and transposed Chinese characters) $\times$ stimulus emotional valence (three levels: positive, neutral, and negative).

Three hypotheses were proposed. First, we predicted to reveal reliable priming effects not only in behavioral performance, but also in the ERP components (the early effect, N400, and LPC). Second, if lag length was a critical factor that in determining the distributions of the priming effects, the components would differ in both lag cases, which would thereby induce a stronger effect for immediate cases. Alternatively, if the pre-existing memory representation was critical, we would expect to see fairly distinct components for normal vs transposed characters. If lag length and pre-existing memory representation both contributed, an interaction should appear. Finally, either lag length or pre-existing memory representation would interact with stimulus emotional valence.

2 | METHODS

2.1 | Participants

A total of 17 right-handed young adults (10 males, 19-30 years old) were recruited for this study. All had normal or corrected-to-normal visual acuity and were native Chinese speakers. None reported any history of neurological or psychiatric disorders. Furthermore, written informed consents were provided to all participants before the

experiment. The procedures were approved by the Research Ethics Board of Zhejiang University. After the experiment, all participants received compensation for their participation.

2.2 | Design

The current study was a 2 (prime: unprimed and primed) $\times$ 2 (pre-existing memory representation: normal and transposed Chinese characters) $\times$ 3 (stimulus emotional valence: positive, neutral, and negative) $\times$ 2 (lag length: immediate repetition and delayed repetition) within-subject design. Normal Chinese characters were shown in their formal order (eg, “侮辱” and “花朵”), while transposed Chinese characters were in their swapped order (eg, “辱侮” and “朵花儿”). The emotional valences for transposed characters were defined by their normal ones. The lag length referred to the character numbers that intervened between an unprimed and primed character, the numbers were either 0 (immediate repetition) or 4 (delayed repetition).

2.3 | Materials

All stimuli were originally derived from the Affective norms for English words (ANEW),³² which were translated into Chinese. Merely two-word characters were kept. The characters were subdivided into three groups (240 characters per group), based on the pleasure value evaluated by voluntary undergraduates on a 9-point scale: positive (7.54), neutral (5.29), and negative (2.49). In each group, half of the characters were normal, while the other half were transposed. As such, there were 120 normal characters and 120 transposed counterparts in each group (positive, neutral, and negative groups). Subsequently, each of these six types of characters was further subdivided into two conditions: immediate repetition and delayed repetition. In the experiment, the characters were distributed into six blocks. Thus, there were 20 trials per type in each block. The blocks equated on the frequency, stroke, spelling, and pronunciation of the characters.

2.4 | Procedure

Participants sat in a quiet room with dim light. Before the formal experiment, they were given several practice trials (not appeared

later) with feedbacks to ensure a full understanding of the instructions. The instructions of the practice trials were the same as in the formal experiment. In each block, an instruction was displayed firstly, according to which participants were required to perform a lexical decision task (ie, to differentiate normal from transposed characters) by pressing two separate keys (“F” and “J” on the keyboard). A fixation cross (“+”) was placed at the center of the monitor for 1000 ms, which was followed by a stimulus. Each stimulus was displayed for 500 ms, followed by an inter-stimulus interval of 1500 ± 200 ms. Responses beyond 1500 ms were considered as null. Figure 1 illustrates the experimental procedure.

During the experiment, the participants were instructed to fixate on the center of the screen and minimize eye blinks while stimuli were displayed. They were encouraged to respond as quickly and accurately as possible. The stimuli were programmed using a presentation software, and centrally displayed against a black background on a 21-inch SAMSUNG SyncMaster monitor, with a viewing distance of 70 cm. Screen refresh frequency and resolution were 75 Hz and 1024×768 , respectively. Similar to a previous study,³³ a continuous recognition paradigm was used to control the lag length. The trial presentation was pseudo-randomized after it was controlled for lag length within each block, and no more than three trials with the same valence occurred consecutively. The horizontal and vertical angles of each stimulus were 6.82° and 3.40° , respectively. All stimuli were in white font, and none of them was re-presented across blocks. The resting interval was always 5 minutes between two consecutive blocks. Key pressing was performed using the index fingers, the assignment of fingers was counterbalanced among blocks for each participant, and the response keys were counterbalanced across participants.

2.5 | Electrophysiological recording

The electroencephalogram was continuously recorded with Synamp amplifiers from 32 Ag/AgCl electrodes that extended from the 10/20 system.³⁴ The horizontal electrooculogram (EOG) was recorded from electrodes placed at the external canthi of both eyes, while the vertical EOG was recorded from electrodes

FIGURE 1 Schematic illustration of experimental procedure

placed on the supra- and infra-orbital ridges of the left eye. The right mastoid served as the reference electrode online, and the data were algebraically re-referenced offline to the average of both mastoids after recordings. All signals were amplified with a gain of 500, digitized at a sampling rate of 500 Hz per channel, and filtered with a band-pass of 0.05–100 Hz. Electrode impedances were kept below 5 k Ω .

3 | DATA ANALYSIS AND RESULTS

3.1 | Behavioral measurement and the data

In the current study, no analyses were made for accuracies, as they were almost higher than 90%, reflecting the fact that lexical decisions were quite easy for participants. Figure 2 plots the reaction times for unprimed and primed trials as a function of pre-existing memory representation by stimulus emotional valence and by lag length. The repeated-measures ANOVA for reaction time revealed the statistically significant main effects for all factors ($F[1,16] = 42.14$ – 91.83 , $P_s < 0.001$) and the four-way interaction ($F[2,32] = 38.09$, $P_s < 0.001$). Subsidiary analyses with Bonferroni's correction confirmed reliable priming effects for all six types of stimuli in both immediate repetition ($F[1,16] = 44.74$ – 134.85 , $P_s < 0.001$) and delayed repetition ($F[1,16] = 6.81$ – 59.03 , $P_s < 0.05$), demonstrating faster responses for primed vs unprimed stimuli.

Figure 3 shows the priming effects of the reaction times as a function of pre-existing memory representation, stimulus emotional valence, and lag length. The ANOVA revealed the reliable main effects for these three variables ($F[1,16] = 7.22$ – 62.10 , $P_s < 0.01$), and the three-way interaction ($F[1,16] = 38.09$, $P < 0.001$); post hoc tests indicated that immediate repetition held greater priming effects than delayed repetition ($P < 0.001$), and this pattern was mirrored for transposed vs normal characters ($P < 0.05$).

3.2 | Electrophysiological averaging and the data

Figure 4 presents the grand-average waveforms of unprimed and primed normal and transposed stimuli per condition. Figure 5 plots the topographic maps of the priming effect over the entire scalp for the intervals of interest. The grand-average waveforms were collapsed separately for correctly classified normal and transposed characters in each case. Similar to previous studies,^{6,7,35–37} eye artifact correction was accomplished using a semi-automatic procedure before averaging. Following correction, trials contaminated by eye blinks or movements that exceeded $\pm 75 \mu\text{V}$ were excluded using a PCA-based algorithm before collapsing.³⁸ Epochs of 1300 ms (including a 100 ms baseline) were extracted from the continuous recording and were corrected over the prestimulus interval. All average trials per condition were above 45.

As motivated by previous research,^{9,10} amplitude comparisons of primed and unprimed trials concerned the cortical regions. Thus, four electrodes (Fz, Cz, Pz, and Oz) and three latency windows (200–300, 300–550, and 550–800 ms) were selected. The two late latencies were separately for N400 and LPC. In order to directly test the presence of priming effects for each stimulus type in both lag cases, a 2 (prime: unprimed and primed) $\times$ 4 (cortical region: frontal, central, parietal, and occipital) repeated-measures ANOVA were performed for each latency. The comparisons of ERP priming effects (difference waveforms by minus unprimed from primed trials) were also analyzed. Thus, the repeated-measures ANOVAs, with pre-existing memory representation, stimulus emotional valence, lag length, and cortical region as variables, were performed for each time window. Greenhouse-Geisser correction was used when appropriate.

3.2.1 | ERP priming effects in immediate repetition

For positive normal Chinese characters at 200–300 ms, prime interacted with cortical region ($F[3,48] = 4.82$, $P < 0.05$), which confirmed a positive-going early effect over the parietal and occipital regions

FIGURE 2 Reaction times for unprimed and primed trials as a function of pre-existing memory representation, stimulus emotional valence and lag length

FIGURE 3 Priming effects of reaction times as a function of pre-existing memory representation by stimulus emotional valence through lag length

($F[1,16] = 10.08-15.39$, $P_s < 0.01$). Latency at 300-550 ms revealed the reliable main effect of prime ($F[1,16] = 38.05$, $P < 0.001$) and the two-way interaction ($F[3,48] = 5.96$, $P < 0.01$). Post hoc tests revealed a reliable N400 across all regions ($F[1,16] = 25.61-42.40$, $P_s < 0.001$). A similar main effect and interaction were revealed at 550-800 ms ($F[1,16] = 38.50$, $P < 0.001$; $F[3,48] = 9.61$, $P < 0.01$), showing a negative LPC at the central, parietal, and occipital regions ($F[1,16] = 5.15-27.58$, $P_s < 0.05$).

Positive transposed characters revealed an interaction at 200-300 ms ($F[3,48] = 3.93$, $P < 0.05$), post hoc tests indicated a positive early effect over the parietal and occipital regions ($F[1,16] = 14.36-27.04$, $P_s < 0.01$). The significant main effect of prime and the interaction was found at 300-550 ms ($F[1,16] = 82.01$, $P < 0.001$; $F[3,48] = 12.13$, $P < 0.001$). Post hoc tests confirmed a positive-going N400 across all regions ($F[1,16] = 13.89-35.72$, $P_s < 0.01$). Similar reliable main effect and interaction were found within 550-800 ms ($F[1,16] = 14.07$, $P < 0.01$; $F[3,48] = 6.16$, $P < 0.05$), suggesting a negative LPC across the central, parietal, and occipital regions ($F[1,16] = 11.75-21.14$, $P_s < 0.001$).

The neutral normal characters within 200-300 ms revealed the two-way interaction ($F[3,48] = 3.55$, $P < 0.05$), showing a positive early effect over the parietal and occipital regions ($F[1,16] = 10.00-15.39$, $P_s < 0.01$). The reliable main effect of prime and the two-way interaction were found within 300-550 ms ($F[1,16] = 81.31$, $P < 0.001$; $F[3,48] = 22.54$, $P < 0.001$), such that a positive N400 was revealed across all regions ($F[1,16] = 11.44-45.00$, $P_s < 0.01$). At 550-800 ms, similar reliable main effect and interaction was confirmed ($F[1,16] = 9.53$, $P < 0.01$; $F[3,48] = 8.82$, $P < 0.01$), showing a negative LPC across the central, parietal, and occipital regions ($F[1,16] = 6.38-18.09$, $P_s < 0.05$).

For neutral transposed characters at 200-300 ms, the prime effect was not significant (all $P > 0.05$). At 300-550 ms, a significant main effect of prime and the two-way interaction was observed ($F[1,16] = 93.02$, $P < 0.001$; $F[3,48] = 18.18$, $P < 0.001$), confirming the positive N400 across all regions ($F[1,16] = 5.32-36.41$, $P_s < 0.05$). At 550-800 ms, similar reliable main effect and interaction were found ($F[1,16] = 11.41$, $P < 0.01$; $F[3,48] = 5.50$, $P < 0.05$),

demonstrating a negative LPC at the central, parietal, and occipital regions ($F[1,16] = 9.85-17.99$, $P_s < 0.01$).

The negative normal characters during the 200-300 ms revealed the two-way interaction ($F[3,48] = 15.46$, $P < 0.001$), confirming the positive early effect at the parietal and occipital regions ($F[1,16] = 11.18-30.39$, $P_s < 0.01$). The reliable main effect of prime and the two-way interaction was found at 300-550 ms ($F[1,16] = 35.91$, $P < 0.001$; $F[3,48] = 8.96$, $P < 0.01$); a positive-going N400 could be seen across all regions ($F[1,16] = 5.28-34.80$, $P_s < 0.05$). At 550-800 ms, the analogous main effect and interaction were found ($F[1,16] = 30.33$, $P < 0.001$; $F[3,48] = 10.11$, $P < 0.001$), suggesting a negative-going LPC across the central, parietal, and occipital regions ($F[1,16] = 8.47-23.04$, $P_s < 0.05$).

The negative transposed characters at 200-300 ms revealed the interaction of prime by cortical region ($F[3,48] = 5.07$, $P < 0.05$), confirming a positive early effect at the parietal and occipital regions ($F[1,16] = 13.08-24.13$, $P_s < 0.01$). At 300-550 ms, the reliable main effect of prime and two-way interaction were found ($F[1,16] = 71.62$, $P < 0.001$; $F[3,48] = 11.03$, $P < 0.001$), showing a positive-going N400 across the regions ($F[1,16] = 10.97-31.51$, $P_s < 0.01$). Merely the reliable main effect of prime was confirmed within 550-800 ms ($F[1,16] = 14.24$, $P < 0.01$).

3.2.2 | ERP priming effects in delayed repetition

The positive normal characters revealed no effects of prime within 200-300 ms (all $P > 0.05$) and 550-800 ms (all $P > 0.05$). The significant main effect of prime was only revealed at 300-550 ms ($F[1,16] = 6.74$, $P < 0.05$).

For positive transposed characters at 200-300 ms, prime interacted with cortical region ($F[3,48] = 3.45$, $P < 0.05$), such that a positive early effect was found over the parietal and occipital regions ($F[1,16] = 14.97-25.51$, $P_s < 0.01$). At 300- to 550-ms intervals, the main effect of prime and the two-way interaction was reliable ($F[1,16] = 27.92$, $P < 0.001$; $F[3,48] = 11.38$, $P < 0.001$), showing a positive-going N400 across all regions ($F[1,16] = 11.90-34.31$, $P_s < 0.01$). However, no effect was found at 550-800 ms (all $P > 0.05$).

The neutral normal characters within 200-300 ms revealed the two-way interaction ($F[3,48] = 5.50$, $P < 0.05$), such that a positive early effect was observed over the parietal and occipital regions ($F[1,16] = 18.17-25.45$, $P_s < 0.01$). The main effect of prime and its interaction with cortical region were significant at 300-550 ms ($F[1,16] = 25.52$, $P < 0.001$; $F[3,48] = 9.59$, $P < 0.01$), confirming the positive-going N400 across all regions ($F[1,16] = 15.08-41.96$, $P_s < 0.01$). A similar reliable main effect and interaction were revealed at 550-800 ms ($F[1,16] = 11.86$, $P < 0.01$; $F[3,48] = 4.59$, $P < 0.05$), suggesting the negative-going LPC at the central, parietal, and occipital regions ($F[1,16] = 6.29-29.96$, $P_s < 0.05$).

The neutral transposed characters at 200-300 ms revealed no effect of prime (all $P > 0.05$). At 300-550 ms, the reliable main effect of prime and its interaction with cortical region were revealed ($F[1,16] = 11.57$, $P < 0.01$; $F[3,48] = 4.88$, $P < 0.05$), indicating

FIGURE 4 Grand-average waveform comparisons between unprimed and primed trials for correctly classified normal and transposed stimuli with different emotional valences separated in the two lag cases

a positive-going N400 across all regions ($F[1,16] = 5.30-30.43$, $P_s < 0.05$). At 550-800 ms, the two-way interaction was significant, ($F[3,48] = 3.64$, $P < 0.05$), showing a negative LPC across all regions ($F[1,16] = 6.99-28.82$, $P_s < 0.05$).

The negative normal characters at 200-300 ms revealed no effect of prime (all $P > 0.05$). The main effect of prime and its interaction with cortical region were significant at 300-550 ms ($F[1,16] = 19.01$, $P < 0.001$; $F[3,48] = 7.32$, $P < 0.01$), showing a positive N400 across all regions ($F[1,16] = 19.45-28.62$, $P_s < 0.001$). At 550-800 ms, only the main effect of prime was confirmed ($F[1,16] = 4.88$, $P < 0.05$).

The negative transposed characters at 200-300 ms failed to reveal any prime effect (all $P > 0.05$). At 300- to 550-ms interval,

the reliable main effect of prime and the two-way interaction was observed ($F[1,16] = 17.32$, $P < 0.01$; $F[3,48] = 5.82$, $P < 0.01$), confirming a positive-going N400 across all regions ($F[1,16] = 7.03-28.62$, $P_s < 0.05$). At 550-800 ms, the effect of prime was insignificant (all $P > 0.05$).

3.2.3 | ERP priming effects comparison

At 200-300 ms, the interaction of lag length by stimulus emotional valence by cortical region was statistically significant ($F[6,96] = 3.38$, $P < 0.05$), post hoc analysis confirmed a larger and earlier effect in immediate repetition compared with delayed repetition for negative

FIGURE 5 Topographic maps for waveform differences between unprimed and primed trials for normal and transposed stimuli with different stimulus emotional valences separated in the two lag lengths. Each was revealed at the latency window of interest

stimuli at both frontal and central regions ($F[1,16] = 7.11$ – 17.66 , $P_s < 0.05$).

The main effect of lag length and the interaction of lag length by stimulus emotional valence were found at 300–550 ms ($F[1,16] = 79.00$, $P < 0.001$; $F[2,32] = 3.973$, $P < 0.05$), indicating that the N400 was greater for all three emotional valence stimuli in the immediate repetition ($F[1,16] = 18.58$ – 71.10 , $P_s < 0.01$).

The 550- to 800-ms interval revealed the main effects of lag length, pre-existing memory representation, and cortical region

($F[1,16] = 32.12$, $P < 0.001$; $F[1,16] = 22.00$, $P < 0.001$; $F[3,48] = 9.96$, $P < 0.01$). Both the two-way interaction of lag length by cortical region and the three-way interaction of lag length by pre-existing memory representation by stimulus emotional valence were statistically significant ($F[2,32] = 3.46$, $P < 0.05$; $F[3,48] = 13.00$, $P < 0.001$), showing a greater LPC for positive normal, negative normal, positive transposed, neutral transposed, and negative transposed characters in immediate repetition vs delayed repetition ($F[1,16] = 4.53$ – 20.53 , $P_s < 0.05$).

4 | DISCUSSION

The major purpose of the current study was to assess to what extent that the repetition sensitivity time-course and scalp distributions differed for stimuli with different emotional valence as a function of pre-existing memory representation and lag length. Repetition priming effects relevant with such manipulations, particularly with lag length, were recorded from both behavioral data and neural activity with distinctive time-course, amplitude, and scalp distributions of waveforms.

4.1 | Repetition facilitation in reaction times

As expected, this experiment revealed the significant priming effects in reaction times for all six types of stimuli in lag length. However, the results failed to observe any differences between emotional and neutral stimuli, demonstrating similar patterns with earlier findings of faces.²⁹ With regard to lag length, a stronger priming effect for immediate repetition vs delayed repetition was observed, which replicated the pattern of previous studies concerning this factor.^{3-7,14,17} In a word, the current and previous data suggest that lag length could be a potential mediator of repetition priming effect. Consistent with most previous studies,²⁸⁻³⁰ but not to one particular study,²⁶ the current study indicated no reliable behavioral evidence for stimulus emotional valence on repetition-related priming effect. We consider that it is possible to draw a conclusion that the influence of stimulus emotional valence on the priming effect at a behavioral level is rather weak in certain circumstances.

The priming effect was larger for transposed vs normal Chinese characters, which was somewhat incongruent with previous research showing a larger priming effect for stimuli with previously stored representations compared to those without.^{5-8,13,17,18,20,23} It seems that the current transposed characters can benefit from repetition as much as normal ones. Unlike those that resemble previous real unfamiliar stimuli, such as pseudo-words, transposed characters still keep certain degree of semantic meanings. Participants might consider the current transposed characters as ambiguous stimuli semantically related to original normal characters. After all, transposed characters can be meaningful as long as the participants read it from right to left. However, this interpretation must be considered with caution, as it remains unclear whether the transposed Chinese characters differ from the totally unfamiliar pseudo-words. Future studies might consider to compare transposed words with pseudo-words, which may provide more clear evidence.

4.2 | ERP priming effects are sensitive to lag length and stimulus emotional valence

As mentioned in Introduction, the repetition effects highly depend on lag length, and it is likely that short and long-lag repetition paradigms tap into different memory processes. In line with previous studies,^{3-6,15} the current study also confirmed the mediation of lag length, showing all three repetition-related ERP

priming effects (the early effect, and the subsequent N400 and LPC), which greatly reduced from immediate repetition to delayed repetition. As such, the priming effects in immediate repetition and delayed repetition were likely to reflect differential neural processing. Moreover, the mediation of lag length interacted with stimulus emotional valence.

4.2.1 | N400 is sensitive to lag length

As shown in the grand-average waveform in Figure 4, the amplitudes of N400 indexing semantic retrieval were all more positive for primed vs unprimed trials in both lag conditions. Although one previous immediate repetition paradigm study revealed that primed words associated with reduced N400 responses, compared with unprimed words,³⁹ our findings support the positivity that came from some other investigations either in immediate repetition or in short prime presentation cases.^{30,40,41} As claimed by Méndez-Bértolo et al,³⁰ the positive-going N400 could be attributed to the weak concept activation of primes with brief durations, which was the product of the fairly less accessibility of primed targets vs unprimed targets.

In addition, the current study revealed reliable N400 for both lag lengths, in which immediate repetition raised larger amplitudes for this deflection vs delayed repetition, which bore a greater similarity to previous findings: shorter lag led to the greater positive shift of N400.¹⁴ In this light, the current data not only demonstrate that lag length is dominant in eliciting the N400, and that this influence might be quantitative rather than qualitative, but also further reinforces that the semantic knowledge that associated with primed targets are less accessible following a longer prime presentation.

Unfortunately, we confirmed no evidence of distinct N400 in topography between normal and transposed characters, which indicates the lower sensitivity of N400 to the manipulated attributes of representations from pre-experimental exposure. The absence of evidence was somewhat unusual, but bore a greater similarity to those reported by Henson et al and one of our previous study,^{3,7} as both revealed no amplitude differences for famous vs unfamiliar faces. However, it appeared in apparent contradiction with those reported by Swick and Knight,¹⁴ in which the waveforms differed between words and non-words. It is noteworthy that the current transposed characters were not definitely unfamiliar. That is, the semantic processing for Chinese characters might be more similar to faces than that of English words. This question needs to be clarified in the future.

Finally, we failed to gather reliable evidence for the qualitative difference in N400 in terms of the function of stimulus emotional valence in both lag lengths, suggesting a stimulus' emotional content that captures attentive interference unrelated to semantic processing, at least in the current study.

4.2.2 | The early effect and LPC are modulated by both lag length and stimulus emotional valence

The question of particular interest is whether or not the early effect and the later LPC behave like N400. Our data revealed that

the amplitudes of the early effect and LPC were not only sensitive to lag length, but also modulated by whether a stimulus held high emotional valence. Interestingly, neither the early effect nor LPC observed in this study were selective to emotional stimuli in delayed repetition. What's more, the LPC in the current study was negative-going, which was interesting but not surprising, as a previous study has revealed a similar pattern. Codisposti et al⁴² stated that repetition effects could sometimes be transposed or absent, particularly in the case of high arousal or affective stimuli, which gave rise to increased LPC by themselves.

Considering the absence of the early effect for negative characters in delayed repetition, the result was akin to the findings reported by Morel et al,³¹ which revealed the early effect for neutral, but not for emotional stimuli in delayed repetition. Together, the pattern appears to reasonably show that this effect is more likely related to the early visual discriminative processing that encoded stimuli. Furthermore, our data added novel support to the notion that the processing related to this effect was sensitive to whether the stimuli held different emotional arousing content, and that the influence of stimulus emotional valence might strongly interact with retention interval.

Unlike one previous electrophysiological study,³⁰ which did not describe any late repetition-related component that varied depending on stimulus valence, the current study, in contrast, provided strong evidence of LPC for all positive, neutral, and negative items in immediate repetition, and only specifically for neutral items in delayed repetition. The comparison difference conducted between that reported by Méndez-Bértolo et al³⁰ and the current study might explain such apparent discrepancies: The comparison conducted by Méndez-Bértolo et al³⁰ was between negative and neutral targets, while that conducted in the current study was directly between primed and unprimed trials with the same emotional valence.

The study conducted by Morel et al³¹ and the current study did not reveal any ERP sensitivity effect to the property of stimulus emotional valence in the longer lag case. One possible explanation may be that both studies share a similar comparison between the primed and unprimed, with the same emotional valence. Another explanation is that the primed stimuli attract more attentive resources in the immediate repetition vs delayed repetition. Thus, the delayed case prompts the allocation of further processing resources in a way that impairs the spreading activation mechanisms. This is associated with the processing of the orthographic and/or early semantic aspects of the current characters, especially those with higher arousal level (including positive and negative valences) relative to neutral stimuli.

4.3 | Summary

Significant repetition priming effects were found in reaction times for all six types of stimuli as a function of lag length and pre-existing memory representation. The early effect, N400, and LPC were all sensitive to lag length. N400 was irrespective of stimulus emotional

valence, while the early effect and LPC for emotional items were larger in contrast to those for neutral trials in delayed repetition, demonstrating that the repetition-related ERPs are differentially activated for stimuli with differential emotional contents, and such activities are significantly reduced following a longer retention interval.

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