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The impact of emotion intensity on recognition memory: Valence polarity matters

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ABSTRACT

Although the effects of emotion of different emotional intensity on memory have been investigated, it remain unclear whether the influence of emotional intensity on memory varies depending on the stimulus valence polarity (i.e., positive or negative). To address this, event-related potentials were recorded when subjects performed a continuous old/new discrimination task, for highly negative (HN), mildly negative (MN) and neutral pictures in the negative session; and for highly positive (HP), mildly positive (MP) and neutral pictures in the positive session. The results showed that relative to neutral stimuli, both HN and MN stimuli showed increased memory discrimination scores, and enhanced old/new effect in early FN400 (Frontal Negativity), but not late positive component (LPC) amplitudes. By contrast, relative to MP stimuli, HP and neutral stimuli showed increased memory discrimination scores and enhanced old/new effect in LPC but not FN400 amplitudes. Additionally, we observed a significant positive correlation between the memory discrimination score and the old/new effect in the amplitudes of the FN400 and LPC, respectively. These results indicate that both HN and MN stimuli were remembered better than neutral stimuli; whereas the recognition was worse for MP stimuli than Neutral and HP stimuli. In conclusion, in the present study, we observed that the effect of emotion intensity on memory depends on the stimulus valence polarity.

1. Introduction

The question of how emotions affect memory is not only important for clinical interference of affective disturbances (Bremner et al., 1999; Drevets, 1998; Gorman et al., 2000), but is also important for forensic practices (Kiehl et al., 1999). Since the 1990s considerable studies have been published concerning the relationship between emotion and memory (Uttl et al., 2006). A pervasive observation is that emotional events are more likely to be remembered with a greater amount of perceptual and sensorial details, as well as an enhanced confidence in accurate recollection of the previous encounter (Schaefer and Philippot, 2005). This, in turn, facilitates judgment of whether the events have been previously learned (Schaefer and Philippot, 2005; Schaefer et al., 2011).

Emotional stimuli, however, differ not only in respect to the valence polarity (negative or positive), but also in respect to emotional intensity. In fact, a great number of previous studies demonstrated that the intensity of emotional stimuli is important (Leppänen et al., 2007; Meng et al., 2009; Schaefer et al., 2009; Yuan et al., 2007), and emotion of diverse intensities modulates cognitive functions, such as novelty detection, and behavioral control, differently (Yuan et al., 2012; Yuan et al., 2008). Nevertheless, to the best of our knowledge, currently no study has explored whether the influence of emotional intensity on memory varies depending on the stimulus valence polarity when subjects performed a continuous recognition task.

Negative emotion was thought to reflect defensive motivation, whose activation has been established to narrow attentional focus and enhance attention to emotion features (Gable and Harmon-Jones, 2010a). Previous studies showed that attention plays an important role in memory and enhanced attention facilitates the encoding of stimuli (Glass and Newman, 2009). Despite the same valence polarity, negative scenes of increasing emotion intensity, may activate defensive motivational reaction more rapidly (Yuan et al., 2007), and evoke narrower, more focused attentional scope (Rowe et al., 2007). Thus, highly negative scenes, which are characterized by salient threat features, are likely to be memorized better relative to mildly negative stimuli. Similarly, mildly negative stimuli are likely to be memorized better relative to neutral stimuli, which are free of negative features.

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However, the impact of positive emotion on memory does not necessarily follow this linear trend. Previous studies have shown that increased attentional focus enhances attention to emotion features and facilitates the encoding of stimuli, whereas increased attentional breadth diverts attention and impairs the encoding of emotional features (Gable and Harmon-Jones, 2010a). Moderate levels of positive stimuli have been reported to broaden attentional breadth than neutral stimuli (Gable and Harmon-Jones, 2010a; Rowe et al., 2007). Thus, mildly positive stimuli are likely to be memorized worse relative to neutral stimuli. In contrast, highly positive stimulus activates strong appetitive motivation, which may lead to impulsive behavior, unexpected cost and consequently, ambivalent rather than simple positive emotions (Mauss et al., 2011). Thus, this impairing effect may not apply to highly pleasant stimuli. On the other hand, according to the reward saliency hypothesis verified by recent converging evidences (Jensen et al., 2007; Madan and Spetch, 2012), the extreme reward values are experienced more saliently than the medium values, and consequently the effect of reward intensity on memory will show a U-shaped relationship, with both the highest and the lowest reward being remembered better than the intermediate reward. Consistent with this view, Madan and Spetch (2012) manipulated multiple reward intensity and observed that highest and lowest value items are remembered best while intermediate-value items remembered worst. In addition, prior studies have consistently suggested that reward is the major source where positive emotion is from (Heller and Mcewen, 2009; Yuan et al., 2012). Thus, highly positive stimuli are likely to be memorized better relative to mildly positive stimuli, and as a result, the impact of pleasant stimulus intensity on memory-related processing probably follows a nonlinear, U-shaped trajectory. Therefore, based on these analyses, we hypothesized that the memory accuracy of negative stimuli is increased with the emotional intensity of negative stimuli, whereas the memory accuracy of positive stimuli does not necessarily follow this linear trend.

Thus, the present study aims to investigate whether the influence of emotional intensity on memory varies depending on the stimulus valence polarity (i.e., positive or negative), by using ERP technique and a continuous recognition task. ERP technique was used in the current study as it is helpful in depicting the timing features, specifically; the automatic and controlled retrieval of emotional stimuli. ERP recognition was examined by using either a study-test paradigm or a continuous recognition task. In both tasks, the electrophysiological old/new effect has been established to represent recognition function (Van Strien et al., 2005; Van Strien et al., 2007; Rugg et al., 1998; Rugg and Curran, 2007). The old/new effect concerns the difference between the ERPs elicited by new and old stimuli, where the ERP waveform for old stimuli is usually more positive going than for new stimuli. This ERP old/new effect comprises an early Frontal Negativity (FN400) which is larger for new relative to old items in the 300–500 ms post stimulus, and a later parietal old/new difference (500–800 ms). With the study-test task, the early mid-frontal old/new effect has been thought to reflect familiarity (i.e. recognition without retrieval of details), whereas the later parietal old/new effect is thought to reflect recollection (i.e. recognition with the retrieval of associated details, see Curran and Dien, 2003; Rugg and Curran, 2007).

However, in the continuous recognition procedure, the time interval between the first and second presentation of a stimulus is shorter than with the study-test task. While the study-test task separates the stimulus encoding and retrieval into two different phases, the continuous recognition procedure alternates the stimulus encoding and retrieval. Thus, using a familiarity vs. recollection account for the distinctions between early FN400 vs. late LPC old/new effects may not apply to the continuous recognition task. For instance, there are evidences showing that the old/new effect related FN400 amplitudes were independent of stimulus repetition that increases familiarity (Van Strien et al., 2005). Van Strien et al. (2005) presented each word nine times in a modified continuous recognition paradigm. They observed that the early old/new effect did not change with the number of repetitions. These results indicate that the early old/new effect in the continuous recognition task reflects an automatic matching process that is independent of memory strength or familiarity. In addition, it has been reported that this early old/new effect is larger during immediate relative to delayed repetitions, and this enhancement of early old/new effects was linked with better recognition but weaker recalled memory (Van Strien et al., 2007). Therefore, the early ERP old/new effect in continuous recognition paradigm was later interpreted as a reflection of implicit, automatic memory retrieval rather than familiarity-based deliberate process (Van Strien et al., 2009).

Recently, several studies investigated whether and how ERP old/new effects are impacted by emotion (Inaba et al., 2005; Schaefer et al., 2009; Schaefer et al., 2011; Van Strien et al., 2005). These studies reported inconsistent results. Several studies reported that both FN400 and LPC old/new effects have been shown to be influenced by the emotional salience of the stimuli (Schaefer et al., 2011) whereas other studies demonstrated that emotion did not affect FN400 or the parietal LPC old/new effect (Windmann and Kutas, 2001). Notably, many studies have established that negative stimulus and its emotional intensity are preferentially encoded and analyzed in the brain relative to neutral and positive stimuli (Huang and Luo, 2007; Ito et al., 1998), even in shortage of attention (Kang and Wang, 2013; Meng et al., 2009; Yuan et al., 2012). By contrast, the encoding and analysis of positive information and its intensity entail the involvement of controlled processing resources (Kang and Wang, 2013). Thus, we hypothesize that negative but not positive emotion intensity would influence the ERP old/new effect at earlier, automatic retrieval stage associated with the FN400 component, whereas positive emotion intensity influences the ERP old/new effect only in the later, controlled recollection stage.

Additionally, in order to avoid cultural bias that has been reported by Chinese subjects when IAPS (International Affective Picture System) was adopted directly (Huang and Luo, 2004), the pictures used to elicit emotional responses in the present study were chose from the native Chinese Affective Picture System (CAPS), which was established in a similar way to IAPS (Bai et al., 2005). Additionally, The widely accepted dimensional theory of emotion proposed that the affective significance of a stimulus is defined from the two primary dimensions: valence and arousal (Bradley et al., 2001; Lang et al., 1997). As is common in life setting, intense emotional stimuli are normally associated with higher arousal in comparison with mildly emotional stimuli, irrespective of the positive or negative stimuli (Bradley et al., 1990; Keil et al., 2002; Kuppens et al., 2012; Lang et al., 1997). Thus, we selected emotional stimuli in the laboratory setting to more closely resemble emotional events in natural settings, that is, intense negative experiences defined by the valence dimension and intense physiological activations defined by the arousal dimension (Yuan et al., 2012). Based on above considerations, we chose that the rating of highly positive pictures would be more positive and more arousing than that of mildly positive pictures; and the rating of highly negative pictures would be more negative and more arousing than that of mildly negative pictures. Additionally, in order to avoid that stimuli of one valence (e.g. positive) may obscure the intensity effect of the other valence (e.g. negative), we used a design with one block presenting highly positive, mildly positive and neutral pictures while the other block presenting highly negative, mildly negative and neutral pictures.

2. Materials and methods

2.1. Subjects

As paid volunteers, 34 students (17males, 17 females) undergraduate students participated in the experiment. All subjects were healthy, right-handed, had normal or corrected to normal vision, and had no history and current symptoms of affective disorder. The experimental procedure was in accordance with the ethical principles of the 1964 Declaration of Helsinki (Organization, World Medical, 1996). All experimental protocol was approved by the ethics committees of Southwest University. All participants signed an informed consent form for the experiment.

2.2. Stimulus materials

The present study included two experimental sessions, with one presenting highly positive (HP), mildly positive (MP) and neutral conditions while the other presenting highly negative (HN), mildly negative (MN) and neutral conditions. Each session consisted of seven blocks of 48 pictures (grouped into three conditions). Affective pictures rather than words were used as pictorial stimulus has greater arousal (Keil, 2006). The pictures were pseudo randomly presented, with the constraint that the pictures of the same condition were not presented consecutively. Each picture was presented twice in the same block, and the two presentations were at least four and at most 30 stimuli apart. Altogether, each emotional condition was made up of 56 pictures, for either presentation. All the pictures were selected from the Chinese Affective Picture System (CAPS). In the positive session, the three sets of pictures differed significantly from one another in both valence [HP = 7.03, MP = 6.22, neutral = 5.01; F (2165) = 487.343, $p < 0.001$] and arousal [HP = 6.35, MP = 5.59, neutral = 4.35; F (2165) = 436.91, $p < 0.001$]. In the negative session, the three sets of pictures differed significantly from one another in both valence [HN = 2.12, MN = 3.46, neutral = 5.53; F (2165) = 962.93, $p < 0.001$] and arousal [HN = 5.52, MN = 4.84, neutral = 4.40; F (2165) = 127.04, $p < 0.001$]. In addition, the luminance level of the pictures was tested and was controlled across the three emotional conditions prior to the experiment. The contrast of the monitor was set to a constant value across subjects.

2.3. Behavioral procedures

In a quiet room, subjects were seated at approximately 150 cm from a computer screen with the horizontal and vertical visual angles below 6°. Subjects were told to perform a continuous recognition task, in which half of the subjects were told to press the “F” key on the keyboard with their left index finger as accurately and quickly as possible if the picture appeared for the first time, and to press the “J” key with their right index finger if the picture appeared for the second time. For the remaining subjects, the assignment of the response hands was reversed. Each subject participated in both experimental sessions, with order of the sessions counterbalanced across subjects. All trials consisted of the following four events: fixation cross with variable duration between 400 and 600 ms, picture for 1000 ms, again a fixation cross for 1000 ms and a blank screen for 1500 ms. Trials with button presses that were given later than 2000 ms after picture onset were discarded. Therefore; each subject was informed that their responses must be made under 1000 ms. Pre-training with 10 practice trials was used before formal experiment in order to familiarize subjects with the procedure, and the pictures used in pre-training were not used in the subsequent experiment.

After the continuous recognition task, subjects were asked to rate the valence and arousal of the pictures using the Self-Assessment Manikin procedure (SAM) (Lang et al., 1997). Using a self-report 9-point rating scale, subjects were required to rate the emotion valence (ranging from 1 = “very negative” to 9 = “very positive”) and arousal (ranging from 1 = “very calm” to 9 = “very excited”) they felt for each image by pressing corresponding number keys in the keyboard. The sequence of the two ratings was counterbalanced across subjects.

2.4. ERP recording and analysis

The 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 (Luck, 2005) (average mastoid reference) and a ground electrode on the medial frontal aspect. Vertical electrooculograms (EOGs) were recorded supra- and infra-orbitally at the left eye. Horizontal EOG was recorded from the left versus right orbital rim. EEG and EOG activity was amplified using a DC ~100 Hz bandpass and continuously sampled at 500 Hz/channel. The EEG was band-pass filtered from 0.01 to100 Hz. All electrode impedances were maintained below 5 kΩ. ERP averages were computed off-line; Trials with EOG artifacts (mean EOG voltage exceeding ±80 μV) and those contaminated with artifacts due to amplifier clipping, or peak-to-peak deflection exceeding ±80 μV were excluded from averaging.

EEG activity in each condition was averaged separately. ERP waveforms were time-locked to the onset of stimuli and the averaging epoch was 1200 ms, including a 200 ms pre-stimulus baseline. The averaged data was smoothed at a cutoff of 24 Hz (24 dB). According to previous literature (Johansson et al., 2004; Schaefer et al., 2009; Schaefer et al., 2011) and visual inspection of the waveforms, mean ERP amplitudes were extracted in two time windows (300–500, 500–800) corresponding to the two old-new effects in different stages: the FN400 and the LPC, respectively. For the statistical analysis of the FN400 and the LPC, we selected PFz, PF1, PF2 (three prefrontal sites), Fz, F3, F4 (three frontal sites), FCz, FC3, FC4 (three frontal-central sites), Cz, C3, C4 (three central sites), CPz, CP3, CP4 (three central-parietal sites), Pz, P3 and P4 (three parietal sites) for statistical analysis. For each time window, a repeated-measures ANOVA was computed including the following factors: stimulus type (two levels: old, new), emotion intensity (three levels: HN, MN and neutral for negative session; HP, MP and neutral for positive session), session (two levels: positive, negative), frontality (six levels: prefrontal, frontal, frontal-central ,central, central-parietal, and parietal) , and laterality (three levels: left, midline and right). The degrees of freedom of the F-ratio were corrected with the Greenhouse-Geisser method. The post hoc pairwise comparisons were conducted using Bonferroni-Holm correction method if a significant main or interaction effect was detected.

3. Results

3.1. Emotion assessment

A repeated measure ANOVA of arousal and valence ratings was conducted with the following factors: emotion intensity (three levels: HN, MN and neutral for the negative session; HP, MP and neutral for the positive session). The results in the positive session showed a significant main effect of emotion intensity in valence rating [F (2, 66) = 162.485, $p < 0.001$]. HP pictures were rated more positive than MP pictures [F (1, 33) = 108.371, $p < 0.001$] which, in turn, were rated positive compared with the Neutral pictures [F (1, 33) = 114.44, $p < 0.001$]. Also, there was a significant main effect of emotion intensity in arousal rating [F (2, 66) = 41.88, $p < 0.001$]. HP pictures were rated more arousing relative to MP pictures [F (1, 33) = 6.793, $p < 0.05$] which, again, were rated more arousing than Neutral stimuli [F (1, 33) = 80.233, $p < 0.001$] (see Fig. 1).

The results in the negative session showed a significant main effect of emotion intensity [F (2, 66 = 147.545, $p < 0.01$] in valence rating. HN pictures were rated more negative than MN pictures [F (1, 33) = 114.561, $p < 0.001$] which, in turn, were rated negative compared with the Neutral pictures [F (1, 33) = 127.895, $p < 0.01$]. Also, there was a significant main effect of emotion intensity [F (2, 66) = 328.303, $p < 0.001$] in arousal rating. HN pictures were rated more arousing relative to MN pictures [F (1, 33) = 350.484, $p < 0.01$] which, again, were rated more arousing than Neutral stimuli [F (1, 33) = 157.313, $p < 0.001$].

These results verified that the pictures used for each condition were valid in eliciting corresponding intensity of the target emotion.

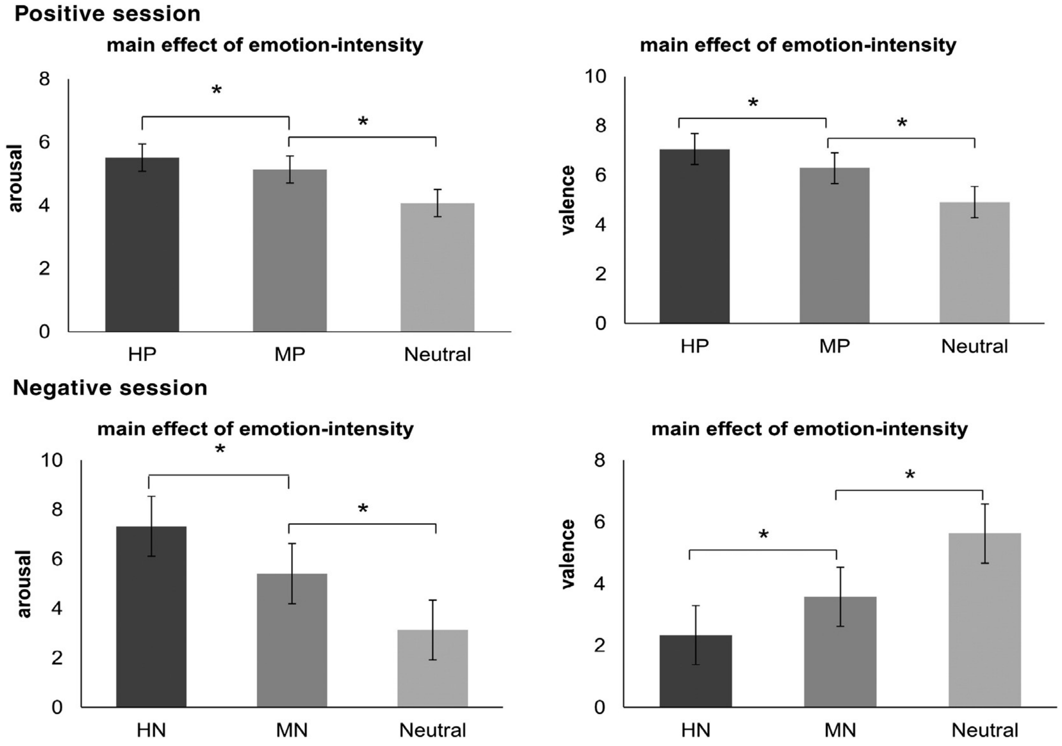

Fig. 1. Schematic illustration of means and standard of valence and arousal assessments given by participants. $^*p < 0.05$.

3.2. Behavioral results

In order to obtain a memory discrimination score, a Pr score [P (hits) − P (false alarms)] (Snodgrass and Corwin, 1988) was calculated. The repeated measures ANOVA on Pr score showed an interaction between session and emotion intensity [$F(2, 66) = 31.457$, $p < 0.001$]. The breakdown of the interaction showed significant main effects in negative [$F(2, 66) = 21.547$, $p < 0.001$] and positive [$F(2, 66) = 20.809$, $p < 0.001$] sessions. The Pr score was larger during HN condition [$F(1,33) = 25.764$, $p < 0.001$] and MN condition [$F(1,33) = 31.452$, $p < 0.001$] than neutral condition, whereas the Pr score was similar during HN and MN conditions[$F(1,33) = 0.024$, $p > 0.05$]. By contrast, in the positive session, The Pr score was larger during HP condition [$F(1,33) = 29.635$, $p < 0.001$] and neutral condition [$F(1,33) = 28.939$, $p < 0.001$] than MP condition, whereas the Pr score was similar during HP and neutral condition[$F(1,33) = 0.442$, $p > 0.05$] (see Table 2).

In order to obtain a response bias, a Br score [P (false alarms)/P(1-Pr)] (Snodgrass and Corwin, 1988) was calculated. The repeated measures ANOVA on Br score showed a main effect of emotion intensity [$F(2, 66) = 31.457$, $p < 0.001$]. Highly emotional stimuli elicited larger Br than mildly emotional [$F(1, 33) = 14.386$, $p < 0.01$] and neutral stimuli [$F(1, 33) = 12.161$, $p < 0.01$], while similar Br were elicited by mildly emotional and neutral stimuli[$F(1,33) = 0.116$, $p = 0.735$] (see Table 2).

The repeated measures ANOVA on RT data showed a significant main effect of stimulus type [$F(2,66) = 4.533$, $p < 0.05$], with RTs to 'old' pictures faster than to 'new' pictures. Moreover, there was a significant interaction effect between session and stimulus type[$F(1, 33) = 7.431$, $p < 0.05$], and between emotion intensity and stimulus type [$F(2, 66) = 71.018$, $p < 0.01$]. In order to facilitate the breakdown of the interaction, we first computed an index of recognition speed = old-new RT cost. The subsequent analysis showed that the recognition speed was faster during negative session than positive session [$F(1, 33) = 7.431$, $p < 0.05$]. Also, the recognition speed was faster during highly emotional than during mildly emotional [$F(1, 33) = 42.455$, $p < 0.01$], which, in turn, was faster than Neutral condition [$F(1, 33) = 15.032$, $p < 0.05$] (see Table 1).

3.3. ERP results

3.3.1. FN400 (300–500 ms)

The repeated measures ANOVA on the averaged amplitudes of the 300–500 ms interval showed a significant main effect of stimulus

Table 1
Mean (standard deviation in brackets) reaction times (RT) for correct responses.

		Old	New	Overall
Negative (n = 34)	HN	646 (63)	679 (62)	663 (59)
	MN	642 (63)	670 (66)	656 (62)
	Neutral	674 (64)	656 (70)	665 (64)
	Overall	654 (64)	668 (66)	666 (62)
Positive (n = 34)	HP	637 (59)	684 (65)	661 (60)
	MP	641 (62)	677 (59)	659 (59)
	Neutral	672 (63)	664 (65)	668 (61)
	Overall	650 (63)	675 (63)	669 (60)

Note. RT are presented in milliseconds.

Table 2
Mean (standard deviation in brackets) hit rate (H), false alarm rate (FA), discrimination index (P_r) and response bias (Br).

		H	FA	P_r	B_r
Negative (n = 34)	HN	0.91 (0.07)	0.07 (0.06)	0.84 (0.10)	0.48 (0.24)
	MN	0.89 (0.09)	0.05 (0.04)	0.84 (0.11)	0.35 (0.23)
	Neutral	0.86 (0.09)	0.06 (0.06)	0.80 (0.10)	0.32 (0.22)
	Overall	0.88 (0.08)	0.06 (0.05)	0.82 (0.10)	0.38 (0.24)
Positive (n = 34)	HP	0.90 (0.06)	0.08 (0.06)	0.82 (0.10)	0.42 (0.23)
	MP	0.83 (0.07)	0.07 (0.05)	0.76 (0.10)	0.26 (0.14)
	Neutral	0.87 (0.06)	0.06 (0.04)	0.81 (0.09)	0.31 (0.15)
	Overall	0.87 (0.07)	0.07 (0.05)	0.80 (0.10)	0.33 (0.19)

Note. A greater discrimination index indicates better recognition accuracy.

type[F (1,33) = 79.9, p < 0.01], and a significant two-way interaction between laterality and stimulus type[F (2,66) = 23.762, p < 0.01] and between frontality and stimulus type[F (5165) = 16.142, p < 0.01]. The old stimuli elicited larger ERP amplitudes than new stimuli, and the old/new difference was largest at middle sites and central-parietal sites. In addition, we observed a significant main effect of emotional intensity [F (2, 66) = 19.163, p < 0.001]. Highly emotional stimuli elicited larger ERP amplitudes than mildly emotional stimuli [F (1, 33) = 18.43, p < 0.01], which elicited larger ERP amplitudes than neutral stimuli [F (1, 33) = 6.143, p < 0.05]. In addition, we observed a significant three-way interaction amongst session, emotional intensity and stimulus type [F (2, 66) = 4.533, p < 0.05]. The breakdown of the three-way interaction showed that the two-way interaction between emotional intensity and stimulus type was significant in negative session [F (2,66) = 3.394, p < 0.05], but not in the positive session [F (2, 66) = 1.857, p = 0.166] (see Figs. 2, 3, 4 and 5). Breaking down the two-way interaction in the negative session showed larger amplitudes for old stimuli compared to new stimuli during Neutral ([F (1, 33) = 14.108, p < 0.01]), MN ([F (1, 33) = 34.923, p < 0.01]) and HN ([F (1, 33) = 40.473, p < 0.01]) conditions. However, the magnitude of the old-new effect, indexed by old-new amplitude differences, was more pronounced during HN [F (1, 33) = 4.295, p < 0.05] and MN [F (1, 33) = 6.195, p < 0.05] condition in comparison with the Neutral condition, while HN and MN conditions showed no significant differences in the old-new effect. In contrast to the negative session, the analysis of results in the positive session showed a similar size of the old-new effect across the three conditions

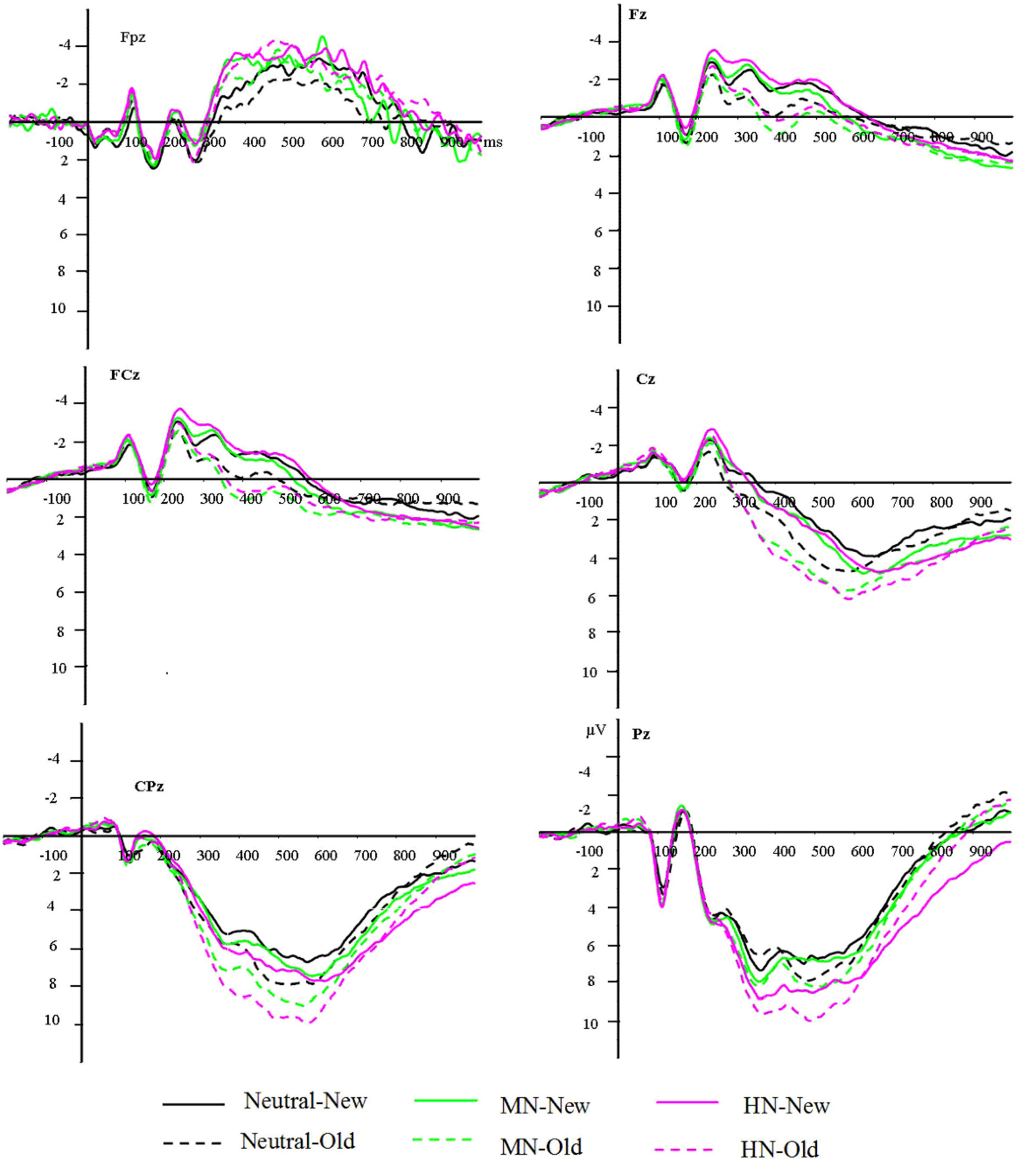

Fig. 2. Grand averaged ERPs for old and new stimuli of each emotion intensity in the negative session at FPz, Fz, FCz, Cz, CPz and Pz electrode sites.

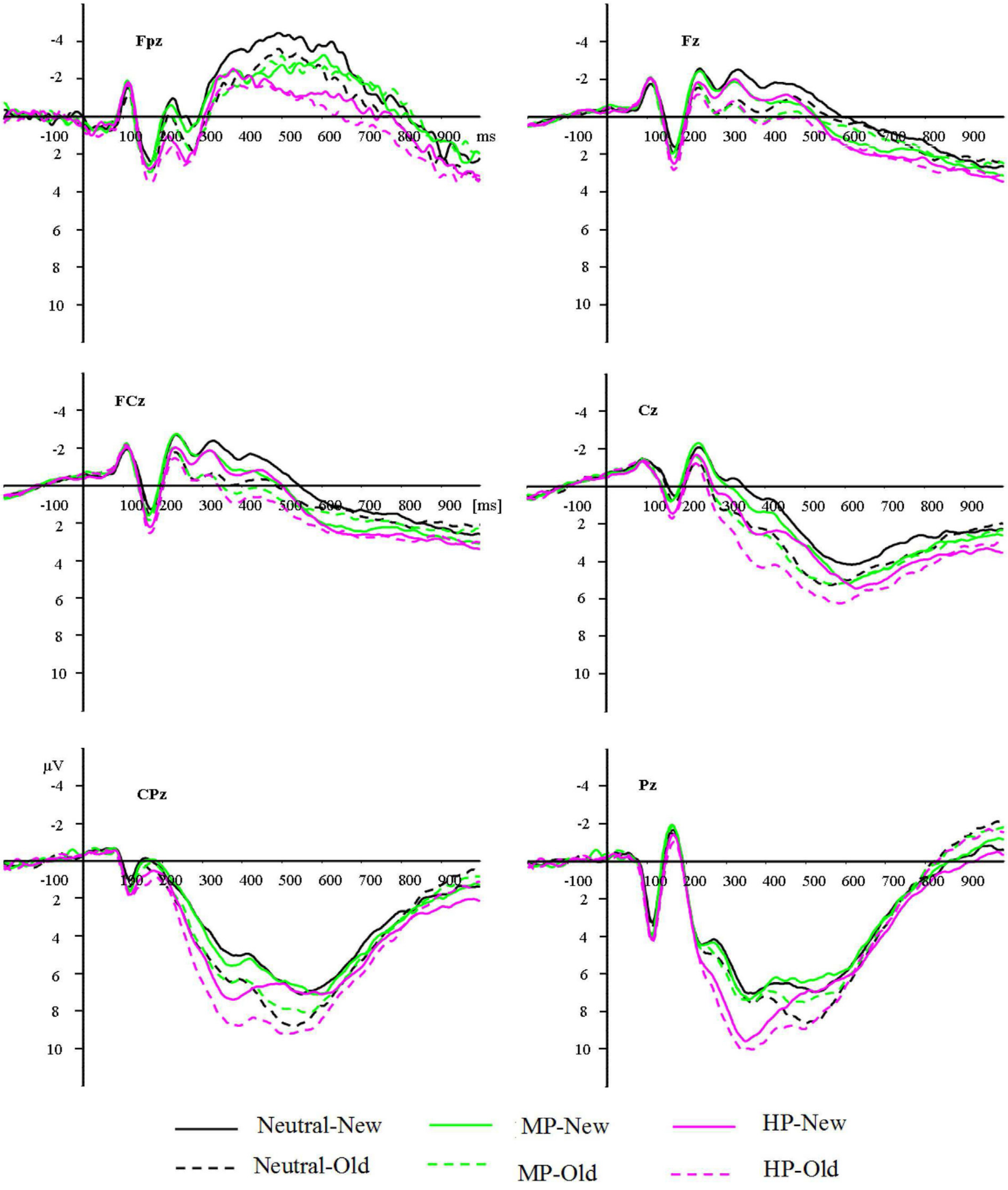

Fig. 3. Grand averaged ERPs for old and new stimuli of each emotion intensity in the positive session at FPz, Fz, FCz, Cz, CPz and Pz electrode sites.

[F (2, 66) = 1.857, p = 0.166] (see Fig. 6). Old stimuli elicited larger amplitudes than new stimuli during Neutral ([F (1, 33) = 41.374, p < 0.01]), MP ([F (1, 33) = 16.636, p < 0.01]) and HP ([F (1, 33) = 34.464, p < 0.01]) conditions.

3.3.2. LPC (500–800 ms)

The repeated measures ANOVA on the averaged amplitudes of the 500–800 ms interval showed main effects of stimulus type [F (1, 33) = 15.048, p < 0.01] and emotional intensity[F (2, 66) = 16.91, p < 0.001]. The old stimuli elicited larger ERP amplitudes than new stimuli. Highly emotional stimuli elicited larger ERP amplitudes than mildly emotional stimuli [F (1, 33) = 17.53, p < 0.01], which elicited larger ERP amplitudes than neutral stimuli [F (1, 33) = 5.413, p < 0.05]. More importantly, we observed a significant three-way interaction amongst session, emotional intensity and stimulus type [F (2, 66) = 4.613, p < 0.05]. The breakdown of the three-way interaction showed that the two-way interaction between emotional intensity and stimulus type was significant in positive session [F (2, 66) = 3.612, p < 0.05], but not in the negative session [F (2,66) = 0.157, p = 0.758]. In the positive session, Old stimuli elicited larger amplitudes than new stimuli during Neutral ([F (1, 33) = 10.594, p < 0.01]) and HP ([F (1, 33) = 14.003, p < 0.01]) conditions, whereas Old and new stimuli elicited similar amplitudes during MP condition ([F (1, 33) = 0.851, p = 0.363]). The further analysis of the old/new effect showed that the old-new effect was significantly

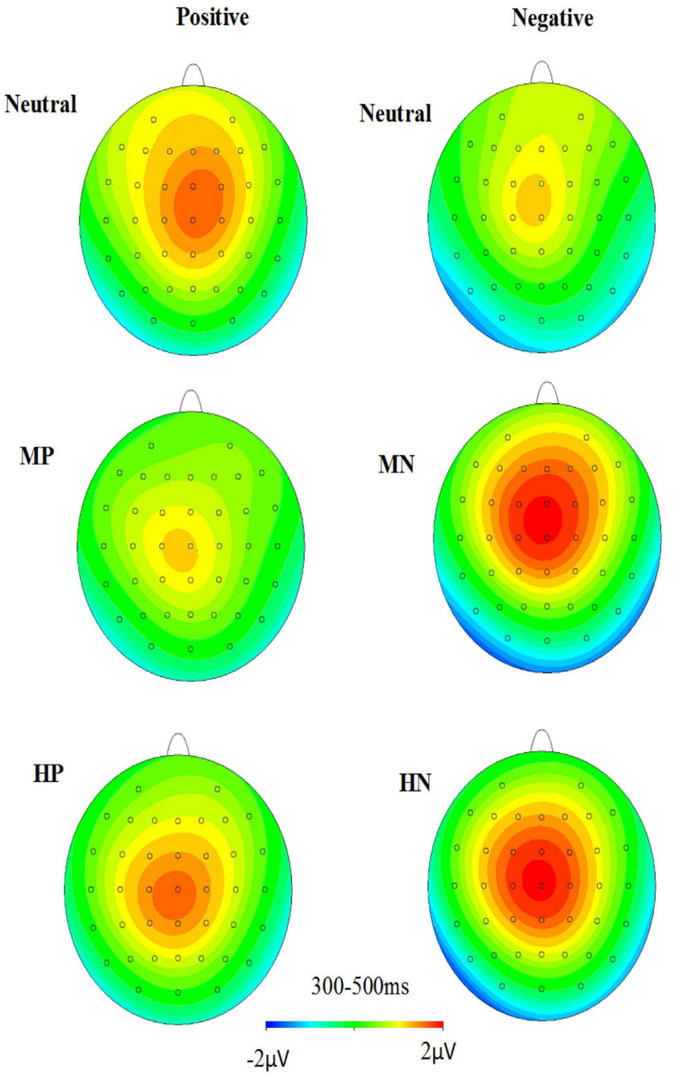

Fig. 4. Scalp distributions of the 300–500 ms old/new effect of each emotion intensity in the negative and positive sessions.

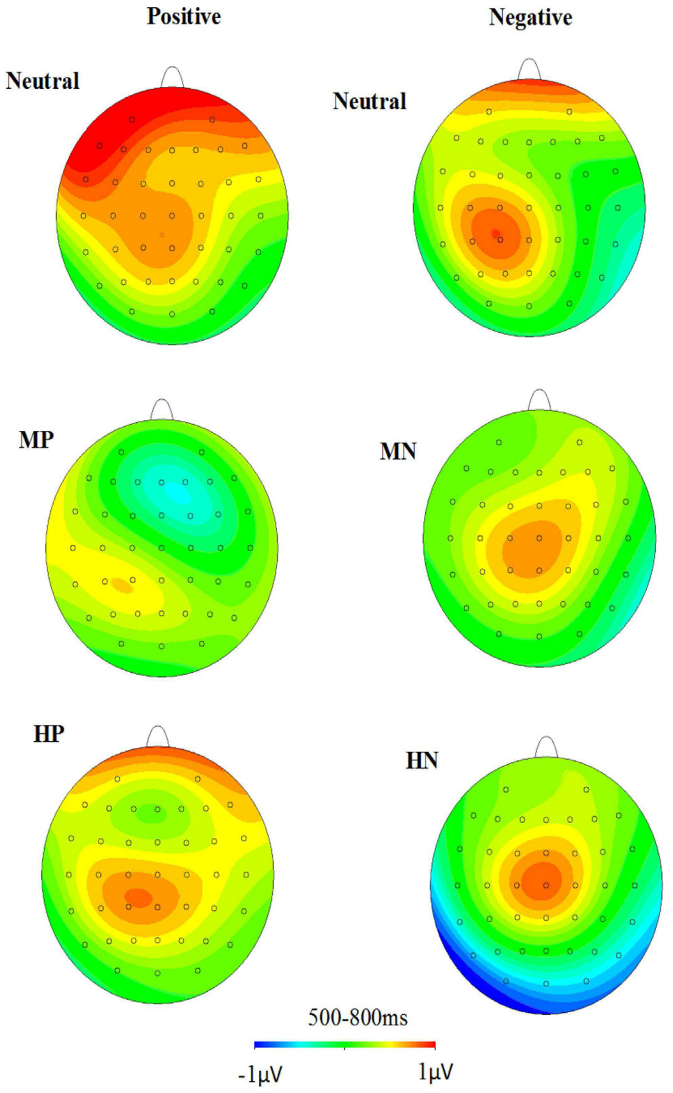

Fig. 5. Scalp distributions of the 500–800 ms old/new effect of each emotion intensity in the negative and positive sessions.

larger during HP condition [F (1,33) = 29.635, $p < 0.001$] and neutral condition [F (1,33) = 28.939, $p < 0.001$] than during the MP condition, whereas old/new effect was similar during HP and neutral condition[F (1,33) = 0.325, $p = 0.573$]. In the negative session, Old stimuli elicited larger amplitudes than new stimuli during Neutral ([F (1, 33) = 6.774, $p < 0.01$]), MN ([F (1, 33) = 6.715, $p < 0.01$]) and HN ([F (1, 33) = 4.772, $p < 0.05$]) conditions, while the old-new effect was not significant across the three conditions.

3.4. The validity of ERP components in reflecting recognition

To test whether the old-new effect obtained from the above-analyzed ERP components is a valid reflection of memory retrieval processing, we performed a correlational analysis. Using the method recommended by Lorch and Myers (1990), we calculated a regression coefficient between the memory discrimination score and the old-new effect in the amplitudes of each component (FN400, or LPC) for every participant. Specifically, we had six ERP values for each component and six memory discrimination measures for every participant, after orthogonally combining all the levels of the emotion intensity and the session factors (3 $*$ 2). In each component, the ERP measure was the participant's mean amplitudes of the old-new difference ERPs in each of the six conditions across 18 selected electrode sites; while the memory discrimination score was the participant's mean hit-false alarm difference during every particular condition. This rendered a regression coefficient for every participant, and we then checked to see whether the standardized beta coefficient was significantly different from zero over all participants (Lorch and Myers, 1990).

The results showed that the regression coefficients for the FN400 [0.20; t (33) = 2.9, $p < 0.05$] and the LPC [0.18; t (33) = 2.236, $p < 0.05$] were all significantly above zero (see Fig. 7). The results indicate a significant positive correlation between memory discrimination score and each of the two ERP components, suggesting that FN400 and LPC most likely represent different stages of recognition processing in the current study.

4. Discussion

Although the emotional intensity effects of negative or positive stimuli on memory-related processing have been investigated separately, it remains unclear whether the influence of emotional intensity on memory varies depending on the stimulus valence(i.e., positive or negative). To clarify this issue, the present study used a continuous recognition task and ERP measures, and manipulated positive and negative stimuli of varying emotional intensity. In the continuous recognition task, ‘new’ and ‘old’ stimuli are intermixed, involving alternated encoding and retrieval. The time interval between encoding and retrieval is

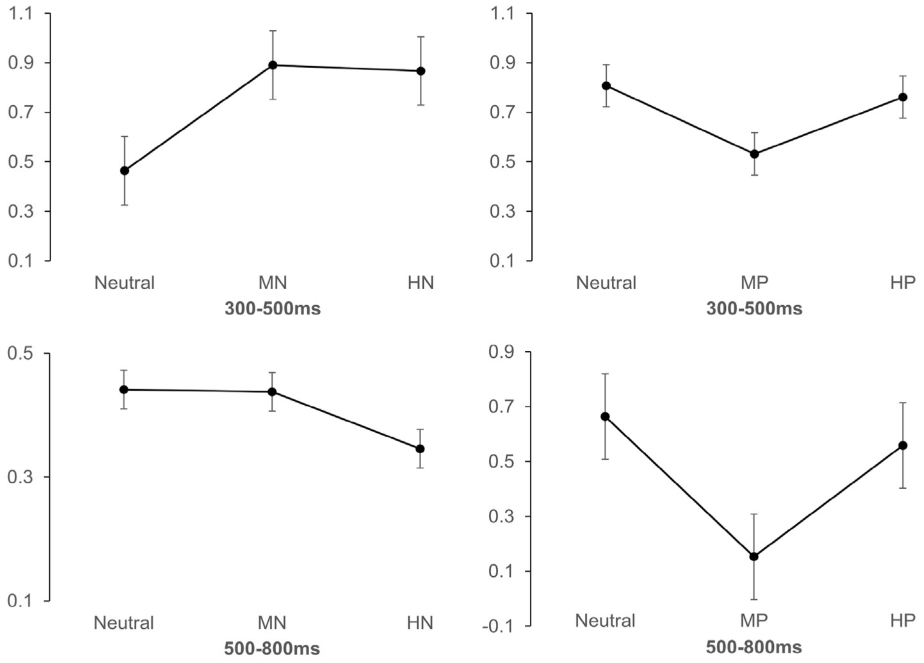

Fig. 6. Means and standard deviants of old-new voltage differences for 300–500 ms (up) and 500–800 ms (bottom) in the negative and positive sessions.

<7 min to control for the contamination of memory attenuation on old/new discrimination and its emotional modulation. We observed that relative to neutral stimuli, both HN and MN stimuli showed increased memory discrimination scores, and enhanced 300–500 ms (but not 500–800 ms) old/new effect in brain potentials. In addition, relative to MP stimuli, HP and neutral stimuli showed increased memory discrimination scores and enhanced 500–800 ms (but not 300–500 ms) old/new effect. The implications of these findings are discussed below.

4.1. The impact of negative emotion on recognition

In the present study, we observe that the retrieval speed was shorter during highly emotional than during mildly emotional, which, in turn, was shorter than Neutral condition. Evidently, the emotion intensity impacts retrieval. Previous studies showed that enhanced metacognitive feelings could increase a sense of vivid and confident (yet probably inaccurate) recollection of the previous encounter and facilitate quick decision (Phelps and Sharot, 2008). It has been hypothesized that the increased retrieval speed for more salient emotional stimuli is due to the enhanced metacognitive feelings triggered by increasing emotional intensities. This hypothesis has been verified by recent empirical evidences (Schaefer et al., 2011), which may explain our finding of faster retrieval speed with enhanced emotion intensity.

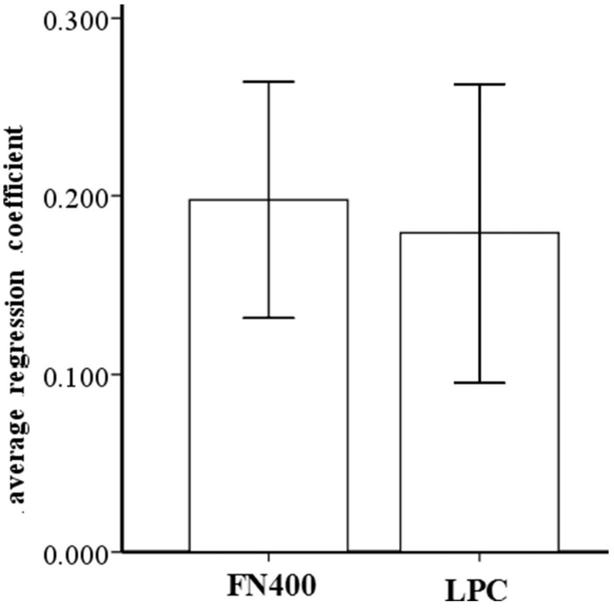

Fig. 7. The average and standard errors of regression coefficient between the memory discrimination score and the old-new effect in the amplitudes of each component.

The early (300–500 ms) frontal old/new difference (300–500 ms) has been accepted to reflect recognition based on automatic match (Rugg, 1995). These results were supported by our correlation analysis showing a role of the 300–500 ms old/new effects in predicting behavioral performance of Pr. Relative to Neutral condition, both HN and MN conditions showed enhanced old/new effect and increased Pr score. These findings are consistent with previous studies suggesting that due to biological significance, both highly and mildly negative scenes may activate defensive motivational reaction rapidly (Yuan et al., 2007), and evoke narrower, more focused attentional scope (Fenske and Eastwood, 2003; Rowe et al., 2007), which may increase the likelihood that both highly and mildly negative visual features will later be easily encoded and recognized (Clark-Foos and Marsh, 2008).

At the 500–800 ms interval, a significant main effect of old/new was observed. Irrespective of emotion intensity of negative stimuli, larger amplitudes were elicited during old stimuli than new stimuli, suggesting that old stimuli elicited enhanced controlled processing relative to new stimuli. The 500–800 ms old/new effect has been accepted as to index recollection (Van Strien et al., 2005). These results were supported by our correlation analysis showing a role of the 500–800 ms old/new effects in predicting behavioral performance of Pr. In contrast with FN400, the LPC old/new effect did not change with the emotional intensity of negative stimuli. This finding is likely due to our experimental paradigm. There is evidence showing that negative stimulus is able to activate defensive motivation rapidly, irrespective of emotion intensity (Sprengelmeyer and Jentzsch, 2006; Yuan et al., 2007). In addition, negative emotion evokes narrower, more focused attentional scope compared to neutral or positive emotions (Chipchase and Chapman, 2012; Fenske and Eastwood, 2003; Rowe et al., 2007). These evidences suggest that the early encoding of visual features may be facilitated by the emotional negativity, regardless of intensity. The current study just required subjects to conduct old/new classification, instead of doing know/remember classification. Thus, subjects may have done old/new classification just based on the early automatic matching, instead of being based on the late controlled recollection (remembering with specific contextual details). Thus, the present study observed that the impact of negative emotion on recognition occur at 300–500 ms old/new effect, instead of 500–800 ms old/new effect.

In addition, notably, relative to Neutral condition, both HN and MN conditions showed increased memory discrimination score. This is inconsistent with previous finding of a nonlinear, inverted U-shaped relationship between the memory discrimination score with the emotional intensity of emotional stimuli. This inconsistent finding between the current study and Schaefer et al. (2011) study could be explained by Yerkes-Dodson law (Broadhurst, 1957), suggesting that the impact of emotion intensity of negative emotion on cognitive activities is modulated by task difficulty. In a relatively easy task condition, the relationship between the emotion intensity of negative emotion and task performance is linear. In a more difficult task condition, the emotion intensity of negative emotion and task performance violates linearity. It is worth noting that the memory discrimination score was <0.5 for all emotional categories when the conventional study-test task was used (Schaefer et al., 2011), while the memory discrimination score is >0.75 for all emotional stimuli when an easy, less demanding continuous recognition task was used in the current study. Thus, the easy task nature most likely accounts for the increased accurate recognition of negative stimuli with the emotion intensity. Future studies need to directly explore the impact of task difficulty on recognition of negative stimuli of varying intensities.

4.2. The impact of positive emotion on recognition

In contrast with that of negative stimuli, the 300–500 ms old/new effect elicited by positive stimuli did not change with the emotional intensity. This is probably because pleasant stimuli are less biologically significant, such that the retrieval of positive stimuli is associated with more of controlled processes. In contrast with the 300–500 ms old/new effect, the 500–800 ms old/new effect was larger during HP condition and neutral condition than MP condition, whereas the old/new effect was similar during HP and neutral conditions. These results suggest that the recognition was worse for MP stimuli than Neutral and HP stimuli. This argument is supported by behavioral result of that the Pr score was larger during HP condition and neutral condition than MP condition, whereas the Pr score was similar during HP and neutral condition. It has been consistently reported that moderate level of positive stimuli broadens attentional breadth and impairs focused attention (Gable and Harmon-Jones, 2010a; Rowe et al., 2007), such that mildly positive stimuli are likely to be memorized worse relative to neutral stimuli. By contrast, highly positive stimulus activates strong appetitive motivation, which narrows attention focus (Gable and Harmon-Jones, 2010a; Gable and Harmon-Jones, 2010b), and may not necessarily lead to positive affective state (Mauss et al., 2011). This most likely explains why HP stimuli did not elicit memory impairment effect. These findings are consistent with the reward saliency hypothesis suggesting that highest and lowest value items are remembered best and mildly positive items are remembered worst (Madan and Spetch, 2012). This may be associated with the anchoring effect. The anchoring effect is driven by memory for the ends of the stimulus continuum (Eriksen and Hake, 1957; Petrov and Anderson, 2005; Weber and Johnson, 2006; Madan and Spetch, 2012). Anchoring effects could also play an important role in memory of positive stimuli of diverse emotional intensity during positive session.

Notably, the present findings are likely to be dependent on the experimental paradigm. It has been reported that emotional processes are complex, and experimental paradigm has important influences on outcome variables (Olofsson et al., 2008). The present study used a block design to control for the potential contamination of stimuli of one valence (e.g. positive) on the intensity effect of the other valence (e.g. negative). However, presenting all emotional stimuli of the same valence polarity in one block might produce emotional habituation. Thus, despite insights into the neural mechanisms underlying the impact of emotion intensity on recognition memory, the present results are likely to be specific to the block design.

In conclusion, as the emotional intensity of positive and negative stimuli has different motivational relevance and distinct impact on attention scope, we observed that the influence of emotional intensity on memory varies depending on whether stimuli are of positive or negative valence. Specially, we observed that relative to neutral stimuli, both HN and MN stimuli showed increased memory discrimination score, and enhanced 300–500 ms old/new effect that has been related to recognition based on automatic familiarity. By contrast, we observed that relative to neutral stimuli, HP and neutral stimuli showed increased memory discrimination score and enhanced 500–800 ms old/new effect that has been associated with controlled recollection. This suggests that both HN and MN stimuli were remembered better than neutral stimuli, and this phenomenon is associated with automatic processes; whereas the recognition was worse for MP stimuli than Neutral and HP stimuli, and this phenomenon is associated with controlled processing.

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