Biological Psychology 163 (2021) 108132

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

# When old information is intermixed with new elements: An event-related potential study

Yun-hong Wang [a], Wei Bao [a,1], Jun-long Luo [a,b,*]

[a] Department of Psychology, Education College, Shanghai Normal University, Shanghai, 200234, China
[b] The Research Base of Online Education for Shanghai Middle and Primary Schools, Shanghai, 200234, China

ARTICLE INFO

Keywords:
Old/new effect
Cognitive conflict
N270
N400
Intermixed stimuli

ABSTRACT

Previous research has focused on the event-related potential of the old/new effect, but the mechanism for cognitive conflict and subsequent integration processing both induced by intermixed (old and new) stimuli have not been widely researched. This paper describes the effect of familiar stimuli mixed with new information and presented as intermixed stimuli. Three conditions were set within a study-test paradigm incorporating old, new, and intermixed conditions. The intermixed condition resulted in the lowest accuracy, thereby implying the greatest old/new effect. Moreover, compared with the old condition, the intermixed condition elicited a greater N270 as well as a stronger N400, while the new condition only induced a stronger N270. These results elucidate that when new information is intermixed with old information, the old/new effect is more pronounced, indicating that intermixed stimuli are possibly more difficult to integrate than old and new stimuli.

## 1. Introduction

Numerous studies have made substantial and constructive investigations into the event-related potential (ERP) old/new memory effect, which occurs when unstudied (new) stimuli trigger a more negative waveform than studied (old) stimuli (Curran & Cleary, 2003; Hayama et al., 2008; Rugg & Curran, 2007). The most common perspective that has emerged from studies of this effect is that it is indicative of a dual-process model of recognition memory (familiarity-based and recollection-based). The cognitive conflict was defined as the simultaneous activation of incompatible and competing representations (Botvinick et al., 2004) and the subsequent integration processing, referring to processing that integrated information from different sources (Badre & Wagner, 2004), both being induced by the old/new information (mismatch between old and new information), has not been widely addressed in the literature. Thus, we designed a novel investigative approach that focuses on the form of information inducing cognitive conflict. Furthermore, processing an old/new conflict involved both conflict monitoring and integration as required by the old and new stimuli, and these separately reflected on the N2 (Mograss et al., 2009; Proverbio et al., 2019) and N400 components (Fang & Perfetti, 2017; Stuellein et al., 2016). N2 was a negative wave that peaked between 200 and 350 ms after the onset of stimuli (Folstein and Van Petten, 2008) and N400 was a negative wave that peaked between 200 and 600 ms after the onset of the stimuli (Kutas & Federmeier, 2011). These existing studies have used old or new stimuli as the conditions but did not use a mixed condition with old and new information. Consequently, the motivation for our current study was that we used intermixed conditions to unravel the ERP effect of conflict monitoring and integration.

The intermixed condition can be exemplified by the example of a familiar friend, who always wears a sports jacket whenever you meet, but one day you see that he is wearing a dress suit. In this situation, you may experience cognitive conflict, as the dress suit does not match his usual clothing style. Previous research has emphasized that individuals with cognitive conflict had a greater N2 (Veen & Carter, 2002), indicating that N2 was an index of conflict monitoring (Folstein & Van Petten, 2008; Zhou et al., 2018). Additionally, Mograss et al. (2009) associated N2 with old/new discrimination, where the new stimuli induced a larger N2 compared to old stimuli. Proverbio et al. (2019) face recognition experiment supported Mograss et al.'s (2009) findings. The N270, part of the N2, reflected two types of conflict monitoring: the conflict between two external stimuli and the conflict between memory representation and external stimulus (Wang et al., 2000). In addition, the N270 generally appeared during semantic processing and

* Corresponding author.
E-mail address: luo831023@163.com (J.-l. Luo).
[1] Wei Bao is the joint first author.

https://doi.org/10.1016/j.biopsycho.2021.108132
Received 17 October 2020; Received in revised form 29 May 2021; Accepted 2 June 2021
Available online 4 June 2021

non-semantic conflicts. In their study, Szucs et al. (2007) found that a larger N270 occurred under conditions of conflict in both color recognition tasks (non-semantic) and category recognition tasks (semantic), indicating that the N270 effect appeared in detecting the conflict between prior and present stimuli. In addition, the conflict eliciting N270 was generated by various types of stimuli such as shape, color, spatial location, and simple arithmetic tasks (Bennett et al., 2014). All these studies and several others (Wang et al., 2003; Wang et al., 2004; Wang et al., 2018) proposed that conflict between current stimulus and previous stimulus (memory), played significant roles in the elicitation of N270. Although prior research has generated a wealth of insights into N270 as an index of conflict detection, there is little understanding of how a mixture of old and new stimuli is processed by individuals; and whether individuals classify them as old or new stimuli.

Specifically, familiarity, a way of recognition memory, was one of the key factors to induce cognitive conflict (Schumacher et al., 2010). In the current research, participants temporarily and firmly memorized the relationships between target and origin words in the study phase of a "study-test" paradigm (Finnigan et al., 2002). In the test phase, participants were familiar with the target and origin words in the old condition (e.g., old target word "分" and old origin word "盆"), which may not elicit participants' cognitive conflicts and prompt N270. However, an intermixed condition (e.g., a new target word "为" and an old origin word "盆") could evoke a stronger N270 than the old condition. The participants were familiar with the relationships between the old target word and the old origin word from the study phase, thus the new target word did not match with the old origin word, inducing cognitive conflict. In the new condition, the new target word was purposely not matched with the old origin word (e.g., new target word "力" and new origin word "务") to induce cognitive conflict and result in a larger N270 than in the old condition. The participants were unfamiliar with the relationships in the new condition and experienced mismatch, as the target and the origin words had not yet been studied. We proposed that if individuals classify intermixed stimuli as new stimuli, then the N270 induced by intermixed stimuli may be stronger than when it is induced by old stimuli. Conversely, there will be no prominent difference between the intermixed and new stimuli.

The recent burgeoning of research on N400 has been indicative of a growing conviction that N400 appeared in integration processing (Fang & Perfetti, 2017; Li et al., 2008; Stuellein et al., 2016). Correspondingly, research showing that N400 was greater in processing new stimuli compared with old stimuli has grown since the early 2000s (Hagoort et al., 2004; Kutas & Federmeier, 2011; Zhou et al., 2018). Likewise, a semantic study suggested that novel and inconsistent sentences with context induced a larger N400 than familiar and consistent sentences with context (Chwilla et al., 2007). This finding indicated that individuals had greater difficulty integrating new information. Furthermore, similar findings using meaningless stimuli were apparent (Draschkow et al., 2018; Wang et al., 2004). The results of a multi-feature stimuli comparison study showed that multiple conflicts (color and shape) induced a remarkable N400, indicating that N400 was also involved in processing complex information conflicts (Wang et al., 2004). Draschkow et al. (2018) further argued that an N400 was not only related to semantic integration but also to the integration of objects and scenes. Taken together, these studies showed that an N400 reflected the endogenous mechanism of conflict integration after the process of cognitive conflict. In our research, we developed the following hypothesis: Individuals clarify intermixed stimuli as new stimuli, and they possibly integrate them with more difficulty in subsequent integration processing. Therefore, intermixed stimuli elicit greater N400 than old and new stimuli.

Different from classical ERP old/new effect studies, Finnigan et al., 2002Finnigan et al. (2002) introduced the "N400 strength effect" by adding repetition priming to the study phase (i.e., repetitive stimuli induced a smaller N400 compared with new stimuli in the test phase, whereas the appearance of preeminent N400 was generated by new stimuli). Prior studies suggested that the discrimination between old and new stimuli was affected by familiarity and that repetition priming was conducive to the enhancement of familiarity for individuals (Rugg & Curran, 2007). This finding allowed individuals to recognize repetitive stimuli without recalling detailed information and to quickly discriminate between old and new stimuli (Paller et al., 2007). In addition, Thakral et al. (2016) demonstrated that familiarity and repetition priming were both regulated by the superior parietal lobule and precentral gyrus, implying that they had a common processing mechanism.

For this current study, it was necessary to understand how the human brain copes with or responds to repetition. There has been some fMRI research to indicate that repeated stimuli reduced neural activity, and novel stimuli triggered stronger brain activity (Grill-Spector et al., 2006; Schacter et al., 2007). Correspondingly, an EEG study described that repeated stimuli induced a smaller N400 compared with novel stimuli (Van Strien et al., 2007). While important, prior research has taken a primarily static view about repeated (old) and novel (new) stimuli without addressing the impact of changes in the form of the stimuli, when including both old and new information. Accordingly, old stimuli and new stimuli are intermixed as a third condition, so that the conditions include an old condition (both target and origin word are repeated), a new condition (both target and origin word are non-repeated), and an intermixed condition (target word is non-repeated and origin word is repeated) in which stimuli are partially identical to the old condition. Finnigan et al.'s study-test paradigm (Finnigan et al., 2002) set repetition in the study phase and three conditions in the test phase. These conditions consisted of three-time repetition, one-time repetition, and no repetition (new). Better behavioral results were achieved in the three-times condition than in the one-time repetition condition. Therefore, to improve the threshold in our study, we increased the maximum number of repetitions to five, and we compared each repetition condition (zero, once, three times, and five times) in pilot research to determine which condition had the greatest repetition effect.

In summary, the goal of the current study was to enhance our understanding of the old/new effect elicited by intermixed stimuli. Specifically, we aimed to clarify the underlying mechanisms through a sequentially cognitive process, that is, conflict monitoring and integration. Therefore, we conducted a study-test paradigm (based on Finnigan et al., 2002) with an Embedded Chinese Character Task (ECCT) (Yu et al., 2018) in pilot and formal research (e.g., judging whether an origin word "盆" included a target word "分" referring to structure). The pilot research determined the number of repetitions required for the old condition and this was used in the formal research. Accordingly, the formal research formulated three conditions: (1) the old condition (old-target word "分" and old-origin word "盆"), (2) the new condition (new-target word "力" and new-origin word "务"), and (3) the intermixed condition (new-target word "为" and old-origin word "盆"). Furthermore, based on previous studies, we used the N270 as the index of cognitive conflict monitoring (Bennett et al., 2014; Wang et al., 2000, 2003, 2004) and the N400 as the index of cognitive conflict integration (Kutas & Federmeier, 2011; Pan et al., 2016; Schlesewsky & Bornkessel, 2006; Zhou et al., 2018).

## 2. Method

We used a one-factor within-subject design with condition types (old, new, and intermixed). Accuracy (ACC), reaction time (RT), and average amplitude were dependent variables.

### 2.1. Participants

We recruited 30 undergraduates (15 males). The average age was 19.07 years (*SD*=0.64 years). All participants were native speakers of Chinese, healthy, right-handed, had normal or corrected to normal vision, and none had a history of neurological disorders. Ethics approval was obtained from the ethics committee of Shanghai Normal University. All participants gave written informed consent and they received monetary compensation.

### 2.2. Stimuli

The stimuli consisted of pairs containing target and origin words. We selected 180 pairs of Chinese characters from the Yu et al. (2018) ECCT as the stimuli for the study (see Fig. 1). There were 90 inclusion pairs and 90 exclusion pairs, so an origin word corresponded to a target word that was included or excluded (e.g., “盆”- “分”/ “为”). The purpose of using the same number of inclusion and exclusion pairs was so that participants would not be able to give only inclusive or exclusive responses. A random selection of 120 inclusive and exclusive word pairs was used in the study phase and ensured that inclusion was equal to exclusion. The software randomly chose 60 pairs from the previous 120 pairs (e.g., “分”- “盆”). These pairs were repeated five times so a total of 300 trials in the study phase. In the subsequent test phase, the same 60 pairs were used so that pairs in the old condition were identical to the pairs in the study phase (e.g., “分”- “盆”). Then, the remaining 60 pairs were used in the intermixed condition (e.g., “为”- “盆”), in which only the origin word was the same as the origin word of pairs used in the study phase. Finally, as a result of the initial random selection of 120 pairs from the original 180 pairs, the new condition (e.g., “力”- “务”) comprised the remaining 60 pairs that had not yet been used. In both the study and test phases, the participants were asked to make a judgment about whether a word pair (target and origin words) was inclusive or exclusive. Moreover, to ensure that the characters were commonly used in everyday life, we chose the characters from the List of Common Standard Chinese Characters from State Council (http://www.gov.cn/zwgk/2013-08/19/content_2469793.htm). Target words corresponding to the same origin word for inclusion and exclusion were comprised of an equal number of strokes. The strokes' numbers of target words ranged from two to six ($M = 4.04$, $SD = 1.02$). For example, an inclusive target word “分” had equal strokes as an exclusive target word “为”, and both of them were related to same origin word “盆” (see Fig. 2). Therefore, the factor of strokes' number was controlled in our research. We constructed a pool containing the inclusive/exclusive target words and their corresponding origin words with an E-prime procedure. Inclusive or exclusive pairs were randomly chosen for any of the three conditions (old, intermixed, and new).

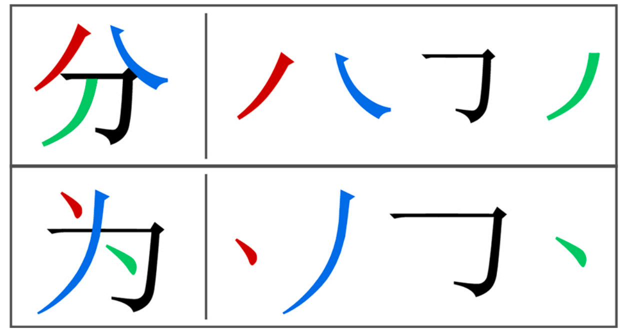

Fig. 2. The strokes in inclusive “分” and exclusive “为” words after decomposition.

To determine the specific number of repetitions required, we conducted a one-factor within-subject design for the pilot research, with four levels of repetition (zero, one, three, and five times). ACC and RT were dependent variables. Twenty-seven undergraduates ($M_{age} = 24.37$ years, $SD = 2.48$, 9 males) were recruited from Shanghai Normal University. We conducted a one-way repeated-measure ANOVA for ACC and RT (see Table 1) of the test phase. The results indicated that no significant difference was observed in terms of ACC [$F(3,78) = 1.30$, $p=0.28$, $\eta_p^2 = 0.05$]. However, there were prominent differences among different conditions [$F(3,78) = 19.45$, $p < 0.001$, $\eta_p^2 = 0.43$]. Specifically, the RT for five repetitions was faster than for no repetitions ($p < 0.001$), one repetition ($p < 0.001$), and three repetitions ($p = 0.005$). The RT for

**Table 1**
Behavioral results of the test phase in the pilot research [*M*(*SE*)].

| Repetition | Accuracy (ACC) | Reaction time (RT) |
|---|---|---|
| No | 0.668(0.035) | 735.05(31.88) |
| Once | 0.689(0.035) | 704.32(36.08) |
| Three times | 0.675(0.042) | 668.37(33.82) |
| Five times | 0.646(0.036) | 624.99(29.92) |

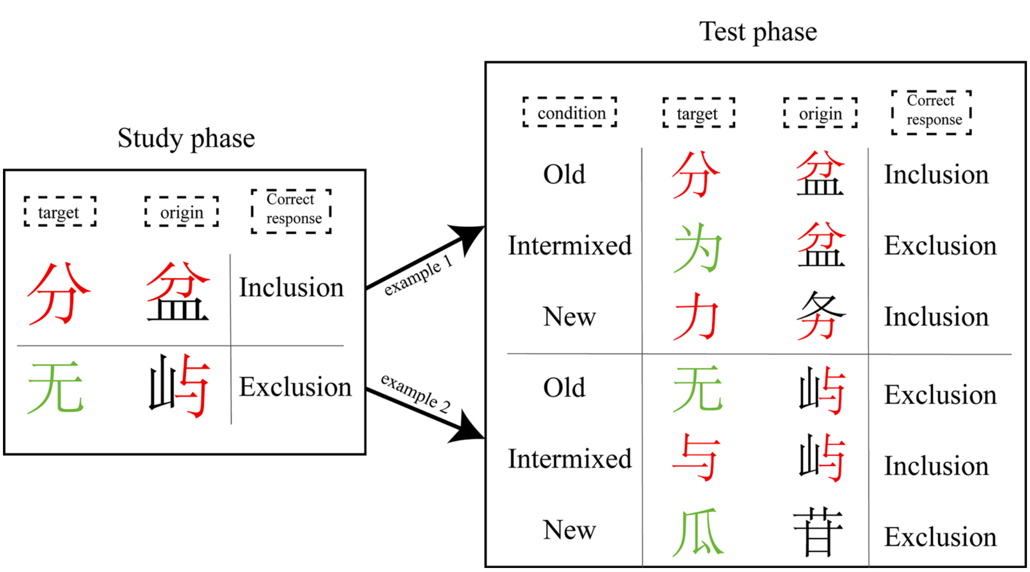


Fig. 1. The Embedded Chinese Character Task (ECCT). We selected some typical Chinese character pairs (examples 1 and 2) to further elaborate the acquisition of this task. The experimental conditions of the Test phase in the formal research were determined by the antecedent Study phase. The color used in the characters assisted non-Chinese speakers in identifying the relationships within structures between the target and the origin words, as well as the relationships involving inclusion and exclusion according to the structure. Red indicated that the target word was identical to the structure of the origin word, and other colors indicated that the origin word did not have the same structure as the target word. The origin characters were the same for the inclusion and exclusion trials. For example, an inclusion trial consisted of a target word “分” and an origin word “盆,” and an exclusion trial consisted of a target word “为” and an origin word “盆.” All stimuli including both origin and target words were repeated five times in the old conditions. Note that only origin words were repeated five times in the intermixed conditions (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

three repetitions was faster than for no repetitions ($p = 0.009$). There were no significant differences for the RT among other conditions ($ps > 0.05$). Therefore, five repetitions enabled participants to quickly form stable relationships within character pairs. The researchers chose the five-repetition condition as the old condition to use in the formal research.

### 2.3. Procedure

The research took place in a laboratory on the university campus. Participants first read and signed the informed consent. One participant at a time was taken to a sound-attenuated, warm, lit room, and was seated in a comfortable chair 60 cm from the computer screen.

E-prime 2.0 was used for programming and data collection. The experiment was conducted on a Lenovo desktop computer with a resolution of 1920 × 1080 and a refresh rate of 60 Hz. The experiment comprised two phases. In the study phase (see Fig. 3, left), a fixation cross was presented for 800 ms in the center of the screen, followed by a target word for 200 ms. After a blank screen was randomly displayed for 600–800 ms, an origin word appeared and remained for 3000 ms. Participants had to respond as quickly and accurately as they could before the origin word disappeared. Finally, a blank screen appeared for 1000 ms.

To rigorously examine the old/new effect, the target word was presented subliminally in the test phase. According to Ortells et al. (2016) and Yu et al.'s (2018) subliminal presence timings, we set the presented time of the target word to 23 ms in the test phase (see Fig. 3, right). The time to complete one refresh was approximately 16.7 ms, therefore, the time to refresh twice was 33.4 ms. In addition, considering factors such as computer latency of approximately 10 ms, the presented time was set to 23 ms, resulting in an actual presented time of 33 ms. Moreover, the 1000 ms mask was presented after the subliminal target word. We extended the mask presentation from 167 ms to 1000 ms in consideration of poor performances possibly due to a short presentation of the mask in the test phase of the pilot research because we needed a relatively greater number of corrective trials utilized to calculate grand average waves in the ERP analysis of the formal research. A blank screen was then presented for 600–800 ms, and the origin word was presented for 3000 ms; participants were required to respond as quickly and accurately as they could before the origin word disappeared. Throughout the experiment, participants were told to respond accurately and quickly and to judge whether the current origin word included the previous target word. They were instructed to press the "F" key for inclusion and the "J" key for exclusion. We included a practice section to ensure that participants grasped the experimental requirements. The participants were allowed to enter the subsequently formal section if they achieved 70 % or greater accuracy. Furthermore, to ensure that the experiment was not affected by other factors such as fatigue, we included two two-minutes rest periods during the test phase. We observed and calculated the total time that would be needed for the formal research as 30 min and 20 min for the study and test phases, respectively.

### 2.4. Data recording and analysis

In the current study, the stimuli display and behavioral data were recorded using E-prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA; http://www.pstnet.com/eprime). Continuous electroencephalographic (EEG) data were recorded using an actiCHamp amplifier (DC-140 Hz bandpass, 500 Hz sampling rate) with 64 Ag/AgCl scalp channels arranged according to the extended international 10–20 system (Brain Products GmbH, Munich, Germany). Horizontal and vertical electrooculograms were recorded with two electrodes mounted 1.5 cm away from the outer canthus of the right eye and 1.5 cm below the left eye. Electrode impedance was maintained below 10 kΩ. The Gnd electrode serving as the grounding electrode was placed at the center of the forehead, and the Fz electrode was the online reference. The EEG data analysis was conducted with Analyzer 2.2 software (Brain Products). First, raw data were re-referenced offline to the average of bilateral mastoid electrodes. Then, the FCz was removed because of a malfunction throughout the EEG data recording. The filter standard was high-pass filtered at 0.1 Hz and low-pass filtered at 40 Hz, and ocular artifacts were corrected via independent component analysis (ICA). Subsequently, EEG data were segmented into 1200-ms epochs, from 200-ms prior to origin word presentation in the test phase onset to 1000-ms after. Each epoch was baseline-corrected according to a pre-stimuli period from -200 to 0 ms. Next, artifacts (activity exceeding ± 80 μV) were rejected from the analysis. The EEG epochs were averaged separately for three different conditions (old, intermixed, new).

According to previous studies and the grand average ERPs (see Fig. 5), we analyzed average amplitudes of N100, P200, N270, and N400, at time windows of 90~140 ms (Khachatryan et al., 2019), 160~200 ms (Khachatryan et al., 2019), 220~380 ms (Ma et al., 2007; Wang et al., 2018) and 400~450 ms (Draschkow et al., 2018; Ku et al., 2020), respectively. The data of N100 (Khachatryan et al., 2019), P200 (Khachatryan et al., 2019), and N270 (Ma et al., 2007; Wang et al., 2018) were analyzed at five electrodes (FC1/FC2, Cz/C1/C2), and data of N400 (Draschkow et al., 2018; Ku et al., 2020) were analyzed at 9 electrodes (Cz/C1/C2, CPz/CP1/CP2, Pz/P1/P2). A repeated measure ANOVA was conducted using SPSS (SPSS version 19.0, SPSS Inc., Chicago, IL, USA). The Greenhouse-Geisser correction was used to adjust the freedom when sphericity was violated, and the Bonferroni correction

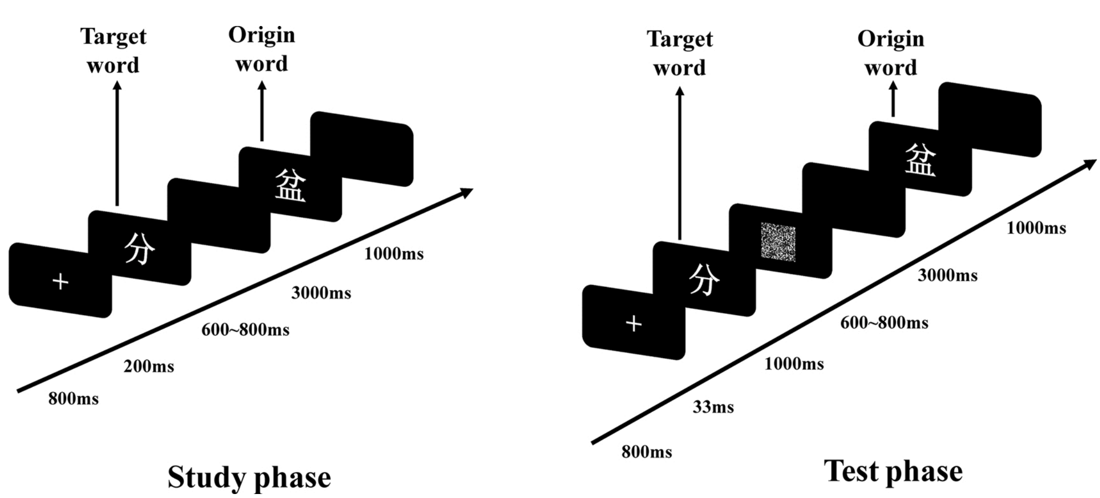


**Fig. 3.** Study (left) and test (right) phases. ERP is time-locked at the presentation of origin word in the test phase.

adjusting *p* value for multiple comparisons was applied to the post-hoc analysis.

## 3. Results

### 3.1. Behavioral data

The one-way repeated measure ANOVA was applied to ACC and RT of the test phase. The results indicated that the differences were significant in old, intermixed and new conditions [$F(1.41, 40.80) = 32.41$, $p < 0.001$, $\eta_p^2 = 0.53$]. Specifically (see Fig. 4), the ACC of old conditions was significantly higher than that of intermixed ($p < 0.001$) and new ($p < 0.001$) conditions. The ACC for intermixed conditions was significantly lower than for new conditions ($p = 0.004$). Meanwhile, the prominent differences for RT were observed in different conditions [$F(1.66, 48.18) = 21.22$, $p < 0.001$, $\eta_p^2 = 0.42$]. The RT with respect to old conditions was significantly faster than for intermixed ($p = 0.001$) and new ($p < 0.001$) conditions, while there were no significant differences between intermixed and new conditions ($p = 0.67$).

### 3.2. EEG data

We conducted 3 (old/new status: old, intermixed, new) × 5 (electrodes: FC1/FC2, Cz/C1/C2) repeated-measure ANOVAs for the average amplitude of **N100**, **P200,** and **N270**, which revealed the following:

**N100**: A main effect of electrodes [$F(1.90, 55.17) = 10.17$, $p < 0.001$, $\eta_p^2 = 0.26$] and old/new status [$F(2, 58) = 6.59$, $p = 0.003$, $\eta_p^2 = 0.19$] was found. Specifically, new conditions evoked the greatest N100 ($M$=-5.97 μV, $SE = 0.48$ μV), which was significantly greater than that induced by old ($p = 0.008$) and intermixed ($p = 0.025$) conditions. No difference was observed, however, between old ($M$=-4.82 μV, $SE = 0.50$ μV) and intermixed ($M$=-5.01 μV, $SE = 0.45$ μV) conditions ($p = 1.00$).

**P200**: A main effect of electrodes [$F(1.93, 56.09) = 16.62$, $p < 0.001$, $\eta_p^2 = 0.36$] and old/new status [$F(2, 58) = 3.57$, $p = 0.034$, $\eta_p^2 = 0.11$] was found. Specifically, P200 induced by new conditions ($M = 1.80$ μV, $SE = 0.62$ μV) was lower than that induced by old ($M = 2.73$ μV, $SE = 0.51$ μV) conditions ($p = 0.011$), while not different from that evoked by intermixed ($M = 2.47$ μV, $SE = 0.57$ μV) conditions ($p = 0.30$). No difference was observed between old and intermixed conditions ($p = 1.00$).

**N270:** A main effect of electrodes [$F(1.79, 51.80) = 6.03$, $p = 0.006$, $\eta_p^2 = 0.17$] and old/new status [$F(2, 58) = 13.25$, $p < 0.001$, $\eta_p^2 = 0.31$] was found. New conditions ($M = 0.04$ μV, $SE = 0.50$ μV) elicited greater N270 than old conditions ($M = 1.61$ μV, $SE = 0.48$ μV) ($p < 0.001$), as did intermixed conditions ($M = 0.67$ μV, $SE = 0.39$ μV) ($p = 0.01$). No significant difference was observed, however, between the new and intermixed conditions ($p = 0.09$).

Researchers conducted 3 (old/new status: old, intermixed, new) × 9 (electrodes: CPz/CP1/CP2, Pz/P1/P2, Cz/C1/C2) repeated measure ANOVAs for average amplitude of **N400**, which indicated that main effects of electrodes [$F(1.83, 53.20) = 19.5$, $p < 0.001$, $\eta_p^2 = 0.40$] and old/new status [$F(2, 58) = 6.95$, $p = 0.002$, $\eta_p^2 = 0.19$] were found. Specifically, N400 for intermixed ($M = 2.86$ μV, $SE = 0.41$ μV) conditions was greater than for old ($M = 1.57$ μV, $SE = 0.37$ μV) conditions ($p = 0.002$). Nevertheless, N400 evoked by new ($M = 1.93$ μV, $SE = 0.40$ μV) conditions was not different from old ($p = 0.88$) nor intermixed ($p = 0.075$) conditions (see Fig. 6).

## 4. Discussion

The present research aimed to contribute to the understanding of the old/new effect elicited by intermixed stimuli by exploring the processes underlying the experience of cognitive conflict. Behavioral data indicate that RT is longer and ACC is lower in the new condition when compared with the old condition. These results show that after five repetitions in the study phase, the apparent old/new effect is observed in the test phase, notwithstanding the subliminal presence of the target word in the formal-research test phase. Notably, responses in the intermixed condition have the lowest ACC, implying the greatest old/new effect. Further EEG data describe that the new condition induces a larger N270 compared with the old condition, but the intermixed condition induces a larger N270 and a larger N400. The reinforcement of ERP components induced under different conditions is specified later.

The new condition on N100 triggers the most negative-going waveform, indicating that the participants notice the appearance of a new origin word. Moreover, for P200, the old condition induces more positive-going waveform relative to the new condition, which is consistent with the results of Evans and Federmeier (2007) who noted the beginning of perception matching. Simultaneously, there is no significant difference between old and intermixed conditions in either N100 or P200. These results indicate that individuals are capable of making accurate and effective old/new judgments in terms of the origin word. Therefore, the consistent change in N100-P200 strongly supports

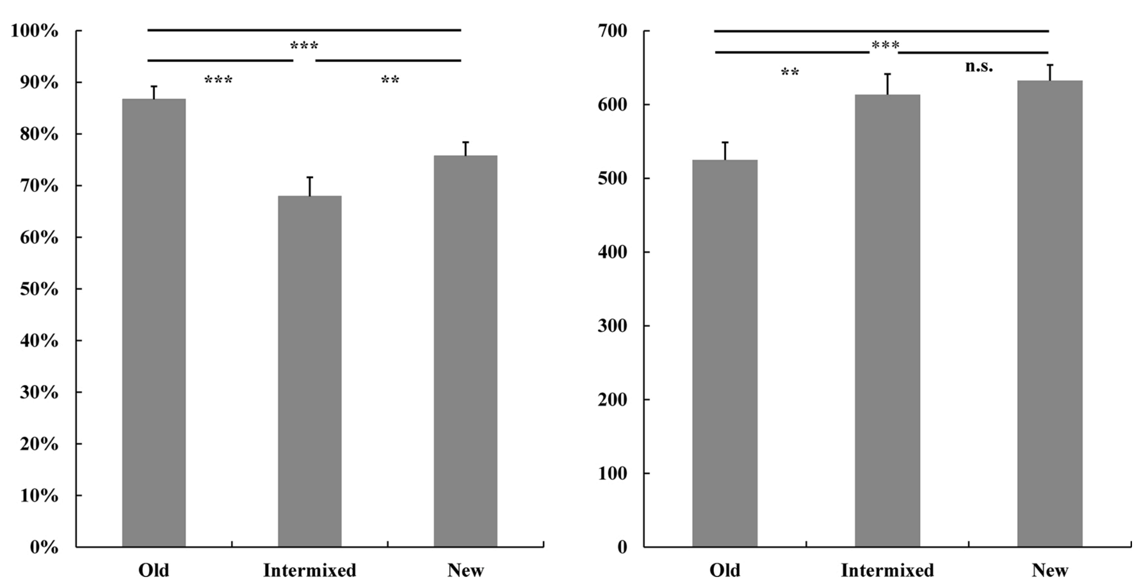


**Fig. 4.** Behavioral data for the test phase: left side is ACC (%) and right side is RT (ms). The error bar is the standard error (*SE*). **: $p < 0.01$, ***: $p < 0.001$, n. s.: not significant.

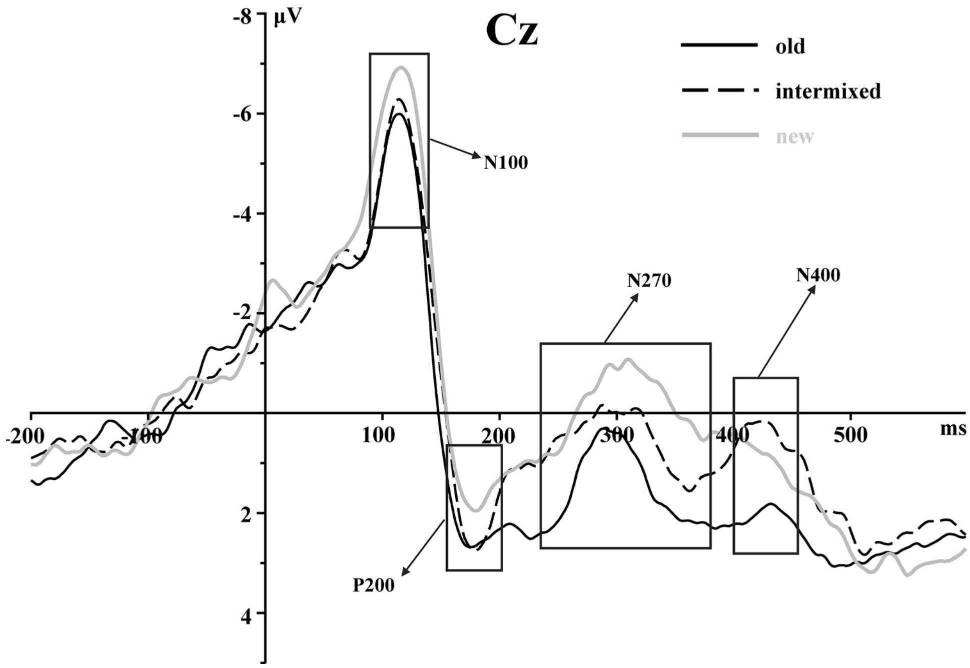


**Fig. 5.** Grand average ERPs at Cz.

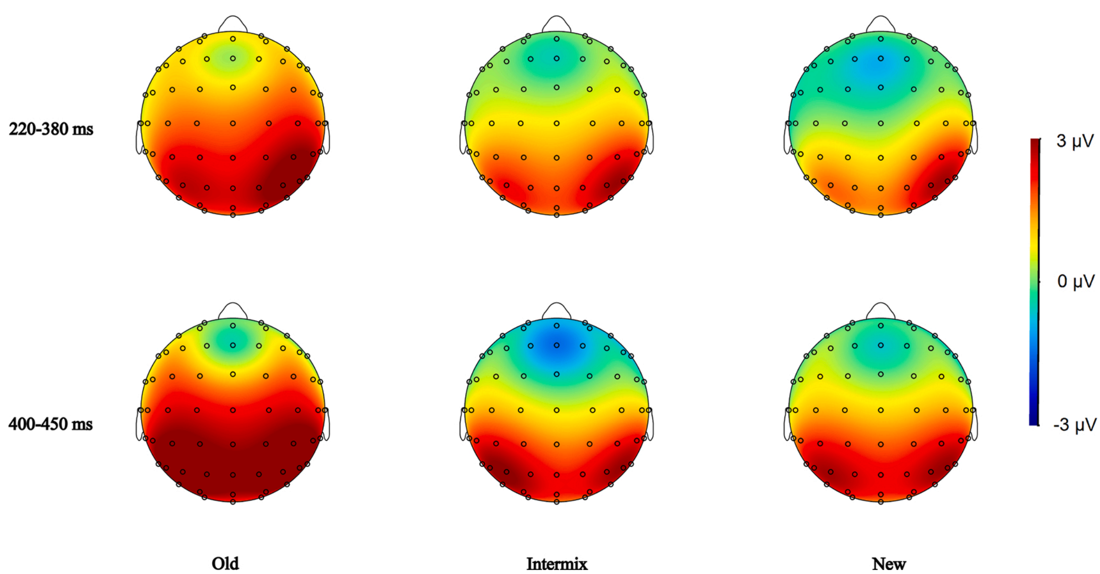


**Fig. 6.** Topographic maps of mean amplitudes of N270 and N400.

the effectiveness of memory representation of five repetitions during the study phase, enabling individuals to identify a new origin word in the new condition at an early stage of attention and perception. Further, individuals quickly identify the new origin word in new conditions versus the old origin word in old and intermixed conditions. In other words, the new origin word gains more attention allocation (Xin et al., 2010). Notably, our results also contribute to the view that familiarity caused by repetition enabled individuals to make a preliminary judgment on the old/new status of stimuli during the attention stage (Ecker & Zimmer, 2009; Rugg & Curran, 2007).

Moreover, in the current research, the old/new differentiation is one of the match/mismatch differentiations. A pair in the test phase that does not appear in the study phase is the new condition, and participants do not form match relationships for this condition, regarded as the mismatch. A pair in the test phase that is partially the same as a pair in the study phase is the intermixed condition, and this condition also belongs to the mismatch condition. A pair in the test phase that is the same as a pair in the study phase is the old condition, and this condition is regarded as a match relationship.

N270 is significantly larger in the new condition than in the old condition, which indicates that the participants experience greater cognitive conflicts when processing new words, because target and origin words in the new condition have not been learned. These results are in line with previous studies. For instance, Wang et al. (2000) found that N270 appeared along with conflict when the left and right sides of a mathematical equation were not equal (e.g., $2 + 6 = 9$). In addition, Wang et al. (2004) discovered that N270 was triggered when there was a mismatch between previous and current shapes and colors of objects. Moreover, there were similar findings in the experiments conducted by Bennett et al. (2014). Collectively, these prior studies proposed that the conflicts between current and previous stimuli were critical for inducing N270, which implied that N270 was indicative of cognitive processing of conflict. Accordingly, the current study makes an important contribution to the comprehensive knowledge of N270 elicited by conflict. Specifically, the pairs of Chinese characters in the new condition are never learned by participants, hence they are compared with old pairs that are learned during the study phase. The initial presence of these new stimuli triggers a conflict monitoring mechanism, which in turn induces a larger N270.

As expected, N270 in the intermixed condition is prominently larger than in the old condition but not different from the new condition. These results demonstrate that cognitive conflicts occur when participants discriminate between intermixed and old pairs that exist in memory. Meanwhile, in the monitoring processing, participants are inclined to classify the intermixture as new pairs, which may be like processing pairs in the new condition. We infer that the way participants cope with intermixture is similar to how they cope with new pairs. Specifically, due to a new target word in the intermixed condition, the participants break the consolidated association formed through five repetitions in the study phase. As a result, a mismatch occurs between new and old pairs, leading the cognitive-monitoring mechanism to detect the conflict, which, in turn, induces a greater N270. Taken together, these results are partially in accordance with the findings of previous scholars (Szucs et al., 2007) who proposed that the mismatch condition in both color and category tasks triggered salient N270, which was considered an index of an individual's processing of conflicts and detection of mismatches. Moreover, Xie et al. (2018) conducted a study with country-of-origin images in which stereotype-inconsistent groups elicited larger N270 relative to stereotype-consistent groups. However, in this research, we set an intermixed condition in which the target word is new, and this is the source of conflict and further triggers the cognitive-monitoring mechanism. One possible explanation is the way that processing conflict is guided by the new target word, thus, participants are inclined to process intermixed pairs as new pairs.

The N400 in the intermixed condition is significantly larger than in the old condition, implying that integration of such conflict is difficult. In addition, it is apparent that N400 in the intermixed condition has a salient peak, which might be due to the existence of mismatch between the new target- and old origin-words. Specifically, as participants are affected by memory representation in the integration process, they are possibly more difficult to judge and rebuild the mismatch relationship between origin and target words. The evidence of Van de Meerendonk et al. (2010) provided clear support for our findings. In their study, strong mismatch induced greater N400 than mild mismatch, suggesting that the difficulty of integration increased due to increased intensity of mismatch. Accordingly, the present results elucidate that the mismatch induced by the intermixed condition is more intense, and results in more difficult integration processing for individuals.

Nevertheless, compared with the intermixed condition, a typical N400 disappears in the new condition. There is no statistically significant difference between new and old conditions, which indicates that N270 in the new condition may also be involved in the conflict integration processing, that is, the conflict monitoring and integration both conducted by the new pair are completed at one time. The reasons can only be speculative. For instance, because the pairs in the new condition are comprised of new words, participants might regard them as new information; such "old/new" conflict is quickly connected with the integration process after being monitored. In the old condition, however, participants automatically activate the corresponding origin word and react quickly through the top-down process, possibly without an integration process. However, we cannot ignore that old stimuli (pairs) were repeated five times during the study phase and new stimuli (pairs) did not induce apparent N400. These results are incongruent with the findings of Finnigan et al. (2002), in which new stimuli induced a more negative-going waveform of N400 (old/new: one repetition $<$ three repetitions $<$ new), indicating that N400 was affected by memory strength. It shows that with the improvement in memory strength, the approach of integrating new stimuli presumably changes; in other words, the process of integration for new stimuli is included late in the detection process, while for intermixed stimuli, there is a distinct process of monitoring and integration.

To the best of our knowledge, this study is one of the first attempts to evaluate the mechanisms of cognitive monitoring and integration triggered by intermixed stimuli. Despite the strengths of this study, its limitations should also be taken into consideration. It was unclear how these changes impact cognitive monitoring and integration if the proportion of new or old stimuli in intermixed stimuli are altered in some way. Another limitation was that although the inclusion/exclusion factor was counterbalanced in the current research, we did not consider this factor which had the potential to impact the results because we did not conduct solely inclusive or exclusive trials for comparison. Although the goal of the present research was to explore the memory effect that occurs in intermixed stimuli, memory effect (i.e., new vs. old pair) and conflict (i.e., mismatch between target and origin word in exclusion vs. match between target and origin word in inclusion) may not have been disentangled enough for analysis. Specifically, conflict possibly occurred in exclusion due to the different structure of target and origin words, although it did not occur in inclusion, and this aspect potentially impacted the memory effect. Therefore, intermixed stimuli were more difficult to integrate than old and new stimuli, this fact may just reflect a memory difference rather than greater conflict. Future studies should aim to replicate the results in various ways by controlling the proportions of new and old stimuli and inclusion/exclusion. In addition, further research could examine non-native Chinese speakers' performance in ECCT.

To conclude, this research provided initial evidence that intermixed stimuli induced both a larger N270 and N400 than old stimuli, and new stimuli only elicited larger N270 compared to old stimuli. These results shed light on the processing of intermixed information containing old and new stimuli and show that individuals not only experience conflicts in the monitoring stage but also allocate more cognitive resources to deal with difficulties encountered in the integration process.

## Declaration of Competing Interest

There are no conflicts of interest to declare.

## Acknowledgments

This work was supported by "Shuguang Program" supported by Shanghai Education Development Foundation and Shanghai Municipal Education Commission (19SG43). We wished to thank Meng Cao for his sincere and valuable help for data collection.

## References

Badre, D., & Wagner, A. D. (2004). Selection, integration, and conflict monitoring: Assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron, 41*, 473–487. https://doi.org/10.1016/S0896-6273(03)00851-1

Bennett, M. A., Duke, P. A., & Fuggetta, G. (2014). Event-related potential N270 delayed and enhanced by the conjunction of relevant and irrelevant perceptual mismatch. *Psychophysiology, 51*(5), 456–463. https://doi.org/10.1111/psyp.12192

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences, 8*(12), 539–546. https://doi.org/10.1016/j.tics.2004.10.003

Chwilla, D. J., Kolk, H. H. J., & Vissers, C. T. W. M. (2007). Immediate integration of novel meanings: N400 support for an embodied view of language comprehension. *Brain Research, 1183*, 109–123. https://doi.org/10.1016/j.brainres.2007.09.014

Curran, T., & Cleary, A. M. (2003). Using ERPs to dissociate recollection from familiarity in picture recognition. *Cognitive Brain Research, 15*(2), 191–205. https://doi.org/10.1016/S0926-6410(02)00192-1

Draschkow, D., Heikel, E., Vo, M. L., Fiebach, C. J., & Sassenhagen, J. (2018). No evidence from MVPA for different processes underlying the N300 and N400 incongruity effect in object-scene processing. *Neuropsychologia, 120*, 9–17. https://doi.org/10.1016/j.neuropsychologia.2018.09.016

Ecker, U. K. H., & Zimmer, H. D. (2009). ERP evidence for flexible adjustment of retrieval orientation and its influence on familiarity. *Journal of Cognitive Neuroscience, 21*(10), 1907–1919. https://doi.org/10.1162/jocn.2009.21135

Evans, K. M., & Federmeier, K. D. (2007). The memory that's right and the memory that's left: Event-related potentials reveal hemispheric asymmetries in the encoding and retention of verbal information. *Neuropsychologia, 45*(8), 1777–1790. https://doi.org/10.1016/j.neuropsychologia.2006.12.014

Fang, X., & Perfetti, C. A. (2017). Perturbation of old knowledge precedes integration of new knowledge. *Neuropsychologia, 99*, 270–278. https://doi.org/10.1016/j.neuropsychologia.2017.03.015

Finnigan, S., Humphreys, M. S., Dennis, S., & Geffen, G. (2002). ERP "old/new" effect: Memory strength and decisional factor(s). *Neuropsychologia, 40*(13), 2288–2304. https://doi.org/10.1016/S0028-3932(02)00113-6

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*(1), 152–170. https://doi.org/10.1111/j.1469-8986.2007.00602.x

Grill-Spector, K., Henson, R., & Martin, A. (2006). Repetition and the brain: Neural models of stimuli-specific effect. *Trends in Cognitive Sciences, 10*(1), 14–23. https://doi.org/10.1016/j.tics.2005.11.006

Hagoort, P., Hald, L., Bastiaansen, M., & Petersson, K. M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science, 304*(5669), 438–441. https://doi.org/10.1126/science.1095455

Hayama, H. R., Johnson, J. D., & Rugg, M. D. (2008). The relationship between the right frontal old/new ERP effect and post-retrieval monitoring: Specific or non-specific? *Neuropsychologia, 46*(5), 1211–1223. https://doi.org/10.1016/j.neuropsychologia.2007.11.021

Khachatryan, E., Wittevrongel, B., Hnazaee, M. F., Carrette, E., Dauwe, I., Meurs, A., Boon, P., van Roost, D., & Van Hulle, M. M. (2019). Semantic and perceptual priming activate partially overlapping brain networks as revealed by direct cortical recordings in humans. *NeuroImage, 203*, 116–204. https://doi.org/10.1016/j.neuroimage.2019.116204

Ku, L. C., Chang, Y. T., & Chen, H. C. (2020). How do extraverts process jokes? An event-related potential study on humor processing. *Brain and Cognition, 141*, Article 105553. https://doi.org/10.1016/j.bandc.2020.105553

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621–647. https://doi.org/10.1146/annurev.psych.093008.131123

Li, X. Q., Hagoort, P., & Yang, Y. F. (2008). Event-related potential evidence on the influence of accentuation in spoken discourse comprehension in Chinese. *Journal of Cognitive Neuroscience, 20*(5), 906–915. https://doi.org/10.1162/jocn.2008.20512

Ma, Q., Wang, X., Dai, S., & Shu, L. (2007). Event-related potential N270 correlates of brand extension. *NeuroReport, 18*(10), 1031–1034. https://doi.org/10.1097/wnr.0b013e3281667d59

Mograss, M. A., Guillem, F., Brazzini-Poisson, V., & Godbout, R. (2009). The effect of total sleep deprivation on recognition memory processes: A study of event-related potential. *Neurobiology of Learning and Memory, 91*(4), 343–352. https://doi.org/10.1016/j.nlm.2009.01.008

Ortells, J. J., Kiefer, M., Castillo, A., Megias, M., & Morillas, A. (2016). The semantic origin of unconscious priming: Behavioral and event-related potential evidence during category congruency priming from strongly and weakly related masked words. *Cognition, 146*, 143–157. https://10.1016/j.cognition.2015.09.012.

Paller, K. A., Voss, J. L., & Boehm, S. G. (2007). Validating neural correlates of familiarity. *Trends in Cognitive Sciences, 11*(6), 243–250. https://doi.org/10.1016/j.tics.2007.04.002

Pan, F., Shi, L., Zhang, L., Lu, Q., & Xue, S. (2016). Different stages, different signals: The modulating effect of cognitive conflict on subsequent processing. *PloS One, 11*(9), Article e0163263. https://doi.org/10.1371/journal.pone.0163263

Proverbio, A. M., Vanutelli, M. E., & Vigano, S. (2019). Remembering faces: The effect of emotional valence and temporal recency. *Brain and Cognition, 135*, Article 103584. https://doi.org/10.1016/j.bandc.2019.103584

Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences, 11*(6), 251–257. https://doi.org/10.1016/j.tics.2007.04.004

Schacter, D. L., Wig, G. S., & Stevens, W. D. (2007). Reductions in cortical activity during priming. *Current Opinion in Neurobiology, 17*(2), 171–176. https://doi.org/10.1016/j.conb.2007.02.001

Schlesewsky, M., & Bornkessel, I. (2006). Context-sensitive neural responses to conflict resolution: Electrophysiological evidence from subject-object ambiguities in language comprehension. *Brain Research, 1098*(1), 139–152. https://doi.org/10.1016/j.brainres.2006.04.080

Schumacher, E. H., Seymour, T. L., & Schwarb, H. (2010). Brain activation evidence for response conflict in the exclude recognition task. *Brain Research, 1329*, 113–123. https://doi.org/10.1016/j.brainres.2010.03.015

Stuellein, N., Radach, R. R., Jacobs, A. M., & Hofmann, M. J. (2016). No one way ticket from orthography to semantics in recognition memory: N400 and P200 effect of associations. *Brain Research, 1639*, 88–98. https://doi.org/10.1016/j.brainres.2016.02.029

Szucs, D., Soltesz, F., Czigler, I., & Csepe, V. (2007). Electroencephalography effect to semantic and non-semantic mismatch in properties of visually presented single-characters: The N2b and the N400. *Neuroscience Letters, 412*(1), 18–23. https://doi.org/10.1016/j.neulet.2006.08.090

Thakral, P. P., Kensinger, E. A., & Slotnick, S. D. (2016). Familiarity and priming are mediated by overlapping neural substrates. *Brain Research, 1632*, 107–118. https://doi.org/10.1016/j.brainres.2015.12.008

Van de Meerendonk, N., Kolk, H. H. J., Vissers, C. T. W. M., & Chwilla, D. J. (2010). Monitoring in language perception: Mild and strong conflicts elicit different ERP patterns. *Journal of Cognitive Neuroscience, 22*(1), 67–82. https://doi.org/10.1162/jocn.2008.21170

Van Strien, J. W., Verkoeijen, P. P. J. L., Van der Meer, N., & Franken, I. H. A. (2007). Electrophysiological correlates of word repetition spacing: ERP and induced band power old/new effect with massed and spaced repetitions. *International Journal of Psychophysiology, 66*(3), 205–214. https://doi.org/10.1016/j.ijpsycho.2007.07.003

Veen, V. V., & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience, 14*(4), 593–602. https://doi.org/10.1162/08989290260045837

Wang, P., Tan, C. H., Li, Y., Zhang, Q., Wang, Y. B., & Luo, J. L. (2018). Event-related potential N270 as an index of social information conflict in explicit processing. *International Journal of Psychophysiology, 123*, 199–206. https://doi.org/10.1016/j.ijpsycho.2017.03.005

Wang, Y., Cui, L., Wang, H., Tian, S., & Zhang, X. (2004). The sequential processing of visual feature conjunction mismatches in the human brain. *Psychophysiology, 41*(1), 21–29. https://doi.org/10.1111/j.1469-8986.2003.00134.x

Wang, Y., Kong, J., Tang, X., Zhuang, D., & Li, S. (2000). Event-related potential N270 is elicited by mental conflict processing in human brain. *Neuroscience Letters, 293*(1), 17–20. https://doi.org/10.1016/S0304-3940(00)01480-4

Wang, Y., Tian, S., Wang, H., Cui, L., Zhang, Y., & Zhang, X. (2003). Event-related potentials evoked by multi-feature conflict under different attentive conditions. *Experimental Brain Research, 148*(4), 451–457. https://doi.org/10.1007/s00221-002-1319-y

Xie, Y., Chen, M., Zhang, W., & Cui, F. (2018). Neural correlates of country-of-origin image (COI) stereotype. *Neuroscience Letters, 687*, 164–168. https://doi.org/10.1016/j.neulet.2018.09.045

Xin, Y., Li, H., & Yuan, J. J. (2010). Negative emotion interferes with behavioral inhibitory control: An ERP study. *Acta Psychologica Sinica, 42*(3), 334–341. https://doi.org/10.3724/sp.J.1041.2010.00334

Yu, T., Yin, Y., Wang, S., Zhou, S., Tang, X., & Luo, J. (2018). Positive effect of intuitive processing is modulated by cognitive resources under different levels of consciousness. *Acta Psychologica Sinica, 50*(6), 583–591. https://doi.org/10.3724/sp.J.1041.2018.00583

Zhou, S., Yin, Y., Yu, T., Stupple, E. J. N., & Luo, J. (2018). Exploring the experience of novelty when viewing creative adverts: An ERP study. *Frontiers in Psychology, 9*, 471. https://doi.org/10.3389/fpsyg.2018.00471