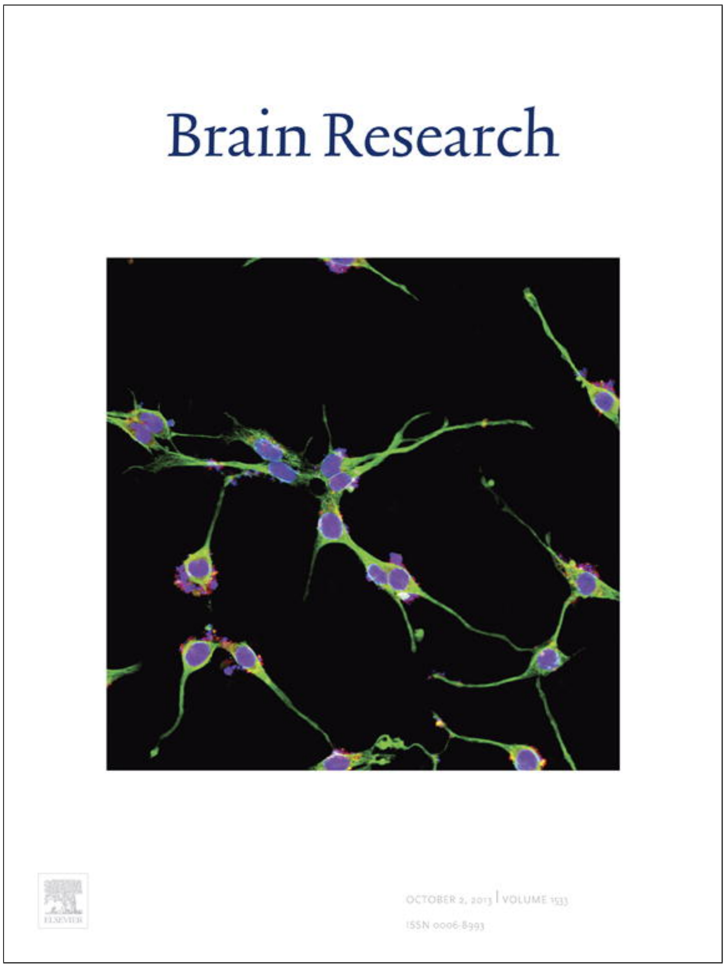

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Research Report

Positive words or negative words: Whose valence strength are we more sensitive to?

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ABSTRACT

The present study investigates the human brains′ sensitivity to the valence strength of emotionally positive and negative chinese words. Event-Related Potentials were recorded, in two different experimental sessions, for Highly Positive (HP), Mildly Positive (MP) and neutral (NP) words and for Highly Negative (HN), Mildly Negative (MN) and neutral (NN) words, while subjects were required to count the number of words, irrespective of word meanings. The results showed a significant emotion effect in brain potentials for both HP and MP words, and the emotion effect occurred faster for HP words than MP words: HP words elicited more negative deflections than NP words in N2 (250–350 ms) and P3 (350–500 ms) amplitudes, while MP words elicited a significant emotion effect in P3, but not in N2, amplitudes. By contrast, HN words elicited larger amplitudes than NN words in N2 but not in P3 amplitudes, whereas MN words produced no significant emotion effect across N2 and P3 components. Moreover, the size of emotion-neutral differences in P3 amplitudes was significantly larger for MP compared to MN words. Thus, the human brain is reactive to both highly and mildly positive words, and this reactivity increased with the positive valence strength of the words. Conversely, the brain is less reactive to the valence of negative relative to positive words. These results suggest that human brains are equipped with increased sensitivity to the valence strength of positive compared to negative words, a type of emotional stimuli that are well known for reduced arousal.

1. Introduction

It has been established that emotional reactivity is a reflection of motivational activation (Cacioppo and Berntson, 1994; Lang and Bradley, 2010). Accordingly, pleasant and unpleasant emotions reflect the activation of approach and defensive motivations, respectively, as indicated by the bipolar structure theory of emotion(Ito and Cacioppo, 2005; Cacioppo and

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Berntson, 1994; Cacioppo and Gardner, 1999). According to this theory, the increased stimulus arousal is associated with a more intense responding in defensive compared to appetitive motivational systems, as it is evolutionarily important to avoid a threatening event faster than to approach a rewarding target (Cacioppo and Gardner, 1999; Peeters and Czapinski, 1990; Taylor, 1991). Consequently, elevated stimulus arousal is linked with a prioritized processing of unpleasant over pleasant stimuli throughout the information processing stream, which was termed by prior studies as emotional negativity bias (Hansen and Hansen, 1988; Carreti’e et al., 2001; Huang and Luo, 2006). In contrast, the bipolar structure theory of emotion predicts that the approach motivational system responds more strongly than the withdrawal motivational system, when emotional stimuli have low arousal inputs (Cacioppo and Berntson, 1994; Cacioppo and Gardner, 1999). This leads to an emotional positivity bias that is embodied by the enhanced processing of pleasant over unpleasant stimuli in many previous studies (Ito and Cacioppo, 2005; Kanske and Kotz, 2007; Herbert et al., 2006; Scott et al., 2009; Bayer et al., 2012; Hinojosa et al., 2010; Palazova et al., 2011).

Many studies that investigated emotion and valence effects in brain potentials used emotionally evocative pictures as stimulus materials (Schupp et al., 2000; Carretié et al., 2001, 2004; Huang and Luo, 2006), which were verified as stimuli of elevated arousal (Delplanque et al., 2005; Schupp et al., 2000). Consequently, the studies using emotionally arousing pictures consistently reported a negativity bias that unpleasant events were preferentially processed relative to neutral and positive events from attentional, cognitive to response readiness stages (Delplanque et al., 2004; Delplanque et al., 2005; Huang and Luo, 2006). Consistent with the evidences of negativity bias, a number of recent studies observed an emotional valence intensity effect during processing of unpleasant pictures or negative facial expressions. The valence intensity effect showed that the human brain is sensitive to valence strength differences in unpleasant stimuli, such that the brain is not only emotionally reactive to both highly and mildly aversive stimuli, but the brain is also more responsive to aversive stimuli of greater valence strength (Yuan et al., 2007; Leppänen et al., 2007; Sprengelmeyer and Jentzsch, 2006; Meng et al., 2009). In contrast, this sensitivity was absent in response to pleasant stimuli (Yuan et al., 2007; Leppänen et al., 2007). Specifically, using emotional pictures whose arousal was controlled across different valence intensity conditions, previous studies in our lab showed that highly negative pictures elicited more negative ERP deflections across frontal P2, centrofrontal N2 and parietal P3 and slow negative components in comparison with mildly negative pictures during distracting tasks (Yuan et al., 2007; Meng et al., 2009). The similar ERP effects were also observed for emotional facial expressions during implicit (e.g. gender discrimination task, Sprengelmeyer and Jentzsch, 2006) and explicit (e.g. affective assessment, Leppänen et al., 2007) emotional tasks.

On the other hand, emotional words are consistently accepted as materials of low arousal (Ito and Cacioppo, 2005; Liu et al., 2009, Carretié et al., 2008; Hinojosa et al., 2009). Many studies showed that verbal materials were lower in emotion arousal than facial expressions and emotionally evocative scenes (Carretié et al., 2008;Keil et al., 2006; Kissler et al., 2006; Mogg and Bradley, 1998). Some studies suggested that the actual arousal levels of emotional words were lower than those of pictures even though they received comparable arousal ratings, probably because words were less colorful and vivid in depicting the act of emotional events (Liu et al., 2009; Herbert et al. 2006). As a result of reduced arousal, word materials were indicated less capable of disrupting cognitive performance than pictures, especially in the case of unpleasant stimulation (Liu et al., 2009; Carretié et al., 2008). Consequently, when low-arousal materials such as emotional words were used, it was reported that the human brain is more responsive to pleasant than to unpleasant stimulation (Kanske and Kotz; 2007; Herbert et al. 2006), regardless of task demand (Bayer et al., 2012). This effect was not only evidenced by shorter reaction times and less error commission for positive versus negative words in lexical decision tasks (Schacht, and Sommer, 2009a; Hinojosa et al., 2010), but was also evident in the amplitudes of posterior P100 (Scott et al., 2009; Bayer et al., 2012), Central-frontal P2 (Liu et al., 2009; Kanske and Kotz, 2007); Early Posterior Negativity (EPN; Hinojosa et al., 2010; Palazova et al., 2011); and Late Positive Component (LPC; i.e., parietal P3) when ERP measures were used (Herbert et al., 2006; Bayer et al., 2012).

Specifically, using lexical decision and word reading tasks, Bayer et al. (2012) observed larger early posterior components for positive versus negative German words in the 100–130 and the 190–260 ms intervals. The same authors also observed a trend of larger LPC amplitudes for positive versus negative words (Bayer et al., 2012). This was consistent with the study by Herbert et al. (2006), which demonstrated sustained attention devotion for pleasant words (reflected by enhanced LPC amplitudes for positive vs. negative words), though pleasant and unpleasant words used in this study were equated in arousal (Herbert et al., 2006). These processing biases for positive compared to negative words existed reliably, unaffected by the arousal ratings of the words (Bayer et al., 2012). In addition, Kanske and Kotz (2007) observed larger P2 amplitudes for positive German words in comparison with negative words during a visual hemifield lexical decision task. This processing bias for positive words was later replicated and extended by Liu et al. (2009) who used emotional Chinese words as materials. Using a task that required subjects to evaluate the emotionality of the words preceded by emotion-congruent pictures, Liu et al. (2009) observed that positive Chinese words elicited more pronounced P200, P300 and late positive waves compared to negative Chinese words. Furthermore, the EPN, an occipital-temporal component functionally similar to centrofrontal N2 that reflects attention involvement during perceptual processing (Schacht and Sommer, 2009a), was found to be more pronounced for positive compared to negative words, and the robustness of this effect was unaffected by word class (both nouns and adjectives) and language (both German and Spanish; Hinojosa et al., 2010; Palazova et al., 2011). Therefore, instead of observing a negativity bias, previous studies consistently observed a positivity bias when emotional words were used as stimuli. That is, the human brain is more responsive to pleasant compared to unpleasant words.

In life settings, the pleasant and unpleasant emotions people experience often vary in valence strengths. This is clearly manifested by distinct impacts of mildly and highly unpleasant pictures on the stream of cognitive task processing in prior studies (Yuan et al., 2011a; Yuan et al., 2012b). Though previous studies consistently reported that human brains were sensitive to valence strength differences in unpleasant stimuli instead of pleasant stimuli, this effect was most likely a result of negative bias when high arousal pictorial stimuli were used (Sprengelmeyer and Jentzsch, 2006; Leppänen et al., 2007; Yuan et al., 2007; Meng et al., 2009). However, when low-arousal emotional words are used as stimulus materials, the human brain may not keep elevated sensitivity to the valence strength of unpleasant stimuli. Instead, as predicted by positivity bias (Ito and Cacioppo, 2005), the brain may be more sensitive to the valence strength of pleasant words in comparison with unpleasant words. If mildly emotional words are used, it is likely that people may be more emotionally responsive to mildly pleasant compared to unpleasant words.

Therefore, the present study investigated the human brain's sensitivity to the valence strength of pleasant and unpleasant words. As emotion occurs unpredictably and is usually triggered by accidental stimuli in life settings (Delplanque et al., 2005; Yuan et al., 2007), an experimental design that does not require subjects to evaluate emotion overtly may allow emotional responses in the laboratory setting to more closely resemble nature. Based on this consideration, the present study used a word counting task that required subjects to count the number of words in a screen by pressing different keys, irrespective of the emotional meanings of the words (Whalen et al., 1998). Another consideration for this design was to mask the true purpose of the experiment, consequently to avoid the potential "relevance-for-task" effect that was considered to obscure emotion-related ERPs in affective assessment tasks (Carretié et al., 1996). We used ERP technique for this study, as ERP measures are helpful for unraveling the spatiotemporal features of these different sensitivities. In particular, this technique is desirable in unraveling how different processing stages, indicated by different ERP components, embody the brain's sensitivity to the valence strength of positive and negative words. In order to attribute ERP differences specifically to the effects of valence strength and valence polarity of the words, we matched perceptual features, such as the number of strokes of words, across different valence conditions in this study.

Moreover, according to Lang's theory of emotional dimensions, the affective significance of a stimulus is organized along the two primary dimensions: hedonic valence (i.e. pleasant-approach motivation or unpleasant-defensive motivation, ranging from unpleasant to pleasant) and arousal (i.e. degree of motivational activation, ranging from calm to excited; Lang et al., 1997; Lang and Bradley, 2010). Therefore, valence and arousal are the two primary dimensions that should be considered in emotional studies (Lang et al., 1997; Lang and Bradley, 2010), and that emotion studies which address valence effect on ERPs need to control for arousal influences across conditions (Carretié et al., 1997; Corson and Verrier, 2007; Delplanque et al., 2004; Delplanque et al., 2005; Rozenkrants and Polich, 2008; Yuan et al., 2007). Thus, the present study controlled the arousal levels across different valence polarity and valence strength conditions.

Furthermore, in order to investigate the brain sensitivity to the valence strength of pleasant and unpleasant words, we designed two experimental sessions: one manipulated the valence strength of pleasant words while the other manipulated that of unpleasant words. Another purpose of designing two experimental sessions instead of mingling positive and negative words together, is to avoid potential influences between different emotion categories, such as the influence of preceding positive words on the subsequent processing of negative words or vice versa. As a result of controlling perceptual attributes, we hypothesized that the effect of valence strength (highly, mildly, neutral) and its interaction with valence polarity (pleasant/unpleasant) might not happen in occipital N1 and fronto-central P2, because these components usually peaked before 200 ms post stimulus and were considered to reflect sensory-perceptual encoding (Mangun, 1995; Mitsudo et al., 2011; Thorpe et al., 1996). Instead, we predict that these effects may be observed at more endogenous components, like attention alerting-related N2 (frontal-central distributions; Carretié et al., 2004; Yuan et al., 2007; Olofsson et al., 2008) and cognitive processing-related P3 (parietally peaking, Ito et al., 1998; Delplanque et al., 2005). Specifically, because previous studies associated low stimulus arousal with a positivity bias (Cacioppo and Gardner, 1999) and emotional words are low in arousal (Kissler et al., 2006; Hinojosa et al., 2009), we predict that the biased processing of positive over negative words may be observed at both high and mild valence strength levels. Particularly, previous studies verified that mildly emotional stimulus, which displays reduced biological significance (Yuan et al., 2007), is a sensitive index for detecting emotional sensitivity differences (Li et al., 2008; Yuan et al., 2012a). Thus, we predict that the N2 or P3 component would show a robust positivity bias effect for mildly positive compared to mildly negative words. That is, the human brains might be significantly more reactive to mildly positive compared to mildly negative stimuli at N2 or P3 component. Lastly, given the fact that low stimulus arousal is linked with a positivity bias that favors the processing of positive valences (Herbert et al. 2006; Kanske and Kotz; 2007; Bayer et al., 2012), it is likely to observe that the brain exhibits a prioritized processing of highly over mildly pleasant words in the endogenous N2 and P3 components.

2. Results

2.1. Behavioral performance

False responses were rare, as all the subjects achieved more than 96% accuracy rate for each condition during both experiments. Mean Reaction Times (RTs) were 555±55 ms (M±SD) for the HP, 558±53 ms for the MP, and 559±49 ms for Neutral words in the Positive experiment; while the Mean RTs were 554±60 ms for the HN, 555±57 ms for the MN, and 555±63 ms for the neutral words in the Negative experiment. A repeated measures ANOVA with Valence polarity (2 levels: positive vs. negative) and Valence strength (3 levels: highly, mildly and neutral) as repeated factors showed neither significant main effects of Valence polarity ($F(1, 15)=0.15$, ns) and Valence strength ($F(2, 30) = 0.89$; ns), nor a significant valence polarity by Valence strength ($F(2, 30) = 0.17$; ns) interaction. Thus, behavioral responses were not significantly influenced by the emotionality of words.

2.2. ERP analysis

2.2.1. Preliminary analysis

Before including all the three numbers of words into ERP averaging, we conducted a preliminary data analysis by averaging ERPs for each of the six conditions for one-word, two-word and three-word stimuli respectively. The preliminary analysis was conducted on P2, N2 and P3 amplitudes, with word number (3 levels: one, two and three), valence polarity (2 levels: positive, negative) and valence intensity (3 levels: highly, mildly and neutral) as factors, after collapsing across the factor of electrode sites. The results revealed that the number of words did not interact with valence polarity ($F(2,30)_{maximal} = 1.45$; $p_s > 0.25$), valence intensity ($F(4,60)_{maximal} = 0.53$; $p_s > 0.60$); and did not interact with the interaction term of valence polarity and valence intensity at these components ($F(4,60)_{maximal} = 0.87$; $p_s > 0.45$). Thus, there was no significant influence of word number on the effects of valence polarity, valence intensity or the valence polarity and intensity interaction in P2, N2 and P3 components. Consequently, we included all the numbers of words into ERP averaging and the subsequent data analyses.

2.2.2. Occipital N1 (130–190 ms)

The analysis of N1 amplitudes showed no significant main effects of Electrode sites ($F(2, 30) = 0.13$, ns), Valence polarity ($F(1, 15) = 0.33$, ns) and Valence strength ($F(2, 26) = 1.03$,ns). Also, the factor of electrode sites did not interact with that of valence polarity ($F(2, 30) = 0.14$, ns) or valence strength ($F(4, 60) = 0.96$, ns). Additionally, the Valence strength and Valence polarity interaction ($F(2, 30) = 1.47$,ns), and the Valence strength, Polarity and Electrode sites interaction ($F(4, 60) = 0.05$, ns) were both non-significant. Similarly, the analysis of N1 latencies did not yield significant main or interaction effects.

2.2.3. P200 (160–220 ms)

The analysis of P2 amplitudes showed no other significant main or interaction effects, except for a significant laterality and valence polarity interaction ($F(2, 30) = 8.46$, $p < 0.01$; $\eta^2 = 0.36$). The positive experimental session was associated

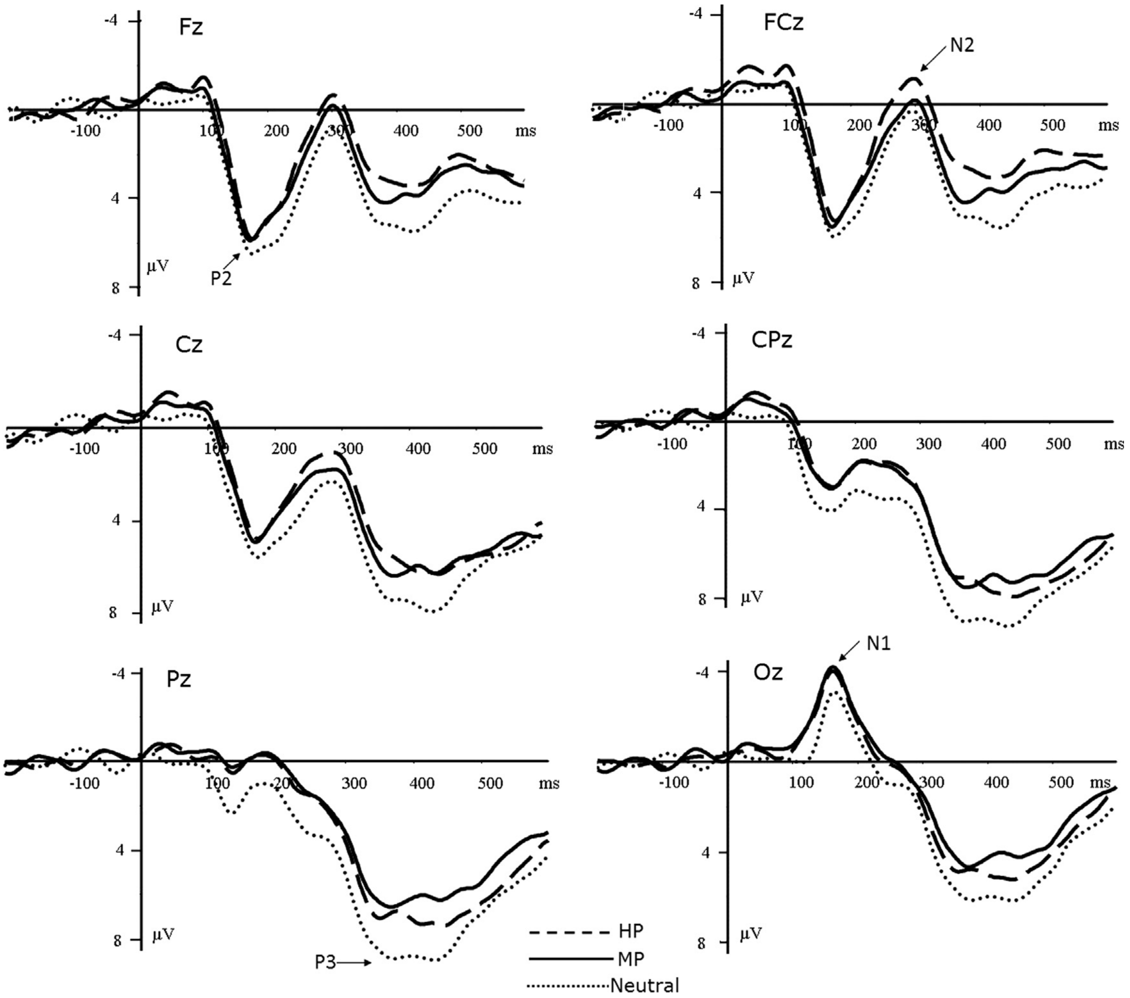

Fig. 1 – Averaged ERPs elicited by HP (dashed lines), MP (solid lines) and Neutral (dotted lines) in the Positive Experiment.

with larger amplitudes than the negative session in the right (6.99 vs.1.76 μV; $F(1,31)=6.86$, $p<0.05$, $\eta^2=0.31$) but not in the midline (5.89 vs. 6.02 μV; $F(1,31)=0.02$, ns) and left (5.62 vs. 4.87 μV; $F(1,31)=0.70$, ns) scalp regions. The analysis of P2 latencies showed no significant main or interaction effects. These results were not altered when the non-obvious parietal P2 was included in the ANOVA (see Supplementary material 1).

2.2.4. *N2 (250–350 ms)*

The analysis of N2 amplitudes showed a significant main effect of laterality ($F(2, 30)=17.15$, $p<0.001$, $\eta^2=0.53$), with the N2 amplitudes more negative in the left (−0.85 μV) and midline (−1.21 μV) compared to the right regions (1.22 μV, $ps<0.01$). In addition, there was a significant main effect of valence strength ($F(2, 28)=4.83$, $p<0.05$, $\eta^2=0.24$). Highly emotional words (M±S.E.:−1.01±0.88 μV) elicited larger amplitudes than mildly emotional words (−0.04±0.90 μV; $F(1, 15)=7.49$, $p<0.05$; $\eta^2=0.33$) and neutral words (0.21±1.00 μV; $F(1, 15)=6.63$, $p<0.05$; $\eta^2=0.31$; Figs. 3 and 5), whereas the amplitude differences for mildly emotional and neutral words failed to meet statistical significance ($F(1, 15)=0.38$; ns, Fig. 4). No other significant main or interaction effects were detected in the analysis of N2 amplitudes. The analysis of N2 latencies showed no other effects, except for longer latencies recorded at frontal vs. central sites ($F(2, 30)=6.93$, $p<0.05$; see Figs. 1 and 2).

2.2.5. *P3 (350–500 ms)*

The repeated measures ANOVA of P3 amplitudes showed that parietal sites recorded larger amplitudes compared to central and frontal sites ($F(4, 60)=4.16$, $p<0.05$; $\eta^2=0.23$). In addition, there was a significant valence polarity by valence strength interaction on P3 amplitudes ($F(2, 30)=3.98$, $p<0.05$; $\eta^2=0.22$). To break down this interaction, we analyzed the effect of valence strength in the positive and negative experimental sessions, respectively. The simple effects analyses showed a significant valence strength effect in the positive experimental session [$F(2, 30)=6.60$, $p=0.01$; $\eta^2=0.31$]. MP words (M±S.E.: 6.23±1.08 μV) elicited more negative amplitudes in comparison with Neutral words (M±S.E.: 8.03±0.92 μV; $F(1, 15)=12.19$, $p<0.005$; $\eta^2=0.45$). Also, HP words (M±S.E.: 6.56±1.19 μV) elicited more negative amplitudes than Neutral words ($F(1, 15)=5.02$; $p<0.05$; $\eta^2=0.25$). The amplitude differences between HP and MP conditions were non-significant ($F(1, 15)=0.77$; ns). On the other hand, the valence strength effect was non-significant in the negative experimental session [$F(2, 30)=0.13$, ns]. The averaged amplitude

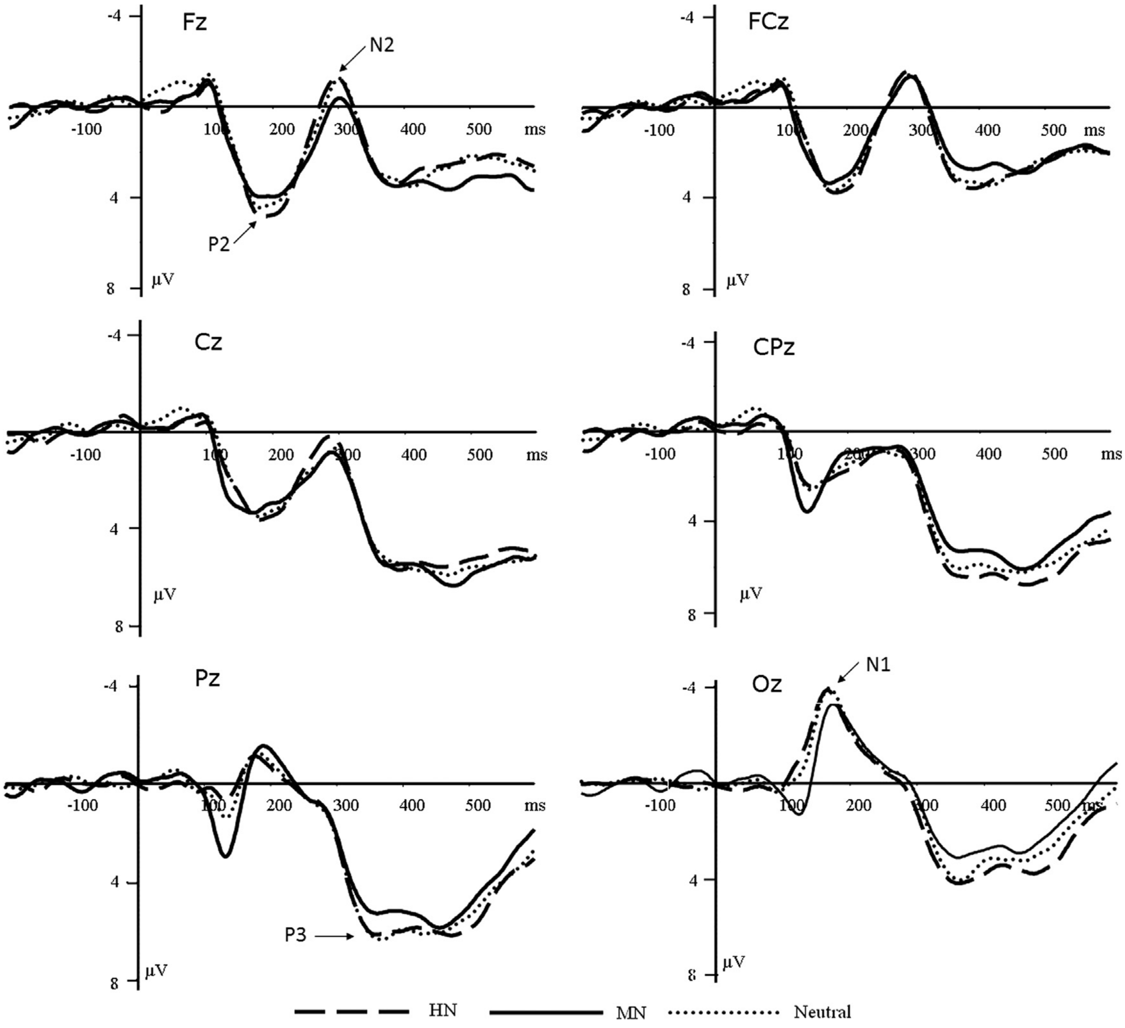

Fig. 2 – Averaged ERPs elicited by the HN (dashed lines), MN (solid lines) and Neutral (dotted lines) stimuli in the Negative Experiment.

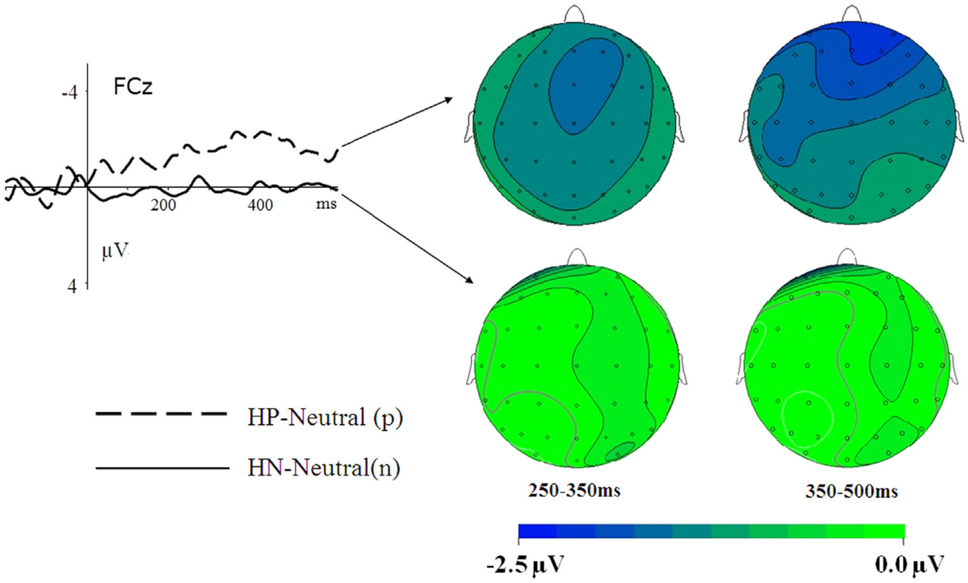

Fig. 3 – HP-Neutral (positive session) and HN-Neutral (negative session) difference ERPs at FCz (Left), and the topographical distributions of the voltage amplitudes of the difference waves in the 250–350 ms and 350–500 ms epochs (Right).

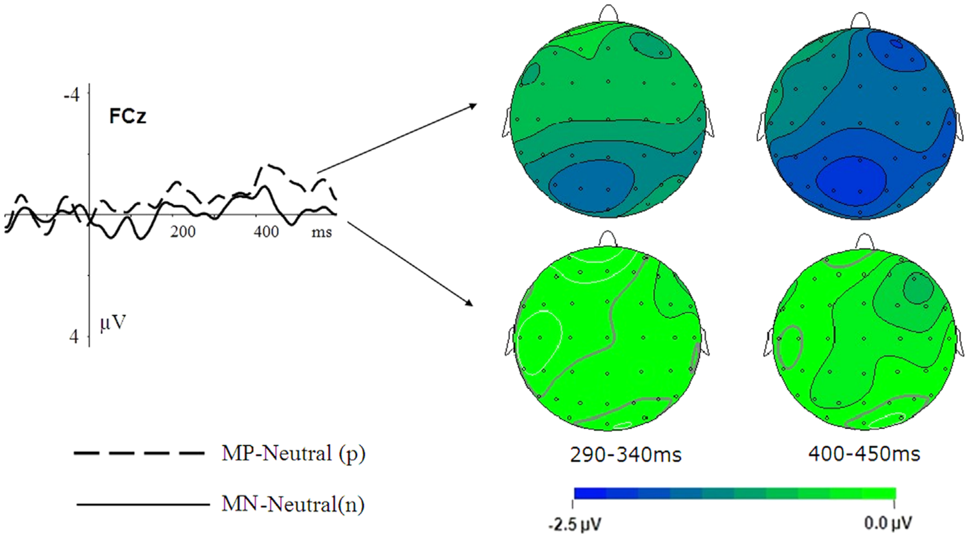

Fig. 4 – MP-Neutral (positive session) and MN-Neutral (negative session) difference ERPs at FCz (Left), and the topographical distributions of the voltage amplitudes of the difference waves in the 250–350 ms and 350–500 ms epochs (Right).

was $6.71 \pm 1.06\ \mu V$ for HN words, $6.91 \pm 1.42\ \mu V$ for MN words, and $7.00 \pm 1.29\ \mu V$ for Neutral words (M±S.E.). The P3 amplitudes for the neutral stimuli in the positive and negative sessions were not significantly different ($t(15)=1.06$; $p=0.304$). No other effect was found at P3 component.

Considering that the preceding N2 emotional effect may contaminate the interpretation of the emotion effects for HP and MP words in P3 amplitudes, we further conducted two separate covariance analysis with the HP (or MP)–Neutral difference amplitudes (at N2) as a covariate. The first analysis did not yield a significant emotion effect for HP words in P3 amplitudes after controlling this effect in N2 amplitudes ($F(1, 14)=0.36$; ns). However, the second covariance analysis continued to show a significant emotion effect for MP words even after controlling MP–NP differences in N2 amplitudes ($F(1, 14)=8.78$; $p=0.01$; $\eta^2=0.39$). Thus, the emotion effect for HP words in P3 amplitudes was likely an extension of this effect at N2 stage, while the P3 effect for MP words was unaffected by N2 amplitudes. There were no other main or interaction effects in P3 amplitudes, and there were no significant main or interaction effects produced by the analysis of P3 latencies.

2.2.6. *The comparison of P3 effects for positive and negative words*

The results of P3 analyses showed emotion effects for positive but not negative words. This implies that P3 amplitudes might be more sensitive to positive compared to negative words. To test this possibility, we compared the size of the P3 emotion effect between positive and negative words at each intensity level, as recommended by Nieuwenhuis et al. (2011). The emotion effect was calculated as the differences between emotional and neutral conditions. Firstly, we compared the

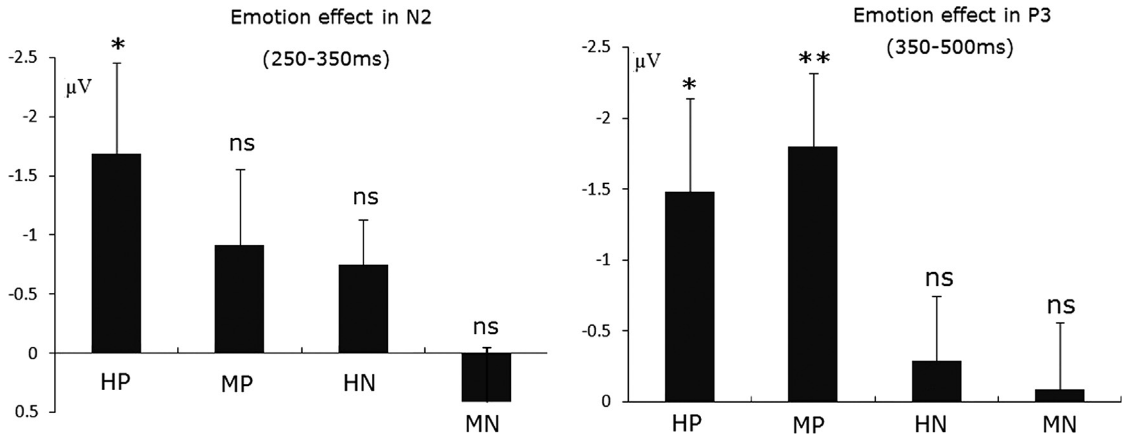

Fig. 5 – Schematic illustration of the emotion effects (emotional-neutral) in N2 (left) and P3 (right) amplitudes during HP, MP, HN and MN conditions. Error bar represents standard error for each mean difference. **$p<0.01$; *$p<0.05$; ns $p>0.05$.

emotion effect between mildly positive and mildly negative words by a separate ANOVA, with Valence polarity (2 levels: positive vs. negative) and Emotionality (2 levels: emotional vs. neutral) as repeated factors. The results showed a significant interaction ($F(1, 15)=5.64$, $p<0.05$, $\eta^2=0.27$). The emotional effect, indexed by the emotion-neutral differences in P3 amplitudes, was significantly larger for mildly positive (−1.80 μV) in comparison with mildly negative conditions (−0.09 μV, $t(15)=-2.37$, $p<0.05$; Fig. 4). These results showed that P3 amplitudes were more sensitive to mildly positive compared to mildly negative words. The comparison of the emotion effect for highly positive and highly negative words did not yield a conventionally significant difference ($t(15)=1.72$, $p=0.11$).

2.2.7. *The timing of emotion effects for HP and MP words*

Also, the above results implied that the emotion effect induced by HP words (N2, 250–350 ms) occurred earlier than that induced by MP words (350–500 ms). In order to test the reliability of this potential timing effect, we conducted a separate ANOVA with timing (2 levels, N2, P3) and pleasantness (HP, MP and Neutral) as factors, after collapsing the amplitude data across the corresponding electrode sites (N2 amplitudes were collapsed across the 9 frontal and central sites, and P3 amplitudes collapsed across the 15 sites). Emotion effects were calculated as the differences between pleasant and neutral conditions. The results showed a significant timing and pleasantness interaction ($F(2, 30)=3.41$, $p<0.05$, $\eta^2=0.19$). The simple effect analyses showed that HP words elicited a significant emotion effect in the N2 (250–350 ms; ($t(15)=-2.18$, $p=0.046$) and the P3 ($t(15)=-2.24$, $p=0.041$) time windows. In contrast, MP words did not elicit an emotion effect in the N2 (250–350 ms; ($t(15)=-1.43$, $p=0.17$), but elicited a significant emotion effect in the later P3 time window ($t(15)=-3.49$, $p=0.003$). These results confirmed that HP words elicited a faster emotional effect in comparison with MP words.

3. Discussion

Using Event-related potential technique and a word counting task, the present study investigates whether human brains are more sensitive to the valence strength of positive relative to negative words. The results basically confirmed our hypotheses by showing that (1) both HP and MP words elicited a significant emotion effect in brain potentials, and the emotion effect of HP words (in N2 and P3) occurred earlier than that of MP words (in P3); (2) HN words elicited an emotion effect in N2 but not in P3 amplitudes; while MN words elicited no emotion effect across N2 and P3 components; and (3) the emotion-neutral differences in P3 amplitudes were significantly larger for MP compared to MN words.

Firstly, we observed neither significant main effects of valence polarity and valence strength, nor valence polarity by strength interaction in occipital N1 and frontal P2 components. Occipital N1 activity is widely accepted as an index of early visual-perceptual processing, and its amplitudes were found to increase with the allocation of early spatial attention (Mangun, 1995). Similarly, the frontal P2 that peaks before 200 ms post stimulus was considered as reflecting perceptual encoding of stimulus features (Thorpe et al., 1996; Joyce and Rossion, 2005). Thus, the early visual-perceptual encoding of Chinese words was not significantly influenced by word valence and its strength. This is probably because the physical and perceptual attributes of the words, such as the number of strokes, word size and resolution, were controlled across valence strength and polarity conditions. Because information processing before 200 ms was indicated to happen automatically, inaccessible to controlled cognitive resources (Carretié et al., 2004; Del Cul et al., 2007), the brain was less likely to identify the semantic meanings of emotional words at these early stages, especially when cognitive resources were prepared for processing non-semantic dimensions of the word stimuli. Consequently, this may have led to similar processing for emotional and neutral words.

However, this explanation is inconsistent with several recent studies that demonstrated early effects of positivity bias for emotional words in early P1 or P2 component, which peak before 200 ms post stimulus (Scott et al., 2009; Bayer et al., 2012). Previous research showed that cognitive preparation facilitated early visual processing of the targets (Chen et al., 2008; Yang et al., 2012): the greater the cognitive resources were prepared, the more facilitated the early visual processing was (Chen et al., 2008). In this regard, one possible explanation for this discrepancy is the differences in the cognitive resource demand for word processing in different tasks. Previous studies that observed P1 or P2 effects for emotional words used lexical decision, word reading or affective assessment tasks (Herbert et al., 2006; Kanske and Kotz, 2007; Scott et al., 2009; Bayer et al., 2012), whose task settings entail greater attention focus on word meanings compared to counting the number of the words. Also, the reduced cognitive demand in the present task was evidenced by our observation of faster response latencies and ceiling response accuracy compared to prior studies (Bayer et al., 2012). This may explain the absence of an early emotional effect in the current study and in prior studies which used superficial, non-semantic tasks (Hinojosa et al., 2009; Naumann et al., 1997). For instance, Hinojosa et al. (2009) failed to observe emotional effects in early ERP components when subjects performed a simple perceptual discrimination task, and Naumann et al. (1997) observed that the valence effects for affective nouns in brain potentials were observed in affective assessment tasks but not in a task requiring word structure analysis. However, there was a recent study which showed affective modulations on C1 amplitudes (50–100 ms post word onset) in a superficial word/face discrimination task (Rellecke et al., 2011). The authors explained this finding as “an early detection of emotional relevance” while simultaneously, they indicated that this result was not consistently reported in previous studies and the preconditions for this effect were unclear (Rellecke et al., 2011). Kissler et al. (2006) have assumed that the timing of the emotion effect for word stimuli may depend on the variations in lexical representation of word stimuli. In this regard, whether the task's cognitive demand for semantic processing predicts the timing of valence effects needs to be directly tested in future studies by varying the demand of semantic processing.

Moreover, we observed an N2 component which peaked about 280 ms and was largest at frontal sites, consistent with the morphology of vigilance-related N2 reported in prior studies (Carretié et al., 2004; Nagy et al., 2003; Daffner et al., 2000). Frontal-central N2 that peaks around 300 ms post stimulus is accepted as an index of attention vigilance to potentially salient stimuli (Carretié et al., 2004; Nagy et al., 2003), and its amplitudes were found to increase with the degree of attention alerting (Yuan et al., 2007; Campanella et al., 2002; Nagy et al., 2003). As the N2 component was suggested to represent a frontier between automatic and controlled phases of the orienting response (Carretié et al., 2004), the attention vigilance indexed by the N2 may have involved access to controlled processing resources. In this component, we observed a significant emotion effect for highly emotional words irrespective of valence polarity. This result is consistent with several prior studies which observed similar size of amplitude enhancement for positive and negative words in comparison with neutral words in the EPN component (Kissler et al., 2006; Herbert et al., 2008), which is functionally similar to the frontocentral N2 and is thought to reflect attention orienting during access to emotional meanings (Citron et al., 2011). Because the emotion effect in this latency stage was found to be independent of processing depth and the tasks' emotional nature (Kissler et al., 2006; Schacht and Sommer, 2009b), N2/EPN was considered to be an index of semi-automatic and implicit processing of emotion (Kissler et al., 2006; Citron et al., 2011; Carretié et al., 2004). As such, the lack of full access to controlled processing resources during N2/EPN stage might be an important reason to explain why the current and prior studies observed a similar effect for positive and negative words, instead of a positivity bias, at the N2/EPN stage (Kissler et al., 2006; Herbert et al., 2008; Citron et al., 2011).

However, these findings (i.e., similar emotion effects for positive and negative words in N2/EPN) are in contrast with prior ERP studies using emotional arousing pictures or faces, which showed larger N2 amplitudes for negative vs. positive pictures (Wang et al., 2011; Yuan et al., 2012a), and a sensitivity of the brain to the valence strength of aversive, but not appetitive, pictures (Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007, 2012b; Leppänen et al., 2007; Wang et al., 2011). It is noteworthy that in the current study, HN words had significantly larger valence extremity compared to HP words, indicated by our pre-experiment stimulus assessment (see Section 5.2). Despite smaller valence extremity, HP words elicited a similar emotional effect in N2 amplitudes as the HN words, possibly due to the biased processing of positive over negative information when low-arousal materials such as emotional words are used as stimuli (Cacioppo and Berntson, 1994; Herbert et al., 2006; Hinojosa et al., 2009; Bayer et al., 2012). On the other hand, mildly emotional words, whether positive or negative, did not elicit an emotion effect in N2 amplitudes. This was probably because mildly emotional stimulus was not as affectively intense as highly emotional stimulus. As a result, it usually elicited a delayed emotional effect compared to the latter stimulus (Meng et al., 2009; Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007).

The P3 component was largest at parietal sites in the 350–500 ms interval, which fitted the archetype of the classic P3b component (Delplanque et al., 2005; Yuan et al., 2012a). The P3 has been indicated to reflect updating of stimulus contexts and controlled processing of stimulus meanings (Huang and Luo, 2006; Donchin and Coles, 1988). It was consistently reported that P3 amplitudes were enhanced for emotional vs. neural stimuli in studies which required subjects to overtly assess the emotionality of pictures (Ito et al., 1998; Schupp et al., 2000) and words (Fischler and Bradley, 2006; Herbert et al., 2006) or which entailed semantic processing of emotional words (e.g. word reading, Herbert et al., 2008; or lexical decision, Hinojosa et al., 2010). This effect was interpreted as sustained processing bias for emotional stimuli (Citron et al., 2011; Herbert et al., 2006, 2008). By contrast, in tasks which disengage subjects from emotion assessment or semantic processing of emotional verbal stimuli (e.g. a non-semantic perceptual discrimination task; Hinojosa et al., 2009), P3 amplitudes were extensively reported to be less pronounced for emotional vs. neutral pictorial stimuli (Carretié et al., 1996; Delplanque et al., 2004; Yuan et al., 2007, 2012b) and word stimuli (Citron et al., 2011; Hinojosa et al., 2009). A recent review postulated that this amplitude reduction might reflect reduced attention recruitment to discriminate emotional compared to neutral words from non-word distracters during word processing studies (Citron et al., 2011). On the other hand, our prior studies proposed that this amplitude reduction may reflect the degree to which the brain inhibits task-irrelevant emotional information, especially when pictorial stimuli were used (for discussions, see Yuan et al., 2007, p. 2769; Yuan et al., 2012a, pp. 187–188), because cognitive inhibition of task-irrelevant distractions is linked with smaller P3 amplitudes (Liotti et al., 2000; Chen et al., 2008; Yuan et al., 2011b). Consistent with these covert-emotional studies, we observed smaller P3 amplitudes for pleasant compared to Neutral words in the positive experimental session. However, this effect was absent in the negative session. In this study, the task of subjects was to count the number of words by quick and accurate key-presses, irrespective of word meanings. Thus, the semantic meanings of the emotional words were irrelevant to the task. Consequently, the performance of task-related processing (i.e. counting the number of words) may have required inhibition of the interfering emotion impacts, such as the biased attention to task-irrelevant pleasant meanings and the activation of approach motivation (Lang and Bradley, 2010; Huang and Luo, 2006; Fredrickson, 2004). This may account for the smaller P3 amplitudes during pleasant vs. Neutral conditions. On the other hand, negative words did not evoke a significant emotion impact in the P3 stage. As a result, there was no need to conduct as much inhibitory processing as in the positive experimental session. This possibly accounts for similar P3 amplitudes recorded during negative and neutral conditions.

However, the counting task used in our study is not attention-demanding, as evidenced by the ceiling accuracy and similar RTs across different emotion conditions. Given that no behavioral interference effect (e.g. longer RTs for positive words) was observed, we need to take caution with the above inhibitory account and other possibilities should not be excluded. For instance, given that human brains are sensitive to the valence strength of positive words, both HP and MP stimuli should have drawn privileged attention and both sets of positive words should be represented differently from neutral stimuli in the brain during the late processing stage. Consequently, neutral stimuli, as one-third of the experimental stimuli, might then form a set of deviant stimuli from the background of two-thirds positive words, and previous studies have established that deviant stimuli were associated with more pronounced P3 amplitudes compared to background stimuli (Campanella et al., 2002; Yuan et al., 2010, 2012b). On the other hand, as a result of reduced sensitivity to the valence strength of negative words, negative words might not recruit as biased processing as positive words at late stage. Consequently, neutral words should not have been distinguished from negative words as pop-out stimuli in neural representation. Regardless of which mechanism accounts for this result, our findings that the P3 amplitudes were smaller for HP and MP compared to Neutral words but similar for HN, MN and neutral words demonstrated that the emotion effect was significant for positive words but not for negative words in P3 amplitudes. This was consistent with abundant evidences that showed a positivity bias in P3 amplitudes (Herbert et al., 2006, 2008; Citron et al., 2011).

More importantly, we observed a significant timing and pleasantness interaction. MP words elicited a significant emotion effect in P3 but not N2 amplitudes. This is in contrast with HP words whose emotion impact is significant in N2 and lasts into P3 amplitudes. This suggests that the human brain is more sensitive to pleasant words of greater valence strength, such that the brain detects the emotionality of HP words faster than that of MP words. Thus, it should be reliable to conclude that the brain is sensitive to the valence strength of positive words. However, because the valence differences between high and mild emotional levels are larger in the positive compared to the negative experimental session, one might argue that these effects are also possible to reflect a larger size of valence differences in positive versus negative words, instead of reflecting brain sensitivity to the valence strength of positive words. This concern may be fixed, at least in part, by the fact that both highly and mildly negative words had a larger valence difference from neutral stimuli compared to highly and mildly positive words. Despite this status, the significant emotion effects in P3 amplitudes were observed only for positive words, but not for negative words irrespective of valence strength. This result indicates that the humans are most likely more sensitive to the valence strength of positive compared to negative words.

Additionally, MP words exhibited a larger size of emotional-neutral amplitude differences than MN words. Because the perceptual features of the words were controlled, and the sequence of the two sessions counterbalanced, the amplitude differences between emotional and neutral words had no other sources, except for the interfering emotion impact from word meanings. Thus, these findings probably resulted from the enhanced activation of appetitive over defensive motivations during the presentation of word stimuli, which are reduced in arousal compared to pictures (Carretié et al., 2008; Cacioppo and Berntson, 1994). Thus, the emotional positivity bias that favors the processing of pleasant stimuli most likely accounts for the elevated brain sensitivity to mildly positive relative to mildly negative words.

Many prior studies reported an attention bias for negative versus positive stimuli (Carreti'e et al., 2001; Huang and Luo, 2006) and reported that the human brain was sensitive to the valence strength of negative instead of positive stimuli (Leppänen et al., 2007; Yuan et al., 2007). These studies used emotionally evocative scenes or facial expressions of salient emotion, both of which were known for the efficacy of emotion arousal (Britton et al., 2006). According to the bipolar structure theory of emotion (Cacioppo and Berntson, 1994), defensive motivation would be more activated compared to appetitive motivation when the stimuli provided high arousal inputs, consequently leading to a negative bias that favors the processing of negative over positive events. Thus, it is unsurprising to observe a negative bias at multiple levels and enhanced brain sensitivity to the valence strength of negative stimuli, when arousing pictures are used (Huang and Luo, 2006; Yuan et al., 2007). However, it is biologically significant for organisms to maintain approach motivation, consequently to keep exploring behaviors and seeking goals (e.g. food, procreation) in unfamiliar, or neutral environments that provide low arousal inputs (Cacioppo and Gardner, 1999). This explains why people evaluate neutral stimuli presented subconsciously as positive, and have a normative positive mood and a positive expectation for unknown events as long as threats are unavailable(Diener and Diener, 1996; Cacioppo and Gardner, 1999; Leppänen, and Hietanen, 2003). Based on these characteristics, it is unlikely that the human brain is always sensitive to the valence strength of emotionally negative stimuli as shown by our prior studies (Yuan et al., 2007; Meng et al., 2009; Yuan et al., 2012b). Instead, the brain sensitivity to the valence strength of emotional stimuli probably depends on the arousal characteristics of the stimuli. This suggests that the human brain is likely more sensitive to the valence strength of positive stimuli compared to negative stimuli, if approach motivation overrides defensive motivation during presentation of low-arousal stimuli, such as the word stimuli used in the present study. This conclusion should have been more convincing, if the arousal characteristics of the stimuli (pictures/words) had been manipulated in a single study.

In addition, there was evidence showing that word class influences emotional effects for verbal stimuli (Palazova et al., 2011). For instance, Palazova et al. (2011) observed enhanced processing for emotional relative to neutral German words in the 250–300 ms interval for nouns but not for verbs. Therefore, we need to acknowledge that it was a limitation that the current study controlled word class (by equating the number of nouns and verbs) instead of treating it as an independent variable. In this regard, future studies need to investigate brains' sensitivity to the valence strength of positive and negative nouns, verbs and adjectives respectively. On the other hand, the present study used affective Chinese words as stimuli in native Chinese subjects. Thus, we need to restrict our findings to Chinese language and Chinese culture, and it is still necessary to replicate these findings in other languages.

4. Conclusions

The human brains are equipped with increased sensitivity to the valence strength of positive compared to negative word stimuli, which are well known for reduced arousal. Consequently, the brain is not only reactive to both highly and mildly pleasant words, but generates a faster emotional effect for highly compared to mildly pleasant words.

5. Experimental procedures

5.1. Subjects

As paid volunteers, 16 adults (8 women, 8 men) aged 21–26 years (mean age, 23.05 years) participated in the study. All subjects recruited for this study were healthy, free of anxiety/depression symptoms, and reported no history of neurological or affective disorder. The subjects were all right-handed, with normal or corrected to normal vision. Each subject signed an informed consent form for the experiment. The experimental procedure was in accordance with the ethical principles of the 1964 Declaration of Helsinki (World Medical Organization, 1996).

5.2. Stimuli

The present study includes two experimental sessions each used a word counting task. One investigates the brain sensitivity to the valence strength of positive words (Positive Session), while the other investigates the brain sensitivity to the valence strength of negative words (Negative Session). Each Session consisted of 5 blocks of 72 trials, which included 1–3 identical words in the screen. The words were composed of equal number of nouns and verbs. Also, the number of nouns and verbs was equated for each condition during each block. In the Positive Session, each block included 24 words which were grouped into Highly Positive (HP), Moderately Positive (MP), and the Neutral (i.e. the baseline for Positive words; NP) categories. In the Negative Session, each block included 24 words that were grouped into Highly Negative (HN), Moderately Negative (MN), and the Neutral (i.e. the baseline for Negative words; NN) categories, respectively (Fig. 6). It is noteworthy that different sets of neutral words were used as baseline in the Positive and Negative sessions. Therefore, each stimulus category had 8 words (4 nouns, 4 verbs) and 24 trials (3*8) in every single block. Accordingly, there were 40 (8*5) words and 120 (40*3) trials used for each stimulus category in either session, after taking 5 blocks together. All the words were two-character Chinese words that were popularly used everyday expressions taken from Chinese Affective Words System (CAWS; Wang et al., 2008). The words were selected in such a way that the normative valence of the words differed significantly between each pair of the three conditions whereas the arousal of the words overall matched across conditions and sessions. All words were identical in size and resolution (106 pixels × 60 pixels, 105 pixels per inch).

To test whether the words selected for each category (HN, MN or NN in the Negative; HP, MP and NP in the Positive Sessions) fitted corresponding request of emotional attributes by this category, we recruited another sample of college students aged 18–25 years [$n = 60$; 30 males, Mean age: 21.35] to rate the valence and arousal of the six categories of words using the Self-Assessment Manikin procedure (SAM;

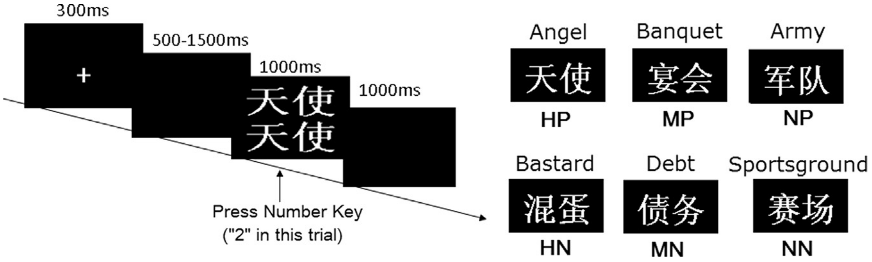

Fig. 6 – Schematic illustration of the behavioral procedure (Left) and the Chinese word examples for each of the six categories (Right).

Lang et al., 1997). Using a self-report 9-point rating scale, subjects were required to rate the emotion valence (ranging from 1="very unpleasant" to 9="very pleasant") and arousal (ranging from 1="very calm" to 9="very excited") they felt for each word by pressing corresponding number keys in the keyboard. The sequence of the two ratings was counterbalanced across subjects. The analysis of valence data, with Valence Polarity (2 levels: positive vs. negative) and Valence strength (3 levels: highly, mildly and neutral) as two repeated factors, showed significant main effects of Valence Polarity ($F(1, 59)=387.36$, $p<0.001$; $\eta^2=0.87$) and valence strength ($F(2, 118)=89.95$, $p<0.001$; $\eta^2=0.60$), as well as a significant valence strength by valence polarity interaction ($F(2, 118)=338.37$, $p<0.001$; $\eta^2=0.85$). The breakdown of this interaction showed a significant effect of valence strength in the negative session ($F(2, 118)=335.39$, $p<0.001$; $\eta^2=0.85$). HN words ($M=2.81$; S.E.$=0.12$) were rated more negative (lower in valence) compared to MN words ($M=3.19$; S.E.$=0.11$; $F(1, 59)=63.34$, $p<0.001$; $\eta^2=0.52$) which, in turn, were rated negative (lower in valence) in comparison with neutral words ($M=5.51$; S.E.$=0.08$; $F(1, 59)=311.84$, $p<0.001$; $\eta^2=0.84$). Also, there was a significant effect of valence strength in the positive session ($F(2, 118)=174.67$, $p<0.001$; $\eta^2=0.75$). HP words ($M=7.03$; S.E.$=0.11$) were rated more positive (higher in valence) compared to MP words ($M=6.26$; S.E. $=0.10$; $F(1, 59)=118.79$, $p<0.001$; $\eta^2=0.67$) which, in turn, were rated positive (higher in valence) in comparison with neutral words ($M=5.33$; S.E.$=0.07$; $F(1, 59)=132.75$, $p<0.001$; $\eta^2=0.69$; Fig. 7). Thus, the words used for our study differed significantly in valence strength across conditions in either experimental session.

Also, we tested whether the positive and negative words at each valence strength level were comparable in valence extremity. For this purpose, valence rating scores for highly and mildly emotional words were both subtracted by the scores of the corresponding neutral words during either session, which resulted in four types of difference scores: HP-neutral (positive), MP-neutral (positive), HN-neutral (negative) and MN-neutral (negative). The paired t-test on the absolute values of the difference scores showed that (1) HN words (diff. score$=2.70$) had a greater valence extremity compared to HP (diff. score$=1.70$; $t(59)=-12.66$, $p<0.001$) words; and (2) MN words (diff. score$=2.32$) had a greater valence extremity compared to MP words (diff. score$=0.93$; $t(59)=-7.61$, $p<0.001$). Thus, negative words, whether they are highly or mildly negative, were stronger in valence extremity compared to the corresponding positive words in the present study. This fact would strengthen the notion of emotional positivity bias, if the results do exhibit greater brain processing of positive over negative words in spite of this status.

On the other hand, the analysis of arousal data, with valence polarity (2 levels: positive vs. negative) and valence strength (3 levels: highly, mildly and neutral) as two repeated factors, showed neither significant main effects of valence polarity ($F(1, 59)=0.85$, $p=0.36$) and valence strength ($F(2, 118)=2.95$, $p>0.07$), nor a significant polarity by strength interaction ($F(2, 118)=0.20$, $p=0.70$; Fig. 7). The averaged arousal was 5.26±1.25 (M±S.D.) for HP words, 5.14±1.10 for MP words, and 5.20±1.16 for neutral (positive) words, 5.21±1.22 for HN words, 4.98±1.27 for MN words, and 5.05±1.14 for Neutral (negative) words.

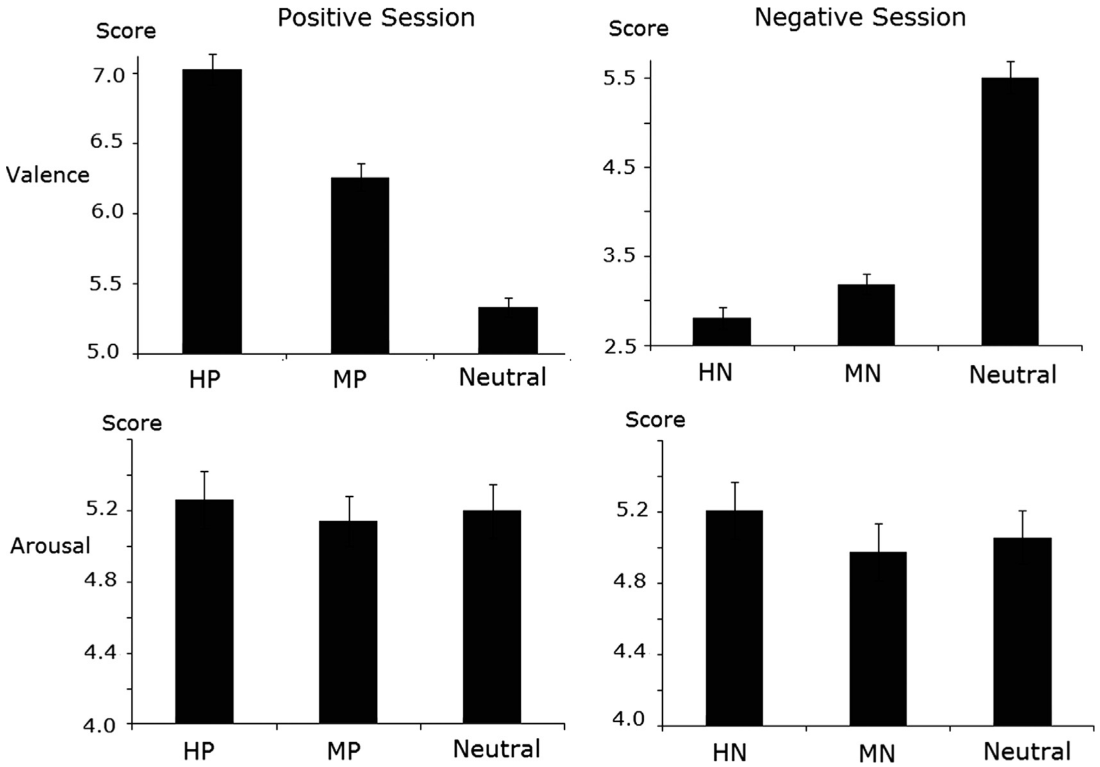

Fig. 7 – The schematic illustration of the averaged valence and arousal ratings for highly emotional, mildly emotional and neutral words in positive and negative experimental sessions ($n=60$; error bars represent ± S.E.)

5.3. *Behavioral procedures*

Subjects were seated in a quiet room at approximately 150 cm from a computer screen with the horizontal and vertical visual angles below 6°. Subjects' index finger, middle finger and ring finger of the right hand were rested on the number buttons 1, 2, 3 respectively during the experiment. E-prime 1.1 software was used for stimulus presentation. Prior to the experiment, all subjects were told that this study was to investigate their ability to make a fast response selection, and that they would see the presentation of 1–3 identical words on the screen. The number of words and the stimulus condition to be presented in each trial were fully randomized, which was realized by a randomization production procedure of the E-prime software. At the end of each block, accuracy rates were given to the subjects as a feedback of their performance. Each trial was initiated by a 300 ms presentation of a small white cross on the black computer screen. Then, a blank screen whose duration varied randomly between 500 and 1500 ms was presented and was then followed by the onset of word stimulus. Subjects were required to count the number of words on the screen and reported their answer via button press (as accurately and quickly as possible). The word stimulus presentation was terminated by a key pressing, or was terminated when they elapsed for 1000 ms. Therefore, each subject was informed that their responses must be made within 1000 ms. Each response was followed by 1000 ms of a blank screen (Fig. 6). Pre-training with 30 practice trials was used before the experiment in order to familiarize subjects with the procedure. All subjects achieved 100% accuracy on 30 practice trials prior to the formal experiment. Each subject participated in both experimental sessions, with the order of the two sessions counterbalanced across subjects.

5.4. *ERP recording and analysis*

Electroencephalography (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products), with the references on the left and right mastoids (Averaged mastoid reference, i.e., EEGs were recorded with reference to the left mastoid, and were re-referenced offline to the average of the potentials of the bilateral mastoids; Luck, 2005) and a ground electrode on the medial frontal aspect. Vertical electrooculograms (EOGs) were recorded supra- and infra-orbitally at the right eye. Horizontal EOG was recorded as the left versus right orbital rim. EEG and EOG activity was amplified with a DC-100 Hz bandpass and was continuously sampled at 500 Hz/channel. All electrode impedances were maintained below 5 kΩ. Averaging of ERPs was computed off-line using the Vision Analyzer software package developed by the Brain Products Company (Munich, Germany). EOG artifacts (blinks and eye movements) were corrected offline, and a 16-Hz low-pass filter was used. Trials with a mean EOG voltage that exceeded ±100 μV and those trials contaminated with artifacts due to amplifier clipping of peak-to-peak deflection that exceeded ±100 μV were excluded from the averaging. The rejected trials were rare, there were on the average 113.9 trials for HN, 114.3 trials for MN, 114.2 trials for Neutral (negative), 113.1 trials for HP, 112.1 for MP and 112.5 trials for Neutral (positive) conditions used for ERP averaging. A repeated measures ANOVA of the number of trials, with valence polarity (positive, negative) and valence strength (high, mild and neutral) as factors showed neither main effects of valence polarity($F(1, 15)=0.50$, ns) and valence strength ($F(1, 15)=0.38$, ns) nor a two-way interaction ($F(2, 30)=1.15$, ns).

EEG activity for word stimuli with correct responses was averaged in each condition, respectively. ERP waveforms were time-locked to the onset of stimuli and the average epoch was 900 ms, including a 200 ms pre-stimulus baseline. The following 15 electrode sites were selected for statistical analysis: F3, Fz, F4 (3 frontal sites), FC3, FCz, FC4 (3 fronto-central sites), C3, Cz, C4 (3 central sites), CP3, CPz, CP4 (3 centroparietal sites), P3, Pz and P4 (3 parietal sites). As shown by the ERP's grand averaged waveforms (see Figs. 1 and 2), there are P2 (160–220 ms) and N2 (250–350 ms) components that are distributed over central and frontal sites, consistent with the notion that voluntary attention allocation indexed by P2 and N2 components is mediated by the activity of the anterior cingulated cortex during a non-emotional distracting task (BA24, BA32;Carretié et al., 2004). Also, the frontal-central distribution of these early components in the current study is consistent with prior studies of covert-emotional and word processing (Carretié et al., 2001; Liu et al., 2009, 2010; Yuan et al., 2011b), and this scalp distribution was further confirmed by our Principal Component Analysis which identified only 3 ERP components in the 0–300 ms post stimulus: Occipital N1, Front-central P2, and Frontal-central N2 (for details, see Supplementary Material 1). It is worth notice that no EPN (Early Posterior Negativity) activity was detected, most likely because we used a simple word counting task instead of lexical/semantic decision tasks (for details, see Supplementary Material 2). In addition, there is a P3 component that is distributed broadly across both anterior and posterior scalp regions, with the amplitudes largest in the posterior- parietal sites in the 350–500 ms time interval (Figs. 1 and 2). Therefore, the present study analyzed the latencies and the peak amplitudes of P2 and N2 at the 9 central-to-frontal scalp sites, and analyzed the latencies and peak amplitudes of P3 component at the whole 15 sites, with Valence strength (3 levels: highly emotional, mildly emotional and Neutral), Valence Polarity (positive vs. negative), Sagittality (F, FC, C, CP, P; 3 levels for P2 and N2; 5 levels for P3), Laterality (3 levels: left, midline, right) as repeated factors. Peak latencies are defined as the duration from stimulus onset to the timepoint when a component reached its peak amplitude. Peak amplitudes are quantified as the peak amplitude values against baseline for all these components. In addition, we also analyzed occipital N1 (130–190 ms) component at Oz, O1 and O2, to see whether the valence polarity (positive vs. negative) and valence strength (highly, mildly and neutral) of emotional words impact the early visual processing of word stimuli (see Figs. 1 and 2). Considering that baseline-to-peak measurement of N1 was reported susceptible to noises (Picton et al., 2000), we measured the amplitudes of occipital N1 using a peak-to-peak approach that was indicated better to increase signal to noise ratio (Picton et al., 2000;Yeung and Sanfey,2004). Specifically, we quantified N1 amplitudes as the peak-to-peak voltage differences between the most negative peak and the preceding positive peak in the 70–190 ms interval. The degrees of freedom of the F-ratio were corrected according to the Greenhouse–Geisser method. Fisher's Least Significant Difference (LSD) method was used for post hoc pairwise comparisons after significant main or interaction effects were detected.

Acknowledgments

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.brainres.2013.08.020.

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