

Neural oscillatory evidence of the difference between emotional and conceptual processing in language comprehension



Xuhai Chen^{a,*}, Jiajin Yuan^b, Jingjing Guo^a, Yuqun You^{a,*}

^a Behavior and Cognitive Neuroscience Key Laboratory of Shaanxi Province, School of Psychology, Shaanxi Normal University, Xi'an 710062, China

^b Key Laboratory of Cognition and Personality of Ministry of Education, School of Psychology, Southwest University, Chongqing 400715, China

HIGHLIGHTS

- Whether conceptual and emotional incongruities can be differentiated was examined.
- Both emotional and conceptual incongruities related to N400 effect.
- Conceptual incongruity induced theta power increase.
- Emotional incongruity induced gamma power increase.

ARTICLE INFO

Article history:

Received 1 July 2013

Received in revised form 9 August 2013

Accepted 19 August 2013

Keywords:

Emotional processing

Conceptual processing

N400

Event-related spectral perturbation

ABSTRACT

Despite ample study of conceptual and emotional information processing in language, it remains unclear whether these two types of processing rely on different neural mechanisms. In the present study, the processing of semantic and emotional information was directly compared in 24 participants undergoing electroencephalograms (EEGs). Participants read 120 scenarios ending in three ways (affectively and semantically congruent, affectively incongruent, and semantically incongruent) and were asked to judge the appropriateness of the last word within the context. The data were analyzed using both event-related potentials (ERPs) and event-related spectral perturbation (ERSP) analysis. In addition to the similar N400 effects evoked by both emotional and conceptual incongruity, conceptual incongruity elicited a larger theta power increase, while emotional incongruity induced a gamma band power increase, compared with the congruent condition. The different oscillatory patterns suggest that emotional and conceptual information in language processing may rely on different neural mechanisms, even though both types of processing produced a similar N400 effect.

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1. Introduction

Language comprehension depends on both conceptual and emotional meaning construction. Numerous studies suggest that both conceptual and emotional incongruities in language comprehension are associated with the N400 effect [1,16]. However, whether the two kinds of meaning constructions can be differentiated by the brain remains unclear. Separating and balancing these two types of information to reach a precise comprehension is of great importance in language processing. Moreover, people are capable of analyzing a situation as conceptually acceptable but affectively shocking, and vice versa. Thus, it is essential to find out

the neural correlates engaged in these two types of meaning construction. To this end, the present study aimed to use EEG data to investigate the comparative neural processes engaged in conceptual and emotional meaning processing.

It is well known that conceptual meaning construction is related to the N400 effect [1,2]. Similarly, it has also been reported that emotional meaning construction is associated with the N400 effect. In previous research, emotional words primed by congruent emotional stimuli evoked smaller N400 amplitudes than those primed by incongruent emotional stimuli [3,21]. Furthermore, recent studies have found that emotional words whose meanings are inconsistent with the preceding emotional context elicit a larger N400 effects than consistent emotional words [16,17,4]. In contrast to studies which emphasized the similarity between emotional and conceptual meaning processing, other studies have suggested a separation between emotional and conceptual processing. Neuroimaging studies have indicated that semantic priming employs the left infero-lateral frontal areas, superior temporal cortex, and

* Corresponding authors: School of Psychology, Shaanxi Normal University, 199# South Chang'an Road, Xi'an 710062, China. Tel.: +86 029 85303236.

E-mail addresses: shiningoceanchan@gmail.com (X. Chen), youxuqun@snnu.edu.cn (Y. You).

Table 1
Conditions, exemplar sentences with approximate literal translations.

Type	Example sentences in Chinese and their English translation	
CON (original sentence)	这本书情节单调, 内容十分 乏味 。 The plot of this book is monotonous, and its content is so tedious .	这篇戏剧人物形象丰满, 故事非常 有趣 。 The images of this drama are life-like, and its story is so interesting .
E-IN (within-pair interchanged) tedious ↔ interesting	这本书情节单调, 内容十分 有趣 。 The plot of this book is monotonous, and its content is so interesting .	这篇戏剧人物形象丰满, 故事非常 乏味 。 The images of this drama are life-like, and its story is so tedious .
C-IN (within-valence interchanged) tedious ↔ arrogant ; interesting ↔ safe	这本书情节单调, 内容十分 傲慢 。 The plot of this book is monotonous, and its content is so arrogant .	这篇戏剧人物形象丰满, 故事非常 安全 。 The images of this drama are life-like, and its story is so safe .

The key emotional word pair are “tedious and interesting”, while “arrogant” and “safe” are the within valence emotional words for tedious and interesting, respectively.

parietal cortex [5,6], whereas the brain regions for affective priming are comprised of the fusiform gyrus and amygdala [7]. Moreover, a recent study found that conceptual and emotional incongruence elicits N400 effects regardless of the specific cognitive focus of the participants. In this study, there was no interaction between conceptual relatedness and emotional congruence, suggesting that conceptual and emotional processes are functionally independent [8].

In sum, the research just discussed implies that though both conceptual and emotional incongruity are associated with the N400 effect, the N400 effects for each type of semantic processing may be independent [8]. However, this independence in terms of N400 effects does not answer the question whether the two processing types can be differentiated by the brain. As discussed above, it is adaptively important for humans to distinguish conceptual and emotional meanings during real-life communications. In this regard, there should be neurophysiologic indexes that embody this dissociation in the brain.

Although the N400 effect is a common neurophysiologic index for conceptual and emotional meaning construction, ERPs are limited in the aspects of the signal to which they are sensitive. For instance, as a result of phase-locked averaging and low-pass filtering, ERPs are unable to reveal cognitive processes associated with the non-phase-locked and fast rhythm activities. By contrast, neural oscillations, which reflect neural rhythm changes of ongoing EEG time-locked to stimulus onset, may provide more information about the dissociation of different semantic processes (for a review, see [9]).

Indeed, neural oscillations have been used to differentiate various semantic features. For instance, Hagoort et al. [11] found that world knowledge violation resulted in gamma synchronization, while semantic violation resulted in a theta band power increase, although both types of violation elicited similar N400 effects. More relevant to the current study, it was suggested that theta frequency range power increases are associated with lexical retrieval [10] and semantic violation [11,12]. On the other hand, the processing of emotional information was related to gamma band activity [13–15] and theta band power change [26]. Furthermore, Molinaro et al. [27] reported increased gamma phase synchronization for the high-constraining compositional context, and increased theta synchronization for the collocational context.

Based on the previous studies, it is reasonable to speculate that conceptual and emotional meaning construction can be differentiated by neural oscillations. Therefore, we monitored both evoked and oscillatory EEG activity of target words embedded in three types of contexts (affectively and semantically congruent “CON”, emotionally incongruent “E-IN”, and conceptually incongruent “C-IN”). We created scenarios composed of two sentences, in which an initial sentence was used to establish the emotional context (see Table 1). The target sentence then contained a critical word that

was either congruent (CON and C-IN) or incongruent (E-IN) with emotional context. Moreover, the critical word was also either congruent (CON and E-IN) or incongruent (C-IN) with the conceptual context.

Since the N400 effect is known to be larger for words that are either conceptually or affectively incongruent with the context [1,16,17], we hypothesized that both conceptually and emotionally incongruent words evoke a larger N400 effect, compared to congruent words. However, based on the neural oscillatory feature reported for semantic [9] and emotional [15] processing, and the fact that neural oscillations appear to differentiate multiple semantic meanings [11], we hypothesized that while conceptual meaning construction is related to theta band power activity, emotional meaning construction is related to a gamma band power increase.

2. Method

2.1. Participants

Twenty-four right-handed native speakers of Mandarin Chinese (12 women, aged 22–25, mean age 23.44) were recruited to participate in the experiment. All participants reported normal auditory and normal or corrected-to-normal visual acuity, and no neurological, psychiatric, or other medical problems. The experiments were conducted in accordance with the Declaration of Helsinki and the guidelines were approved by the Ethical Committee of the Institute of Psychology, Chinese Academy of Sciences. All participants gave written informed consent prior to their inclusion in the study and were reimbursed ¥50 Yuan for their time.

2.2. Stimuli

Sixty pairs of two-syllable emotional words were selected from the Chinese Affective Words System [18]. Each pair consisted of one positive word (**有趣**, **interesting**) and one negative word (**乏味**, **tedious**) which can each be used to describe the same phenomenon, but with an opposite affective valence. The mean valence values for positive words (6.74 ± 0.29) were significantly larger than those for negative words (3.22 ± 0.53 , $t = 43.78$, $p < .001$) while the mean arousal values for both types of words were not significantly different (4.59 ± 0.65 vs. 4.84 ± 0.62 , $t = 3.78$, $p > .05$). Next, 120 scenarios were constructed with the key emotional words as the last words. The appropriateness of the sentences was validated through ratings by 30 university students. Then, the last words were interchanged within one pair to get 120 affectively incongruent but conceptually appropriate sentences (E-IN, within-pair change, see Table 1). The last positive or negative words were interchanged in a Latin square pattern to get another 120 conceptually incongruent but affectively appropriate sentences (C-IN, within-valence change, see Table 1). Note that it seems impossible to qualitatively separate

conceptual and emotional meaning. However, we believe that our manipulation can at least quantitatively disentangle semantic and affective processing. Forty participants rated the affective and conceptual congruency of all the sentences on a 7-point scale. One-way ANOVAs suggested the mean affective congruency for the three conditions were significantly different [$F(2,119)=801$, $p<.001$, $\eta_p^2=.93$], with CON (6.18 ± 0.47) > C-IN (4.90 ± 0.65) > E-IN (1.65 ± 0.43), (p 's < .001). The conceptual congruency rates also differed significantly [$F(2,119)=617$, $p<.001$, $\eta_p^2=.91$], with CON (6.05 ± 0.45) > E-IN (5.03 ± 0.35) > C-IN (1.80 ± 0.79), (p 's < .001).

Next, the 360 sentences were assigned to one of three lists, each including three types of sentences (40 each). Each participant read only one of the lists, which prevented repetition effects of the sentences and key words. The key words were identical across conditions and thus avoided confounding effects of physical differences such as word frequency. Forty filler sentences were included to counterbalance the response possibility and deter subjects' predicting the aim of the current study.

2.3. Procedures

After signing an informed consent document, participants were escorted to a dimly lit, sound-reduced testing room, and seated in a comfortable chair approximately 100 cm in front of a computer monitor. Each sentence was presented one word at a time on the center of the screen. All words were presented in green letters on a black background, with $0.2\text{--}1^\circ$ of visual angle horizontally and 0.2° vertically. The second to the last word was underlined to serve as a warning for the upcoming last word (the target word). Each trial consisted of the following sequence of events: first, a fixation cross was presented for 300 ms; then, the sentence came word by word, with each word lasting for 350 ms. The inter-stimulus interval (ISI) of words was 200 ms. The inter-trial interval (ITI) was 1500 ms. Participants were asked to judge the appropriateness of the last word according to its context by pressing either the "J" or "F" button on the key board. The response hands were counterbalanced across the participants. Practice trials were administered to each participant until they were familiar with the experimental task. Then, 160 trials were randomly presented to each participant in three blocks. Participants had a break between blocks.

2.4. Electrophysiological recording and data reduction

EEG were recorded from 64 Ag–AgCl electrodes embedded in an elastic cap placed according to the 10–20 convention. Both the EEG and electrooculogram (EOG) were sampled at 500 Hz, with a band pass of 0.05–100 Hz, using a Neuroscan SynAmps2 amplifier. EEG data were referenced online to the left mastoid. The vertical EOG was recorded supra- and infra-orbitally at the left eye. The horizontal EOG was recorded from the left versus right orbital rim. Impedances were kept below 5 k Ω . After offline screening for eye movements, muscle artifacts, and electrode drifting using the Neuroscan 4.3, EEG data was segmented to 2200 ms epochs time-locked to the key word, starting 800 ms prior to the key word. Then, the epoched data were imported to an EEGLAB toolbox [19]. Epochs with large artifacts (exceeding $\pm 100 \mu\text{V}$) and incorrect responses were removed (35.04 ± 5.65 , 35.54 ± 5.27 , and 34.34 ± 5.23 trials remain for E-IN, CON, and C-IN, respectively), and channels with poor signal quality were interpolated. Independent component analysis (ICA) using the Infomax algorithm was used to obtain independent components (ICs) from scalp EEG activity, and ICs represent artifacts were removed.

For ERP analysis, the artifact-free data were re-referenced offline to the algebraic average of two mastoids and then low-pass (<30 Hz) filtered. More than 30 trials per condition remained for averaging. The reported data were time-locked to the key word and

baseline-corrected 100 ms before the onset of the key words. Grand average ERPs were computed for each condition separately, with an epoch including the 100 ms preceding, and 800 ms following, key words (as illustrated in Fig. 1). For ERSP analysis, data were average-referenced across all scalp electrodes. We applied Morlet wavelet decomposition to the 2200 ms data epoch using EEGLAB12.0.1.0b running under Matlab7.8.0. For conciseness, we present only the data relevant to our research questions here (4–70 Hz over –100 to 700 ms). Power values were normalized with respect to a 100 ms pre-stimulus baseline and transformed into decibel scale ($10 \cdot \log_{10}$ of the signal), yielding the ERSP (as illustrated in Fig. 1).

2.5. Statistical analysis

For the ERP data, based on visual inspection of the grand average waveforms and previous studies [1,12], we used 350–550 ms as the time window for the N400 component. To statistically clarify differences in the N400 effect, the mean amplitudes during the time of interest were entered into repeated measures ANOVAs with Congruity (E-IN, CON, C-IN), Region (anterior, central, posterior) and Hemisphere (left, middle and right) as the independent factors.²

For the ERSP data, a permutation test was conducted using the statcond function of the EEGLAB toolbox to identify frequency bands and time windows. Based on visual inspection of the permutation test (shown in Fig. 1) and previous studies [12,15], two regions of interest (ROI) were selected (theta: 6–7 Hz over 600–700 ms; and gamma: 42–65 Hz over 400–600 ms). The ERSP values for each subject over each ROI, under each condition, were exported and subjected to repeated-measures ANOVA with the same independent factors used in the ERP analysis.

3. Results

3.1. Behavioral results

Subjects recognized the congruency in the three types of materials with high accuracy ($0.92 \pm .06$, $0.93 \pm .06$, and $0.94 \pm .06$ for E-IN, CON, and C-IN respectively), but significant differences [$F(2,46)=1.09$, $p>.3$, $\eta_p^2=.05$]. However, the response times for the three types of materials were significantly different [$F(2,46)=7.45$, $p<.01$, $\eta_p^2=.26$]. Pairwise comparison showed that the response times for both emotional (945 ± 123 ms, $P<.05$) and conceptual (964 ± 125 ms, $P<.01$) incongruent words were longer than for congruent words (905 ± 129 ms).

3.2. ERP results

The repeated measures ANOVAs showed a significant main effect of congruity [$F(2,46)=5.60$, $p<.01$, $\eta_p^2=.20$]. The ERPs were more negative for both emotionally and conceptually incongruent conditions than for the congruent conditions. Additionally, there was a significant main effect of region [$F(2,46)=15.47$, $p<.001$, $\eta_p^2=.40$] and an interaction between congruity and hemisphere [$F(2,46)=4.08$, $p<.01$, $\eta_p^2=.15$]. The interaction between congruity, hemisphere, and region was marginally significant [$F(8,184)=2.36$, $p=.05$, $\eta_p^2=.09$]. Thus, this three-way interaction was probed with simple effects tests. These tests indicated that congruity effects were significant for anterior-left [$F(2,46)=6.65$, $p<.01$, $\eta_p^2=.22$], anterior-middle [$F(2,46)=4.19$,

² Left anterior: F3, F5, F7, FC3, FC5, and FT7; middle anterior: F1, FZ, F2, FC1, FCZ and FC2; right anterior: F4, F6, F8, FC4, FC6 and FT8; left central: C3, C5, T7, CP3, CP5, and TP7; middle central: C1, CZ, C2, CP1, CPZ, and CP2; right central: C4, C6, T8, CP4, CP6, and TP8; left posterior: P3, P5, P7, PO3, PO5 and PO7; middle posterior: P1, PZ, P2, O1, POZ, and O2; right posterior: P4, P6, P8, PO4, PO6, and PO8.

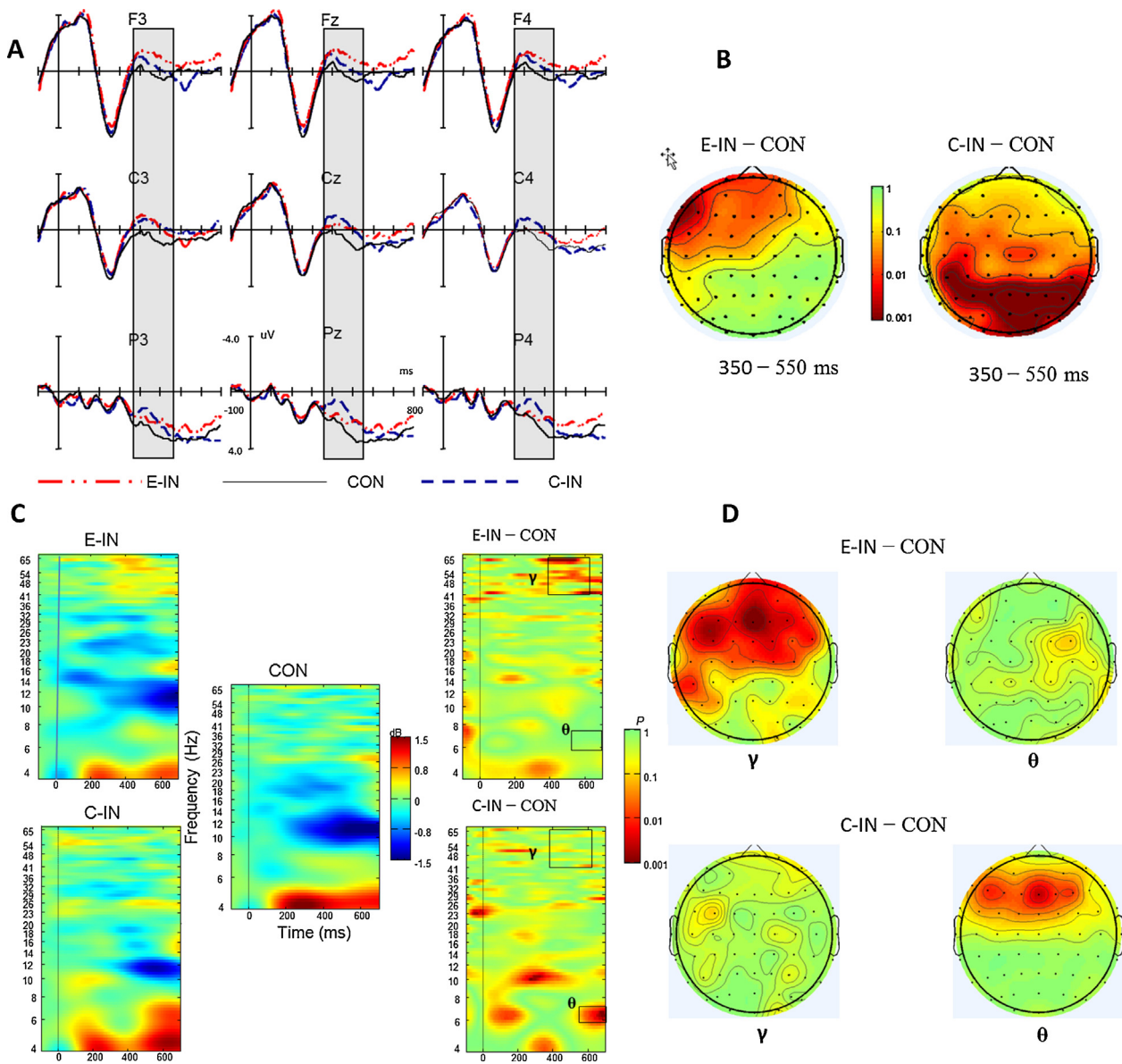


Fig. 1. EEG results. (A) Grand averaged waveforms evoked by the critical words as a function of congruity at nine representative electrodes. Waveforms are time-locked to the onset of the critical words. Negative is plotted upward. (B) Topographies of the N400 for two types of differences. (C) The average oscillatory activities for three conditions and difference between congruent and two types of incongruent conditions. The time–frequency map shows oscillatory activities at Cz electrodes over time (x-axis; 0 is onset of key word) and frequency (y-axis). Red colors indicate more power increase and blue colors indicate more power decrease relative to baseline. The difference showed the permutation test with the red indicating bigger p value. (D) Topographical map showed the three ROIs for two types of differences. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$p < .05$, $\eta_p^2 = .15$], central-left [$F(2,46) = 4.76$, $p < .05$, $\eta_p^2 = .17$], central-middle [$F(2,46) = 4.49$, $p < .05$, $\eta_p^2 = .16$], posterior-middle [$F(2,46) = 6.06$, $p < .01$, $\eta_p^2 = .21$] and posterior right [$F(2,46) = 5.37$, $p < .01$, $\eta_p^2 = .19$]. Pairwise comparison demonstrated that the enhancement of N400 amplitude for affective incongruity was significant only for the anterior area ($p < .01$), whereas that of conceptual incongruity was significant for both central ($p < .01$) and posterior areas ($p < .001$).

3.3. ERSP results

The repeated measures ANOVAs for *theta* bands showed a marginally significant interaction between congruity and region [$F(2,46) = 2.76$, $p = .06$, $\eta_p^2 = .11$]. Simple effect tests probing this interaction showed that the effect of congruity was significant for only the anterior area [$F(2,46) = 4.17$, $p < .05$, $\eta_p^2 = .15$]. Pairwise

comparisons indicated that conceptual incongruity induced significantly larger *theta* band increases than did affective incongruity ($p < .01$) and the congruent condition during this time range ($p < .05$) for the anterior area. The repeated measures ANOVAs for *gamma* bands showed a significant main effect of congruity [$F(2,46) = 4.54$, $p < .05$, $\eta_p^2 = .17$]. Post hoc comparisons indicated that affective incongruity induced a significantly larger *gamma* band increase than both conceptual incongruity ($p < .05$) and the congruent sentences for this time range ($p < .05$).

4. Discussion

The aim of the present study was to test whether emotional and conceptual information processing in language comprehension relies on different neural substrates. We found that both types of incongruity elicited slower response times and similar N400 effects

in comparison with congruent words. However, conceptual incongruity elicited a larger theta band power increase, while emotional incongruity induced a gamma band power increase.

Consistent with previous research [20], the response times were slower for both types of incongruity in comparison to the congruent condition, which might suggest difficulty in accessing semantic memory and reunification. Moreover, both kinds of incongruity elicited N400 enhancement with similar amplitude and latency relative to the congruent condition. This is consistent with previous studies, which reported that the N400 component is sensitive not only to conceptual mismatches, but to affective mismatches as well [4,16,17,21]. This phenomenon might be explained by the comparably low plausibility of the two kinds of incongruity [22].

However, while the N400 effects for conceptual incongruity were centro-parietally distributed, those for emotional incongruity were frontally distributed. This result is in line with previous studies which reported an anterior scalp distributed N400 effect for affective incongruity [21,23]. This finding suggests that incongruity in affective information elicits frontal N400 effects. However, the strength of this conclusion is attenuated by the fact that other studies regarding emotional incongruity did not find a frontally distributed N400 effect [17,24]. According to the view that distribution differences in N400 should be treated in a graded way rather than in a categorical fashion [1], the current topography difference might suggest that emotional and conceptual information in language processing share important elements, but also diverge from each other to various degrees. Indeed, such an inference is in line with previous research that revealed shared neural bases but also a neural dissociation of the two types of meaning construction [25].

More critically, while conceptual incongruity induced a larger theta band power increase, emotional incongruity induced a gamma band power increase as compared with congruent sentences. The theta band power increase for conceptual incongruity is consistent with previous studies [9,11,12], and might represent the retrieval of lexical information from long-term memory. The gamma band increase for emotional incongruity is in line with previous studies which found that gamma band power is related to emotional information processing [13–15]. Though larger theta activity was also observed for emotional incongruity relative to the congruent condition, this effect was not significant. We speculate that this phenomenon is due to theta activity being sensitive to emotional valence [26]. Since the emotional construction in the present study is the congruence between target words and the context preceding them, emotional valence was kept constant across conditions in this study. As in some previous studies [11], the conceptual incongruity in the present study is created by traditional semantic violation, while the emotional incongruity is based on the compositional context of global emotional meaning construction. Given that theta and gamma synchronization can differentiate semantic violation and world knowledge violation [11], and collocational and compositional context [27], it seems reasonable that neural oscillatory dynamics may differentiate emotional and conceptual processing in language comprehension.

Although conceptual and emotional incongruity both elicit similar N400 effects, the different oscillatory responses for conceptual and emotional incongruity indicate that the brain may keep a record of the nature of different meaning constructions. This is important because people need to dissociate subjective emotions and objective knowledge in language comprehension. However, the generalization of such a conclusion needs to be further investigated. In this study, we manipulated conceptual and emotional congruency only quantitatively. Thus, there are limitations on the degree to which we can separate these two types of information processing. Further studies employing the emotional

Stroop paradigm or other designs which better differentiate conceptual and emotional meaning would further elucidate the topic. Moreover, the results of the current research may not be generalizable to other languages, as the present investigation explored the matters of interest in only the Mandarin Chinese language.

5. Conclusion

The present study directly compared electrophysiological responses to emotional and conceptual incongruity in language comprehension. The results show that both types of incongruity elicit N400 effects with similar amplitudes and latency, but with different topography distribution. Moreover, conceptual incongruity induced a larger theta activity increase, while emotional incongruity led to a gamma band power increase as compared with the congruent condition. These results imply that conceptual and emotional information processing in language comprehension relies on different neural substrates even though both types of processing are related to the N400 effect.

Acknowledgements

This research was supported by the Fundamental Research Funds for the Central Universities (GK201102033), National Natural Science Foundation of China (31300835), General Projects for Humanities and Social Science Research of Ministry of Education (12XJC190002) and the Natural Science Foundation of Shaanxi Province, China (2012JQ4010).

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