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EEG theta responses induced by emoji semantic violations

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Abstract

This study investigated emoji semantic processing by measuring changes in event-related electroencephalogram (EEG) power. The last segment of experimental sentences was designed as either words or emojis consistent or inconsistent with the sentential context. The results showed that incongruent emojis led to a conspicuous increase of theta power (4-7Hz), while incongruent words induced a decrease. Furthermore, the theta power increase was observed at midfrontal, occipital and bilateral temporal lobes with emojis. This suggests a higher working memory load for monitoring errors, difficulty of form recognition and concept retrieval in emoji semantic processing. It implies different neuro-cognitive processes involved in the semantic processing of emojis and words.

Key words: emoji; semantic processing; theta responses; EEG; language

Introduction

Human beings not only communicate through language (phonemes, words, phrases, sentences, etc.), but also through paralanguage (various visual and vocal modalities). Among all the paralinguistic cues that have been studied so far, emojis, which refer to picture characters or pictographs have witnessed a sharp increase in computer-mediated communication contexts. Network emojis have similarities with language information in that they directly refer to pre-constructed concepts, emotions, and can construct larger structures. At the same time, they differ from language information because they are not within the scope of phonetics, morphology, or lexical analysis. Despite extensive research on the semantic processing of linguistic messages from different aspects including lexical retrieval, semantic integration, and etc., little is known about the semantic processing of emojis. Some sociolinguists hypothesized that in communications with emojis, it may not require a large cognitive effort to retrieve and select words, phrases, or world knowledge associated with the discourse practices (e.g., Danesi, 2017). Because visual tokens and their inherent nuances are easier to be selected and more comprehensible than those encoded by words. But few research has provided electrophysiological evidence to theoretical hypotheses in emoji processing. The EEG oscillations in specific frequency bands induced by cognitive events is believed to reflect the dynamic recruitment of related neuronal networks involved in cognitive processing (Varela, 2001). Concerning the widely used emojis, the current study aims to explore the semantic processing of emojis in Chinese sentential context by investigating the EEG activities induced in congruent/ incongruent conditions.

Even though an integrated understanding of linguistic processes based on the detailed knowledge of the corresponding neural networks is still incomplete, it has

been widely reported that the theta oscillations (4–7 Hz) play an important role in the activation of neuronal assemblies, representing concepts and words (e.g., Allefeld et al., 2005; Bastiaansen et al., 2005, 2008; Braunstein et al., 2012; Davidson & Indefrey, 2007; Hagoort et al., 2004; Hald et al., 2006; Luo et al., 2010; Penolazzi et al., 2009; Wang et al., 2012; Willems et al., 2008). For instance, semantic violation is closely associated with theta power oscillations. Hagoort, et al. (2004) tested 30 subjects with three versions of sentences such as "the Dutch trains are *yellow/white/sour* and very crowded", which were respectively correct, false (in world knowledge), or semantically violated. The results showed that semantic violation led to an increase of theta power in comparison with correct sentences. In a further study with similar materials, i.e., semantically coherent sentences (e.g., the Dutch trains are YELLOW and blue) or incoherent sentences (e.g., the Dutch trains are SOUR and blue), a theta power increase was observed during 300–800ms after critical word onset at temporal electrodes bilaterally for both sentence conditions, but over midfrontal areas for the semantic violations only (Hald et al., 2006). Davidson and Indefrey (2007) distinguished the relevant frequency oscillation associated with semantic processing and syntactic processing in a test with materials of semantic, phrase structure or number violations and matched controls, and only found semantic violations causing an increase in theta power. Wang et al. (2012) found that only keywords containing semantic violations (e.g., our new green car blocked the narrow *elbow*) caused an increase in the theta (2~5 Hz) band, while keywords with semantic compatibility but low predictability (e.g., our new green car blocked the narrow *entrance*) did not cause this effect.

Unlike the above-stated studies in Dutch, Penolazzi et al. (2009) used Italian sentences which have more flexible word order as stimuli and found no significant

effect of theta band with semantic anomaly. Luo et al. (2010) didn't find the theta band effect with semantic violations in Chinese sentences. Braunstein et al. (2012) asked German-English bilinguals to read three conditions of English (second language) sentences, namely keywords with high predictions, low predictions, or semantic violations, and answer relevant comprehension questions. Time-frequency analysis revealed that both high and low prediction sentences induced higher theta power increases than semantically violated sentences. It has been argued that the language type, L1 or L2, task demand, or the method employed in time-frequency analysis may account for the inconsistent findings of theta power for semantic violation.

Moreover, given that a robust relation was observed between the theta power and working memory (e.g., Bastiaansen, 2002a; Jensen & Tesche, 2002; Tesche & Karhu, 2000; Kahana et al., 1999), or memory encoding/ retrieval (e.g., Bastiaansen et al., 2005; Burgess & Ali, 2002; Fell et al., 2001; Klimesch et al., 2001; Klimesch, 1999), the theta power oscillation corresponding to various linguistic manipulations implies processes at the interface between memory and language in language comprehension, such as retrieval of language-related visual information (e.g., word forms in long-term memory), retrieval of lexical semantic information (e.g., word meaning in long-term memory), integration of lexical meaning into context (e.g., working memory), and etc. These processes in language comprehension were reflected as theta power oscillation in topographical distribution. The theta power oscillation in frontal area may relate to the integration of lexical meaning into context or an expanded explanation of error monitoring. Repeated evidences were from theta oscillation in frontal area. Apart from Hald et al. (2006)'s study which noticed the theta increase in midfrontal areas for the semantic violations, in Maguire et al. (2010), the theta power was found to

increase over right frontal areas for thematic (e.g., leash-dog) versus taxonomic (e.g., horse-dog) relationships, which suggests that thematic relationships, related to contextual relations, engage memory processes in right frontal area. Bastiaansen et al. (2005) observed frontal theta increase of similar magnitude for both correct OC (e.g., nouns, verbs, adjectives) and CC (e.g., articles, prepositions, conjunctions) in a sentence and argued that it reflected error monitoring associated with working memory load in real time processing. Therefore, theta power increase in frontal area may index greater processing efforts, errors, or unexpectations in types of integration, such as lexicon-context, thematic relations, and etc.

The increase in bilateral temporal area may be associated with the lexical-semantic information retrieval, and that in occidental area suggests the visual form retrieval. Bastiaansen et al. (2005) observed a theta power increase over left temporal areas for OC words, but not for CC words. It was argued to reflect the activation of a network involved in retrieving the lexical–semantic properties in temporal area because it is more difficult to retrieve the diversified usages from OC words. And the larger left-occipital theta increase with OC words was argued to reflect the longer and more complex visual forms than CC words. This was further confirmed in Bastiaansen et al. (2008), in which temporal electrodes showed larger theta power increases in processing auditory semantic properties, while occipital area showed larger theta responses with visual semantic properties.

As mentioned above, the direction of the theta oscillation (increase or decrease) associated with semantic violations is not consistent in the results observed in different studies: although a large number of studies have found that semantic violations lead to a theta power increase (Davidson & Indefrey, 2007; Hagoort et al ., 2004; Hald et al., 2006; Wang, et al., 2012), some studies have found the opposite

result, that is, sentences that do not contain semantic violations induce theta power increase (Braunstein et al., 2012; Luo et al., 2010; Penolazzi et al., 2009). Besides, many studies proved that the oscillatory neuronal dynamics in theta band is related to the functional network that serves the role of retrieving visual forms, lexical-semantic properties, and integrating different sources of information in understanding linguistic input. However, the focus of the above-mentioned literature was all about linguistic information processing, emojis fall outside the boundaries of morphology and lexical analysis, and whether the semantic processing of emojis is also related to the theta power oscillation remains unclear.

The current approach will investigate the modulation of oscillatory neuronal activity recorded in the EEG during emoji processing. To be specific, given that the theta power oscillation is closely connected with semantic processing of linguistic information, including visual-form recognition, lexical-semantic retrieval, and lexical-contextual integration/ violation, the present study attempts to explore the magnitude and typographic distribution of theta band oscillation induced by processing congruent/ incongruent emojis in Chinese sentential context, with a contrast of congruent/incongruent words.

Results

Anterior-posterior regions

The main effect for Category was significant, $F(1,21) = 14.596$, $p<0.005$, Partial $\eta^2 = 0.41$, indicating the amplitude of TBA higher for emoji (5.9 μV) than for word stimuli (4.6 μV; Figure 2). This category effect was qualified by an interaction between Category with Congruent, $F(1,21) = 29.88$, $p<0.001$, Partial $\eta^2 = 0.587$, revealing that for congruent condition, the category effect was not significant ($p = 0.615$), while for incongruent condition, emoji elicited higher TBA (6.9 μV) than did

words (4.2 μV; $p < 0.001$) and that incongruent words induced slightly lower TBA than congruent condition (5.0 μV; $p > 0.1$), whereas incongruent emojis induced higher TBA than congruent condition (4.8 μV; $p < 0.001$). In addition, both main effects of Anterior-Posterior distribution [$F(2,42) = 9.16$, $p<0.005$, Partial $\eta^2 = 0.304$] and Laterality [$F(2,42) = 9.75$, $p = 0.001$, Partial $\eta^2 = 0.317$] were significant and particularly, the two-way interaction of Anterior-Posterior distribution by Laterality was also significant, $F(4,84) = 4.77$, $p < 0.02$, Partial $\eta^2 = 0.185$, showing a maximum of 5.6 μV at Cz site. No other effects reached significant level (ps > 0.1).

Temporal regions

Similar to anterior-parietal regions, the amplitude of TBA in temporal regions was also higher for emoji stimuli (6.1 μV) than for word stimuli (4.6 μV; see Figure 2). The statistical significance of this pattern was determined by a main effect for Category [$F(1,21)=24.06$, $p<0.001$, Partial $\eta^2 = 0.534$]. Although the main effect of Congruent did not reach significant level ($F < 1$), the two-way interaction of Category * Congruent was significant, $F(1,21)=26.01$, $p<0.001$, Partial $\eta^2 = 0.553$. Further analysis for this interaction showed that for congruent condition, the category effect was not significant ($F < 1$), while for incongruent condition, emoji elicited higher TAB (6.9 μV) than did words (4.0 μV; $p < 0.001$) and that incongruent words induced lower TBA than congruent condition (5.3 μV; $p < 0.05$), whereas incongruent emojis induced higher TBA than congruent condition (5.2 μV; $p < 0.001$). No other effects reached significant level (ps > 0.1).

Insert Figure 2-3 about here.

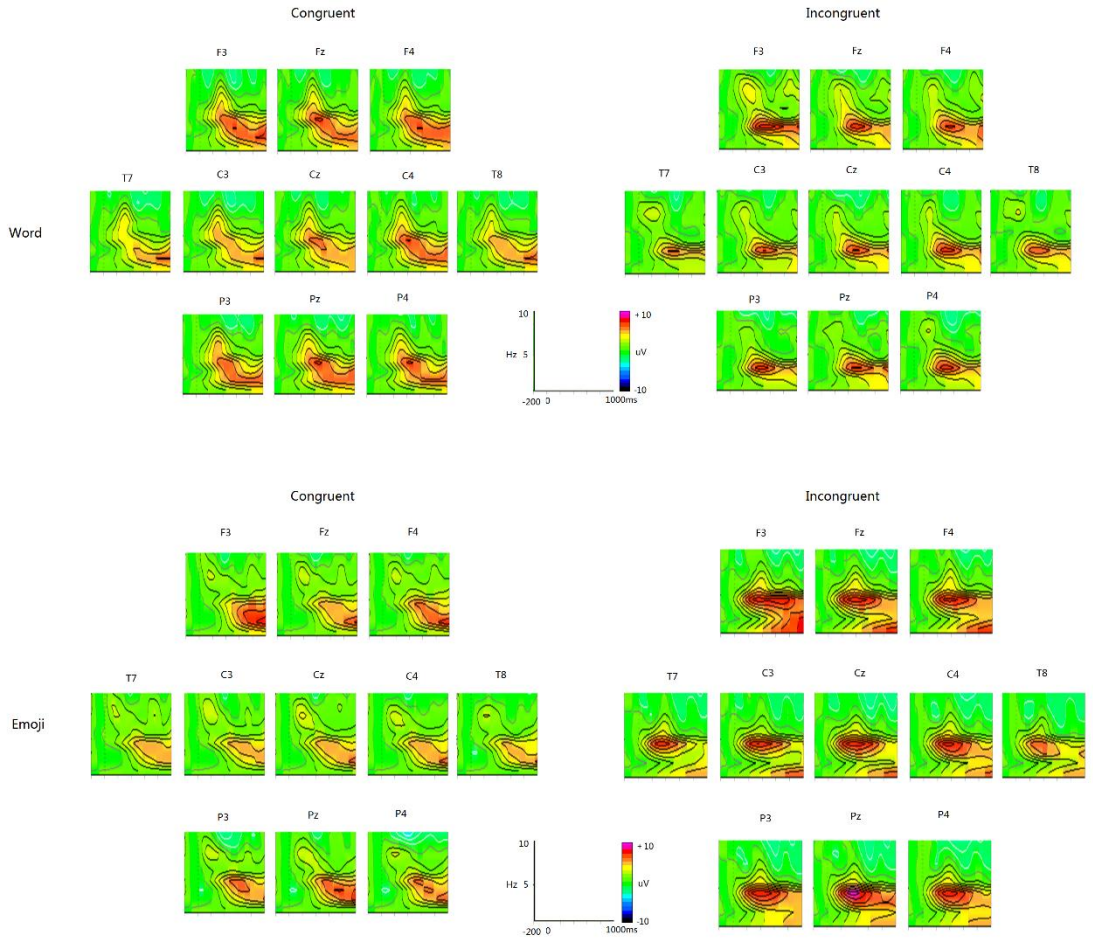


Figure 2. TBAs for word and emoji conditions, respectively.

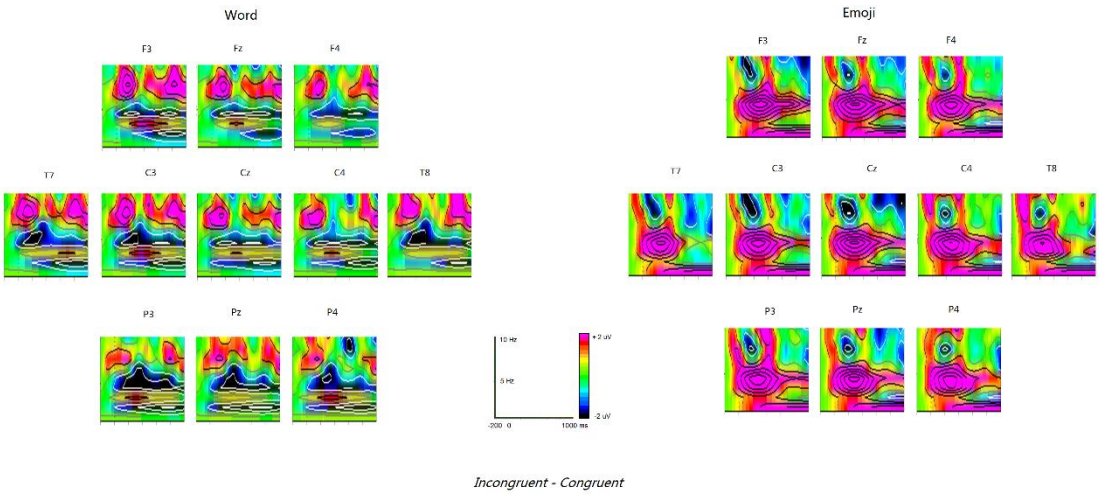


Figure 3. The differences of TBAs between incongruent and congruent conditions for word and emoji conditions, respectively.

Discussion

The present study investigated the semantic processing of emojis via the technique of wavelet-based time-frequency analysis. The last segment of experimental sentences was designed as either words or emojis functioning as adjectives for the expression of comments consistent or inconsistent with the context. The aim was to characterize the nature, i.e., magnitude and scalp topography of EEG power changes that were expected to occur as a result of semantic violation of emojis. We zoom in on the theta band brain dynamics (4-7Hz).

The TF analysis revealed that semantic violations with emojis led to a conspicuous theta power increase while incongruent words induced slightly lower TBA than congruent conditions. From the perspective of topological distribution, the largest magnitude of theta power increase with incongruent emojis occurred in the mid-central area and incongruent words made no significant difference with congruent conditions in anterior-posterior regions. In temporal regions, TBA with emojis is also significantly higher than that of words. It suggests that the neural activities of semantic processing for emojis and words differ not only in theta power oscillation patterns but also in the neuronal network related to certain processes in comprehension.

First, it displayed that the semantic processing of emojis is related to the theta band frequency, and that the semantic violation of emojis is reflected as the theta power increase. Previous research has found that the theta band is associated with improved cognitive processing of linguistic information, sustained attention, increased mental effort or task difficulty, extensive use of memory mechanisms (e.g., Bastiaansen et al., 2005; Davidson & Indefrey, 2007; Golumbic et al., 2009; Hagoort

et al., 2004; Hald et al., 2006; Luo et al., 2010). The current results prove that the cognitive processing of paralanguage information, which falls out of the category of phonetical, morphological, and lexical analysis is also associated with the theta power oscillation, which suggests the general activation of neuronal assemblies, representing meaningful concepts.

In contrast, the slight decrease of TBA with incongruent words shows inconsistent results with some prior research on semantic violations (Davidson & Indefrey, 2007; Hagoort et al., 2004; Hald et al., 2006; Wang, et al., 2012), but is similar to Braunstein et al. (2012), Luo et al. (2010), and Penolazzi et al. (2009)'s findings. It is possibly because of the language structure, and the way to show semantic violation, which makes the less sensitivity of theta oscillation in processing Chinese incongruent words. Studies which observed the theta band effect was mainly carried out in Dutch, while Chinese has more flexible language structure, more diversified way of interpretations and different writing system with Dutch. In Luo et al. (2010) where Chinese sentences were presented, no theta band effect was observed either. An alternative explanation is about the positions of target words, or the way to form a semantic violation. In comparison with Hald et al. (2006) and the forth studies, where the semantic violation is an unexpected adjective (e.g., sour) to the noun (e.g., train), that in the present study was presented as thematical incongruency (e.g., unhappy) to the context (e.g., I successfully passed the exam). However, the emoji seems not to be affected by these factors, instead, the theta power increase shows a high magnitude.

Furthermore, since changes of induced EEG activity can be employed to investigate interactions between neuronal webs underlying linguistic processing, induced oscillatory activity provides a valuable way to explore phenomena involved

in functional networks formation, activation, and uncoupling. The wide topographic distribution of the theta power changes with emojis, hints at the existence of multiple neural generators that may differ in terms of their functional relevance for word and emoji processing.

One notable aspect of the topographical distribution is that like prior findings of theta power increase in frontal area with improved cognitive processing (e.g., Bastiaansen et al., 2005; Hald et al., 2006; Maguire et al., 2010; Summerfield & Mangels, 2005), both word and emoji processing led to an increase. And we found a conspicuous theta power increase in these areas with semantically incongruent emojis. The degree of theta power increase shows a gradual decline from the fronto-central midline to the peripheral frontal area. It has been stated that the theta power increase in frontal area implies greater processing efforts, errors, or unexpectations in types of integration, such as lexicon-context, thematic relations, word length-context and etc (e.g., Bastiaansen et al., 2005; Luo et al., 2010; Maguire et al., 2010). Combining these findings with our emoji-related frontal theta effects, we argue that the current finding with emojis suggests a higher processing difficulty in integrating mismatched emojis into sentential contexts, while mismatched words did not cause a significant higher processing difficulty. Our explanation is that in comparison with words, the integration of mismatched emojis involves larger unexpectations and their mismatched meanings are even harder to be integrated into the context. And this led to a larger working memory load in error monitoring which elicited a dramatic and prolonged increase with the theta frequency largely spread in frontal area.

In occipital area, emojis also produced a relatively strong increase of theta power in comparison with words. Bastiaansen (2005) found that the theta power in left occipital lobe is significantly stronger for processing open-class vocabulary than

closed-class vocabulary. It was explained as that the left occipital area may be related to the visual form processing, because open-class vocabulary is longer and more complex. This was further confirmed in Bastiaansen et al. (2008), in which occipital area showed larger theta responses with visual semantic properties. In terms of forms, emoji does not have the normal morphology of linguistic information, but pictographic and ideographic. We hypothesize that the theta power increase with emoji processing in occipital area reflects the difficulty and complexity in emoji visual-form retrieval.

In addition, we also observed an obvious theta power increase in bilateral temporal lobe with incongruent emojis. It has been reported that theta power increase in the temporal lobe reflects lexical retrieval, associated with long-term memory (e.g., Bastiaansen, 2005; Klimesch, 1999). Emojis fall outside the category of lexical analysis, but they have intrinsic meanings. In a survey of 70,000 emoji-containing tweets in 13 languages, Novak et al. (2015) found that emojis provide a wide array of semantic nuances to written texts. In another word, emojis have pre-constructed concepts that need to be retrieved in semantic processing. From the increase of theta power, we hypothesize that the concept retrieval of emojis is relatively difficult because an emoji has diversified interpretations, corresponding to more than one lexical meaning. For example, a smiling emoji may refer to the verb “smile”, the adjective “happy”, the noun “smile” and etc. So, it might be more difficult to retrieve the lexical meaning of an emoji, and that has been reflected on the intensive increase of theta power on both sides of the temporal lobe.

These empirical results suggest that the semantic processing of emojis may involve several processes including the recognition of forms, retrieval of pre-constructed concepts, and integration of emoji meaning into contexts. More

specifically, the emoji recognition and concept retrieval related to long-term memory are reflected as theta power increase in the occipital and bilateral temporal lobe. The integration of emojis to context requires high working memory, shown as the theta power increase in the frontal lobe. And these processes in emoji processing require more cognitive efforts in comparison with the language semantic processing. Therefore, contrary to the theoretical idea that emoji processing may not need to retrieve or select lexical information and is easier (Danesi, 2017), we tentatively hypothesize that its processes are not fewer but may be more complex and difficult in comparison with language processing.

To sum up, this is the first time-frequency analysis on emoji semantic processing, and theta band oscillations were found to differ from that in word processing in sentential context. This study provides new insights into the nature of emoji semantic processing, including the magnitude and scalp topography which shows a neuronal network with different functional roles. It also contributes to the knowledge of EEG oscillation by expanding the focus to paralanguage semantic processing and providing further evidence on the functional role of theta power. In general, this study shed lights on the neural basis of paralanguage processing.

In sum, the present study explored the neurocognitive basis of emoji semantic processing via EEG experiments. Time-frequency analysis showed that incongruent emojis led to a higher theta power increase than congruent conditions. Furthermore, the theta power increase was observed at midfrontal, occipital and bilateral temporal electrodes with emojis. These results may suggest the cognitive processes of form recognition, concept retrieval, and meaning integration in emoji semantic processing and the higher requirement of cognitive efforts involved in these processes. Further study with other electrophysiological evidences will lead to a more precise

understanding of emoji processing.

Method

All methods were carried out in accordance with relevant guidelines and regulations. All experimental protocols were approved by the Academic Ethics Committee of China University of Petroleum (Beijing).

Participants

Twenty-two participants (12 females; average 22.5 years old) from China University of Petroleum (Beijing) participated in the experiment. All participants were right-handed, with normal or corrected vision, and no neurological or psychiatric disorders was reported. At the request of the Academic Ethics Committee of China University of Petroleum (Beijing), they signed an informed consent to participate in this study.

Stimuli and procedure

Four emojis with high token frequency were extracted from Chinese social media platform WeChat App. Familiarity to the selected emojis and degree of acceptance to their verbal interpretations were carefully controlled. We designed 60 contexts for the four target emojis and their verbal counterparts which were two-character Chinese adjectives (see Table 1). Each sentence was divided into 8 parts with the last part as the target segment. In the incongruency condition, with contextual sentences unchanged, emojis and their verbal counterparts were replaced with expressions with opposite meanings. Examples of these conditions are as follows:

The congruent emoji condition:

期末/考试/顺利/通过了，我/感到/非常/😊

Final/exam/successfully/passed, I/felt/very/😊

I successfully passed the final exam, and I felt very 😊

The congruent verbal condition:

期末/考试/顺利/通过了，我/感到/非常/开心。

Final/exam/successfully/passed, I/felt/very/happy.

I successfully passed the final exam, and I felt very happy.

The incongruent emoji condition:

期末/考试/顺利/通过了，我/感到/非常/😕

Final/exam/successfully/passed, I/felt/very/😕

I successfully passed the final exam, and I felt very 😕

The incongruent verbal condition:

期末/考试/顺利/通过了，我/感到/非常/伤心。

Final/exam/successfully/passed, I/felt/very/sad.

I successfully passed the final exam, and I felt very sad.

In the experiment, participants were asked to read the sentences on the screen. Each trial was displayed segment by segment in the center of the monitor. For the first 7 parts each lasts for 800 milliseconds, and the 8th segment displaying the target emoji / word lasts for 1000 milliseconds. The interval between the two trials was 1500 milliseconds, and a total of 240 trials were randomized under these four conditions.

EEG recording

Electroencephalogram (EEG) signals were continuously recorded by the NeuroLab digital amplifier system, with NeuCap of Ag /AgCl electrodes at 64 sites according to the expanded international 10-20 system (Yiran Sunny Technology Co. Ltd, Beijing, China, http:// www. neurolab.com.cn). The reference electrode was placed on the tip of nose. It was converted into bilateral mastoids for reference in data analysis. To record vertical and horizontal electrooculogram (EOG) signals, two electrodes were placed above and below the right eye respectively, and two electrodes

at the left and right outer canthi. The impedance of the electrodes was kept below 5kΩ. EEG and EOG signals were amplified with a band pass of 0.1–100 Hz at a sampling rate of 1000 Hz.

Data analysis

Data were analyzed using WinEEG software (www.mitsar-eeg.com) as well as house-made Matlab routines. Raw EEG data was 1.0 Hz high-pass filtered (24 dB). Eye movements were corrected using an ICA procedure (WinEEG software; www.mitsar-eeg.com). Remaining artifacts exceeding ±100μV in amplitude or containing a change of over 100μV within a period of 50 ms were rejected. The EEG was then segmented into epochs ranging from 300 ms before to 1000 ms after stimulus onset for all conditions (targets were excluded from the analysis).

Theta-band amplitudes (TBA) were calculated by applying a wavelet analysis to individual trials and averaging the time frequency plots (WinEEG software; www.mitsar-eeg.com). This procedure was applied to frequencies ranging from 4Hz to 7Hz in steps of 0.5Hz (theta band) and the amplitudes were extracted and baseline-corrected yielding time-frequency plots.

The scalp distribution of this TBA was widely spread, therefore, our main analysis compared the mean TBA in left, midline and right clusters of electrodes at anterior, center and posterior regions as well as bio-temporal regions (see Figure 1). We calculated the mean TBA during an epoch between 250-500 ms post stimulus onset and the measurements were subjected to ANOVAs with repeated measures in order to determine statistical reliability. For the anterior-posterior regions, the factors were stimulus Category (word, emoji), Congruent (congruent, incongruent), Anterior-Posterior distribution (anterior, center, posterior), and Laterality (left, medial, right). For the temporal regions, the factors were stimulus Category (word, emoji),

Congruent (congruent, incongruent), and Laterality (left and right). In all the analyses, degrees of freedom and MSEs were corrected for non-sphericity using the Greenhouse-Geisser correction (for simplicity, the uncorrected degrees of freedom are presented).

Insert Table 1 and Figure 1 about here.

Table 1 Target emojis and their verbal counterparts in matched and unmatched conditions

Congruent condition		Incongruent condition	
Emoji	verbal counterpart	emoji	verbal counterpart
😊	happy (开心)	😕	sad (伤心)
😕	sad (伤心)	😊	happy (开心)
😡	angry (生气)	😄	glad (高兴)
👍	good (很棒)	👎	bad (很差)

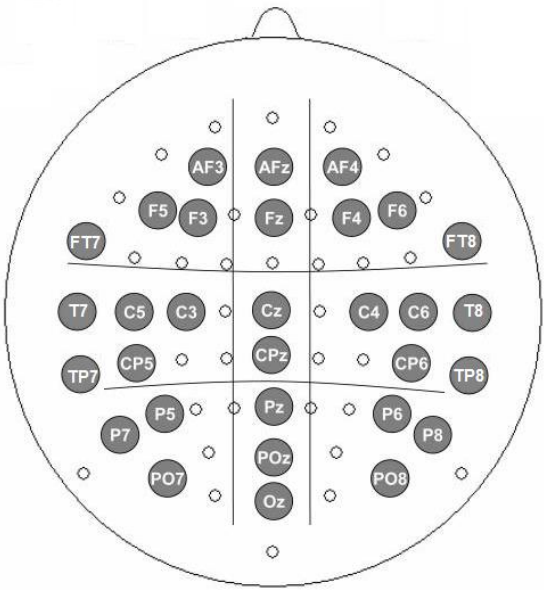


Figure 1. Electrode montages for the different scalp distribution of TBA computation.

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Author Contributions

Tang M. and Chen B. finished data collection and the draft. Zhao X. and Zhao L. finished the design and revised the manuscript.

Competing of Interests Statement

The authors have no competing interests as defined by Nature Research, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

Figure legends

Figure 1. Electrode montages for the different scalp distribution of TBA computation.

Figure 2. TBAs for word and emoji conditions, respectively.

Figure 3. The differences of TBAs between incongruent and congruent conditions for word and emoji conditions, respectively.

Table 1

Target emojis and their verbal counterparts in matched and unmatched conditions

Congruent condition		Incongruent condition	
Emoji	verbal counterpart	emoji	verbal counterpart
😊	happy (开心)	😕	sad (伤心)
😕	sad (伤心)	😊	happy (开心)
😡	angry (生气)	😄	glad (高兴)
👍🏽	good (很棒)	👎🏽	bad (很差)

Figures

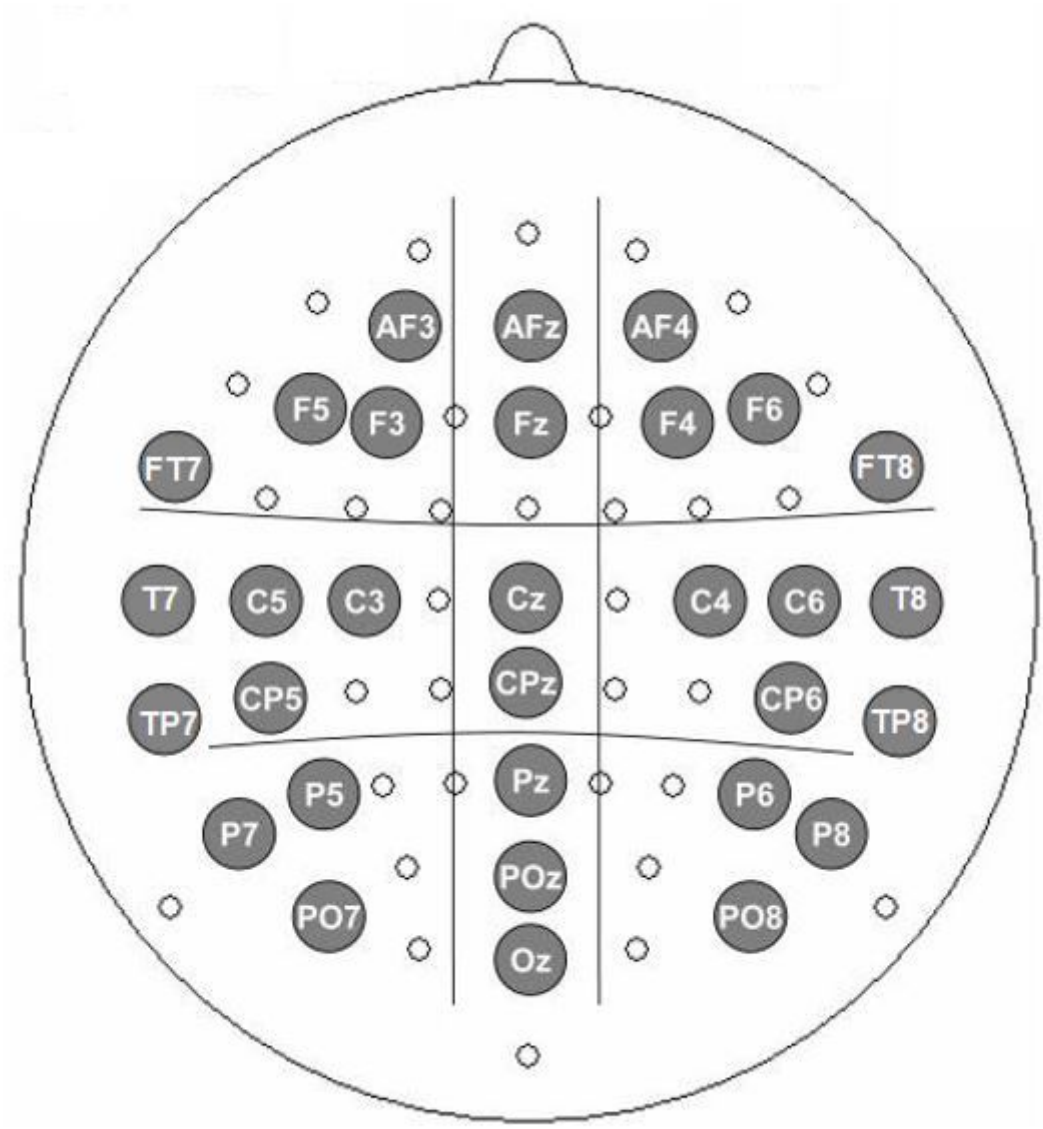


Figure 1

Electrode montages for the different scalp distribution of TBA computation.

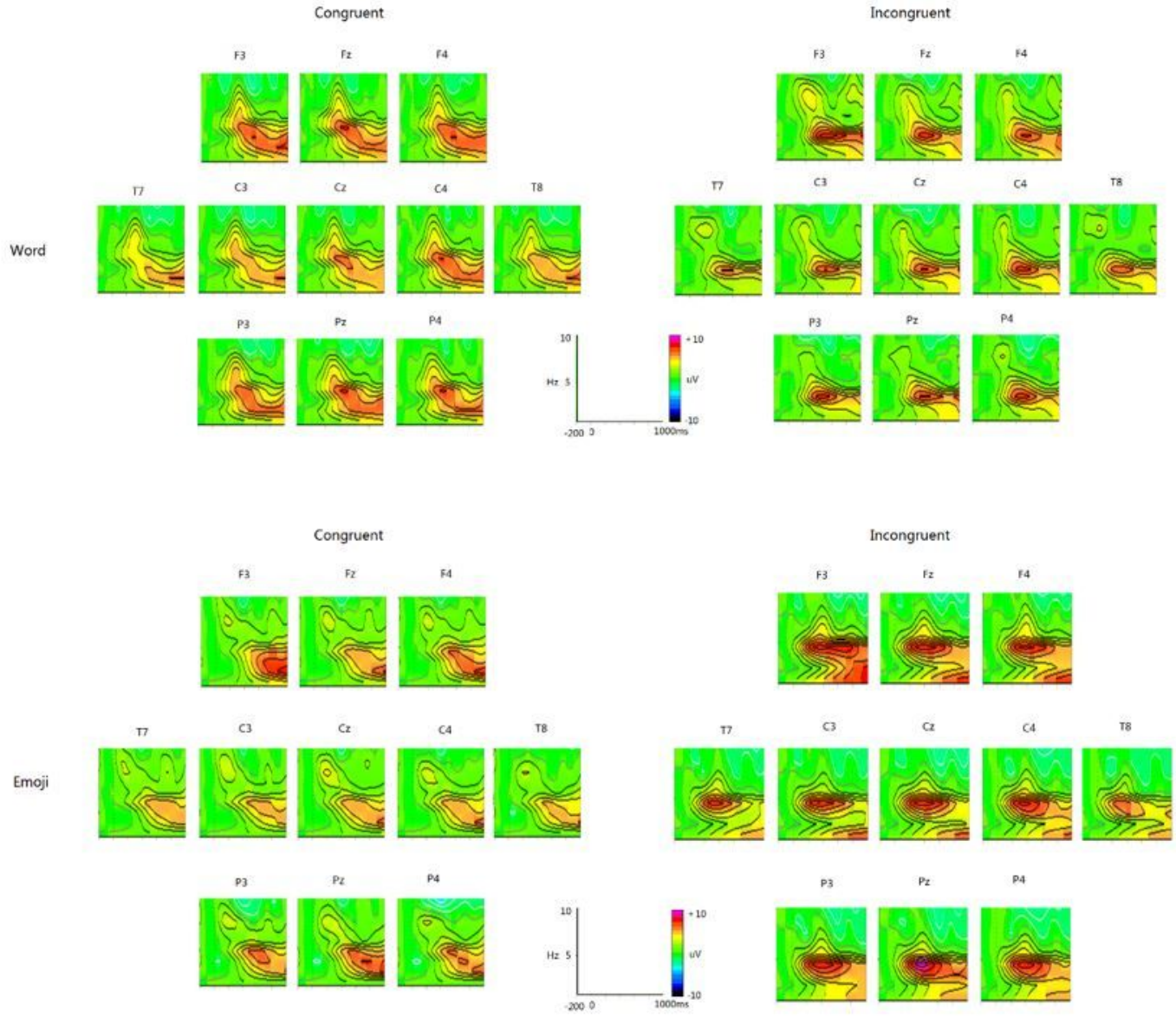


Figure 2

TBAs for word and emoji conditions, respectively.

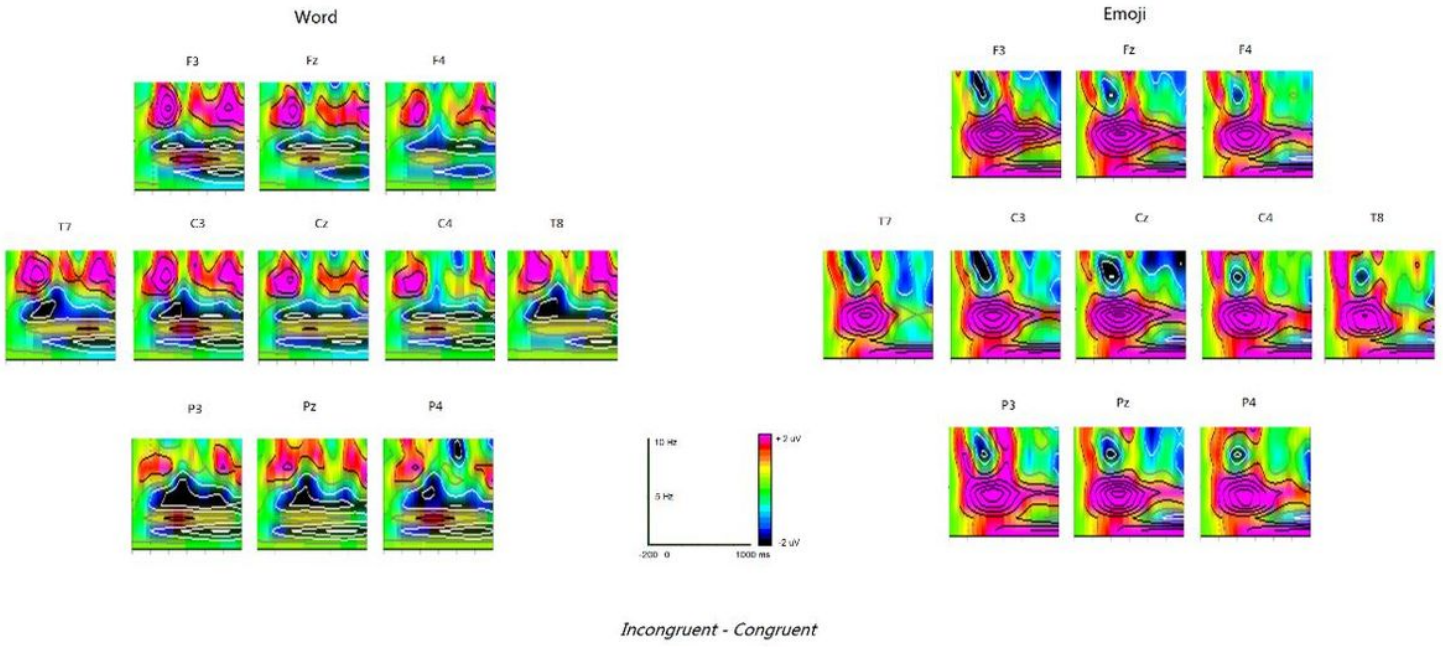


Figure 3

The differences of TBAs between incongruent and congruent conditions for word and emoji conditions, respectively.