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## Engrams for Encoding, Retention, and Retrieval of Disgust and Fear Faces

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### Abstract

The emotional memory enhancement effect is well-established in research on negative emotional memory. Although disgust and fear are both negative emotions signaling threat, their distinct evolutionary significance and physiological functions may lead to different modulatory directions or intensities across the three stages of memory encoding, retention, and retrieval. The present study employed a delayed recognition task and event-related potentials to investigate memory encoding, retention, and retrieval of fear and disgust faces matched in arousal and valence in healthy adult participants. The results showed that: 1) During the early stage of memory encoding, participants showed enhanced attention to fear faces (P1) and structural encoding (N170), while processing of disgust information was suppressed; 2) From the late encoding stage through the entire retention phase, participants' elaborative evaluation of disgust information (P3 in the encoding stage) and rehearsal/maintenance (negative-going slow wave in the retention stage) were both stronger than those for fear information; 3) Relative to fear faces, disgust faces may form stronger representations in the working memory system, allowing participants to retrieve more details and exhibit greater confidence in memory retrieval (P3 in the retrieval stage). These latter two findings explain why disgust-related memory outperforms fear-related memory at the behavioral level. This study provides high-temporal-resolution neural evidence supporting the notion that "disgust has a stronger memory enhancement effect than fear," thereby further elucidating the cognitive mechanisms of negative emotion-enhanced memory.

### Full Text

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### Memory Encoding, Retention and Retrieval of Disgusting and Fearful Faces

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## Abstract

The emotional memory enhancement effect has been repeatedly confirmed in studies of negative emotional memory. Although disgust and fear both belong to negative emotions that signal the presence of threat, their different evolutionary significance and physiological functions may lead to different modulatory directions or intensities across the three memory stages of encoding, retention, and retrieval. The present study employed a delayed recognition task and event-related potentials (ERP) to examine memory encoding, retention, and retrieval of fearful and disgusting faces with matched arousal and valence in healthy adult participants. The results showed that: (1) During the early stage of memory encoding, participants enhanced attention (P1) and structural encoding (N170) for fearful faces, while processing of disgusting information was suppressed; (2) From the late encoding stage through the entire retention stage, participants' elaborate evaluation of disgusting information (P3 during encoding) and rehearsal maintenance (negative-going slow wave during retention) were both stronger than for fearful information; (3) Compared to fearful faces, disgusting faces may have formed stronger representations in the working memory system, enabling participants to recall more details during memory retrieval with greater confidence (P3 during retrieval). These latter two findings account for the superior behavioral memory performance for disgusting compared to fearful emotions. This study provides high temporal resolution neural evidence for the notion that "disgust has a stronger memory enhancement effect than fear," thereby further revealing the cognitive mechanisms underlying negative emotional memory enhancement.

**Keywords:** short-term memory; encoding; memory retention; memory retrieval; negative emotion; disgust

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## Introduction

Numerous studies have found that fearful/angry emotional information and disgusting emotional information have opposite effects on attentional modulation,

with the former attracting attention and the latter inhibiting it (Bertels, Kolin-sky, Coucke, & Morais, 2013; Cisler & Olatunji, 2010; Krusemark & Li, 2013; Liu, Zhang, & Luo, 2015; You & Li, 2016; Zhang, Liu, Wang, Ai, & Luo, 2017; Zimmer, Keppel, Poglitsch, & Ischebeck, 2015). Memory comprises three main stages: encoding, retention (consolidation), and retrieval. Generally, emotional information enhances memory at each of these stages (LaBar & Cabeza, 2006): during encoding, attention is automatically directed toward stimuli or events with significant emotional meaning (Schupp et al., 2007); after emotional information is encoded, the brain engages in more rehearsal and elaborative processing compared to neutral information (Sharot & Phelps, 2004), as well as more accurate retrieval (Buchanan, 2007).

The emotional memory enhancement effect has been repeatedly confirmed in studies of negative emotional memory (Kensinger, 2007). However, can different types of negative emotions enhance memory at all three stages? If so, do they differ in the strength of their memory enhancement effects across stages? This question was inspired by existing attention research, as numerous studies have found that fearful/angry emotional information and disgusting emotional information have opposite effects on attentional modulation, with the former attracting attention and the latter inhibiting it. Since different types of negative emotions can have different effects on attention, they may also have different effects on memory.

To address this question, three studies have reported behavioral results. First, Charash and McKay (2002) observed that after a Stroop task, participants' recall accuracy for disgusting words was higher than for fearful and neutral words. Then, Croucher et al. (2011) found that people's memory performance for disgusting emotional pictures was significantly better than for fearful and neutral pictures. Next, Chapman et al. (2013) still found that disgusting emotional pictures had a significant memory enhancement effect (compared to fearful and neutral pictures) after controlling for factors such as attention intensity during the memory encoding stage and picture arousal. In addition to these three behavioral studies, Marchewka et al. (2016) recently used a directed forgetting paradigm and found that although disgusting, fearful, and sad pictures all produced comparable memory enhancement effects in old/new recognition tests, regression analysis showed that the more significant memory enhancement for disgust was attributed to the disgusting emotion itself rather than the arousal and valence of the emotional pictures. At the same time, correctly recognized disgusting pictures more strongly activated the left amygdala than correctly recognized fearful and sad pictures. These studies all suggest that as a basic emotion type, disgust has a different neural mechanism of memory enhancement from other negative emotions such as fear. It should be noted that among these four studies, only Chapman et al. (2013) matched the valence and arousal of different types of negative emotional materials. Since both arousal and valence of emotional materials have significant effects on memory (LaBar, 2007), we believe that only when these two variables are matched across emotional material conditions can the effects of different emotion types on memory be properly

investigated.

The present study used a delayed recognition task (Langeslag, Morgan, Jackson, Linden, & Van Strien, 2009; Morgan, Klein, Boehm, Shapiro, & Linden, 2008) to examine the memory performance of healthy adult participants for fearful and disgusting faces with matched arousal and valence. This paradigm can effectively separate the three stages of memory encoding, retention, and retrieval, allowing us to investigate the effects of negative emotions on each memory stage separately. Based on the above four studies, we expected that participants' memory performance for disgusting faces would be better than for fearful faces. Unlike the previous four studies, the present experiment simultaneously recorded event-related potentials (ERP) during the encoding, retention, and retrieval stages of memory, allowing us to determine at which specific memory stage and which cognitive component within each stage disgusting and fearful faces elicited stronger (or weaker) brain activity compared to neutral faces. Therefore, this study can provide high temporal resolution neural evidence for negative emotional memory enhancement effects, revealing how different negative emotions influence memory at each stage.

In addition to emotion type, this study also examined the variable of "memory load" (Morgan et al., 2008), because the effect of emotion on memory may differ under different memory loads (Gibbons, Seib-Pfeifer, Koppehele-Gossel, & Schnuerch, 2018; Guhn et al., 2015; Patel et al., 2016).

Referring to existing ERP literature on memory and emotional processing, the ERP components examined in this study include: occipital P1, temporo-occipital N170, and parietal P3 during both memory encoding and retrieval, and the negative-going slow wave (NSW) during memory retention. The occipital P1 is a well-established marker of "early attention" (Hillyard & Anllo-Vento, 1998) that is modulated by emotional information (Schupp et al., 2007; Zhang, Luo, & Luo, 2013; Zhang et al., 2014). N170 is a classic component reflecting facial structural encoding (Eimer, 2000) that is also modulated by facial emotion (Zhang et al., 2013). The parietal P3 (i.e., P3b) is generally considered to reflect top-down allocation of cognitive resources (Zhang et al., 2014). Emotional (particularly negative) stimuli elicit larger P3 than neutral stimuli (Olofsson, Nordin, Sequeira, & Polich, 2008). The P3 component has also been confirmed by many studies to be closely related to memory, with successfully recalled items eliciting larger P3 than failed recall items during both encoding and retrieval stages (Rugg et al., 1998). The frontal NSW reflects the brain's maintenance and rehearsal of information, a component that spans the entire memory retention stage (Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992; Wang et al., 2016).

Previous studies have found that during the memory encoding stage, negative materials elicit larger P3 amplitudes than neutral materials (Hauswald, Schulz, Iordanov, & Kissler, 2011; Xie, Jiang, & Zhang, 2018; Yang et al., 2012), suggesting that people allocate more cognitive resources to negative materials for deeper elaborative processing. Meanwhile, during the memory retrieval stage,

negative materials elicit significantly larger P1 and P3 amplitudes than neutral materials (Xie et al., 2018; Zhang, Xie, Liu, & Luo, 2016); at this stage, N170 amplitude is also modulated by stimuli of different valences (Galli, Feurra, & Viggiano, 2006). Additionally, in spatial working memory, negative emotion causes a more pronounced negative shift in frontal NSW compared to neutral conditions (Li, Chan, & Luo, 2010). Regarding the memory load variable, Morgan et al. (2008) and Langeslag et al. (2009) found that P3 amplitudes during encoding and retrieval and N170 amplitude during retrieval all decreased with increasing memory load; N170 amplitude during encoding increased with memory load; while P1 amplitude was not affected by memory load. Additionally, Ruchkin et al. (1992) found in verbal working memory studies that frontal NSW amplitude increased with working memory load.

This study will refer to the above ERP knowledge from emotional memory research to examine differences in ERP components across the dimensions of emotion and memory load during the encoding, retention, and retrieval of fearful, disgusting, and neutral faces. We expected that as memory load increased, P3 amplitude during encoding and retrieval and N170 amplitude during retrieval would decrease, while N170 amplitude during encoding and NSW amplitude during retention would increase, and that emotion effects would be more pronounced under high memory load. Since there have been no ERP reports on disgusting emotional memory, this study does not make specific predictions regarding the main effects of emotion on each ERP component.

## 2. Methods

### 2.1 Participants

A total of 60 healthy adult participants took part in the behavioral experiment (aged 21-27 years, 30 males), among whom ERP data were collected from 30 participants (15 male). All participants were right-handed with normal or corrected-to-normal vision. Before the experiment, all were informed of the research purpose, experimental content, and precautions, and signed informed consent forms. The experimental protocol was approved by the Ethics Committee of Shenzhen University.

### 2.2 Materials

Face pictures (60 total, half male actors and half female actors) were selected from the Chinese Facial Affective Picture System (Gong, Huang, Wang, & Luo, 2011). Among these, there were 20 fearful, 20 disgusting, and 20 neutral pictures. The picture database provided 9-point ratings for valence and arousal, showing that fearful ( $2.69 \pm 0.36$ ,  $p < 0.001$ ) and disgusting face pictures ( $2.77 \pm 0.37$ ,  $p < 0.001$ ) had significantly lower valence than neutral face pictures (neutral =  $4.40 \pm 0.48$ ;  $F(2,57) = 114$ ;  $p < 0.001$ ;  $2 p = 0.800$ ); fearful ( $6.82 \pm 0.93$ ,  $p < 0.001$ ) and disgusting face pictures ( $6.47 \pm 0.77$ ,  $p < 0.001$ ) had significantly higher arousal than neutral face pictures (neutral =  $3.83 \pm 0.57$ ;  $F(2,57) = 89.0$ ;

$p < 0.001$ ;  $2 p = 0.757$ ); there were no significant differences in valence and arousal between fearful and disgusting face pictures.

Additionally, 60 neutral face pictures were selected from the picture database (half male actors and half female actors). Each picture was cut into a  $6 \times 7$  rectangle, scrambled, and made into a mosaic picture.

All materials were presented on a black background with identical contrast and brightness. Face pictures subtended a visual angle of  $2.4^\circ \times 2.8^\circ$ .

### 2.3 Procedure

This study examined two variables: “emotion” (fear, disgust, neutral) and “memory load” (low load  $n = 1$ , high load  $n = 3$ ), resulting in a  $3 \times 2$  within-subjects design. In each of the six conditions, 64 experimental trials were set up. The “emotion” variable was designed in blocks, with three blocks corresponding to the three emotion types; block order was counterbalanced across participants.

The presentation time of stimulus materials referred to two relevant ERP studies (Morgan et al., 2008; Langeslag et al., 2009). As shown in [Figure 1: see original paper], each trial presented 1 or 3 face pictures (50% probability each) and 3 or 1 mosaic pictures in the four quadrants centered on the central fixation point. Face and mosaic pictures were randomly selected from the 20 face and mosaic pictures in each block by the program. In the low memory load condition ( $n = 1$ ), the probability of 1 face picture appearing in one of the four quadrants was 25%; in the high memory load condition ( $n = 3$ ), the probability of 1 mosaic picture appearing in one of the four quadrants was 25%. Memory encoding time was 2 seconds, and memory retention time was 1 second. Subsequently, in the memory retrieval stage, a new face (not presented in the encoding stage of this trial) or an old face (presented in the encoding stage of this trial) was presented for 500 ms (50% probability each for new and old faces). Participants were instructed to fixate on the center of the screen throughout the experiment and during the memory retrieval stage to judge as quickly and accurately as possible whether the face picture had appeared in the encoding stage of this trial, using both index fingers to press keys on the computer keyboard, with “yes” and “no” corresponding to the F and J keys (the meaning corresponding to F and J was counterbalanced across participants).

### 2.4 Data Acquisition and Analysis

EEG and EOG data were collected using a 64-channel brain amplifier (Brain Products, Gilching, Germany), with electrode impedance below  $5 \text{ k}\Omega$ . The reference electrode was placed on the left mastoid, and offline re-referencing was performed using the average of all electrodes. Horizontal and vertical eye movements in the EEG were removed using the regression procedure built into Scan 4.3 (NeuroScan Inc., Herndon, USA). Data analysis was performed using Matlab R2011a (MathWorks, Natick, USA).

EEG data were processed sequentially as follows: filtering (0.01-30 Hz, zero-phase delay), segmentation, baseline correction (-200~0 ms), and averaging (only trials with correct behavioral responses were selected for averaging).

This article analyzed ERP components corresponding to three stages: encoding (P1/N170/P3), retention (NSW), and retrieval (P1/N170/P3). For P1 and N170, since this study did not find significant differences between the left and right hemispheres, data from both hemispheres were combined. Therefore, the occipital P1 waveform reported below represents the mean of the following electrode sites: O1, O2, PO3, PO4. Similarly, the N170 waveform represents the mean of the following electrode sites: PO7, PO8, P7, P8. The P3 waveform represents the mean of electrode sites: P1, Pz, P2, CP1, CPz, CP2. The NSW waveform represents the mean of electrode sites: F1, Fz, F2, FC1, FCz, FC2.

## 2.5 Statistical Analysis

The onset of the encoding and retrieval stages of memory was used as the zero time point for ERP segmentation, meaning that two ERP waveforms were extracted for analysis in each trial. We performed statistical analysis on the average amplitude of ERP components within a certain time window. Time window selection followed the principle that the midpoint was the peak latency of the ERP component, with wider time windows used for early sharp ERP components. Based on the average waveforms of each component, the time window for the P1 component was 100-140 ms post-stimulus (encoding stage) or 120-160 ms (retrieval stage). The N170 time window was 160-200 ms (encoding stage) or 170-210 ms (retrieval stage). The P3 component was 300-600 ms (encoding stage) or 300-700 ms (retrieval stage). NSW was 800-3000 ms. When measuring P1, N170, and P3 components, slightly different time windows were used for the encoding and retrieval stages because ERP component latencies were longer during the retrieval stage.

It should be noted that this study did not examine the “old/new effect” (Finnigan, Humphreys, Dennis, & Geffen, 2002; Rugg & Curran, 2007), meaning that ERP analysis during the retrieval stage combined “new face” and “old face” conditions. The main reason was that the variables of interest in this study were “emotion” and “memory load”; if the old/new effect were added, there would be insufficient ERP trials per condition (approximately 30% of participants would have fewer than 20 trials).

This study used signal detection theory indices  $d'$  and  $c$  to measure participants' response sensitivity and bias. Where  $d' = (\text{hit rate z-score} - \text{false alarm rate z-score})/1.414$ ;  $c = -0.5 \times (\text{hit rate z-score} + \text{false alarm rate z-score})$ .

Statistical analysis was performed using SPSS Statistics 20.0 (IBM, Somers, USA). Descriptive statistics are presented as “mean  $\pm$  standard deviation.” Two-way repeated measures ANOVA (Greenhouse-Geisser correction) was conducted on behavioral and ERP dependent variables, with within-subject factors of facial emotion type and memory load. The significance level was  $p < 0.05$ . Multiple

comparisons used Bonferroni correction.

### 3. Results

#### 3.1 Behavioral Results

For the reaction time measure (Figure 2 [Figure 2: see original paper]A), the main effect of emotion was significant ( $F(2,118) = 4.10$ ,  $p = 0.019$ ,  $\eta^2 p = 0.065$ ), with memory retrieval reaction times for disgusting faces ( $658 \pm 160$  ms) and fearful faces ( $659 \pm 141$  ms,  $p = 0.002$ ) being shorter than for neutral faces ( $679 \pm 152$  ms).

The main effect of memory load was significant ( $F(1,59) = 279$ ,  $p < 0.001$ ,  $\eta^2 p = 0.825$ ), with high memory load showing longer reaction times ( $737 \pm 149$  ms) than low memory load ( $593 \pm 115$  ms).

For the  $d'$  index, the main effect of emotion was significant ( $F(2,118) = 13.8$ ,  $p < 0.001$ ,  $\eta^2 p = 0.190$ ), with memory retrieval performance for disgusting faces ( $0.794 \pm 0.166$ ) being better than for fearful faces ( $0.768 \pm 0.191$ ,  $p = 0.027$ ) and neutral faces ( $0.743 \pm 0.197$ ,  $p < 0.001$ ), and fearful faces showing better performance than neutral faces ( $p = 0.049$ ). The main effect of memory load was significant ( $F(1,59) = 862$ ,  $p < 0.001$ ,  $\eta^2 p = 0.936$ ), with high memory load conditions ( $0.613 \pm 0.122$ ) showing lower  $d'$  than low memory load conditions ( $0.924 \pm 0.077$ ).

The interaction between emotion and memory load was significant ( $F(2,118) = 5.80$ ,  $p = 0.005$ ,  $\eta^2 p = 0.089$ ). Simple effects analysis showed that the emotion effect was more pronounced under high memory load ( $F(2,118) = 13.8$ ,  $p < 0.001$ ; neutral =  $0.574 \pm 0.121$ , fear =  $0.610 \pm 0.125$ , disgust =  $0.654 \pm 0.107$ ; disgust > fear,  $p = 0.027$ ; disgust > neutral,  $p < 0.001$ ; fear > neutral,  $p = 0.067$ ) than under low memory load ( $F(2,118) = 2.78$ ,  $p = 0.066$ ; neutral =  $0.911 \pm 0.077$ , fear =  $0.926 \pm 0.087$ , disgust =  $0.934 \pm 0.063$ ; disgust > neutral,  $p = 0.040$ ; Figure 2B).

For the  $c$  index, no significant main effects or interactions were found ( $F < 1$ ;  $c = -0.015 \pm 0.490$ ; Figure 2C).

#### 3.2 ERP Results

**3.2.1 Memory Encoding Stage** For the occipital P1 component, the main effect of emotion was significant ( $F(2,58) = 12.7$ ,  $p = 0.001$ ,  $\eta^2 p = 0.305$ ), with fearful faces ( $4.98 \pm 2.56$  V) eliciting larger P1 amplitudes than neutral ( $4.51 \pm 2.23$  V,  $p = 0.007$ ) and disgusting faces ( $3.76 \pm 3.03$  V,  $p < 0.001$ ). Additionally, disgusting faces elicited slightly smaller P1 amplitudes than neutral faces, but this difference was not significant ( $p = 0.083$ ). The interaction between emotion and memory load was significant ( $F(2,58) = 14.0$ ,  $p < 0.001$ ,  $\eta^2 p = 0.326$ ; Figure 3 [Figure 3: see original paper]A): the emotion effect was significant under high memory load ( $F(2,58) = 22.8$ ,  $p < 0.001$ ; neutral =  $4.50 \pm 2.22$  V, fear =  $5.48$

$\pm 2.24$  V, disgust =  $3.29 \pm 3.10$  V; disgust < neutral < fear,  $p$ s < 0.01), but not under low memory load ( $F(2,58) < 1$ ; neutral =  $4.52 \pm 2.28$  V, fear =  $4.49 \pm 2.79$  V, disgust =  $4.22 \pm 2.94$  V).

For the temporo-occipital N170 component, the main effect of emotion was significant ( $F(2,58) = 6.80$ ,  $p = 0.002$ ,  $\eta^2 p = 0.190$ ), with fearful faces ( $-7.64 \pm 4.58$  V) eliciting larger N170 amplitudes than neutral ( $-6.91 \pm 4.33$  V,  $p = 0.014$ ) and disgusting faces ( $-6.64 \pm 4.15$  V,  $p = 0.003$ ). The main effect of memory load was significant ( $F(1,29) = 37.7$ ,  $p < 0.001$ ,  $\eta^2 p = 0.565$ ), with high memory load ( $-7.66 \pm 4.36$  V) eliciting larger N170 amplitudes than low memory load ( $-6.47 \pm 4.28$  V). The interaction between emotion and memory load was significant ( $F(2,58) = 12.3$ ,  $p < 0.001$ ,  $\eta^2 p = 0.297$ ; Figure 3B). The emotion effect was significant under high memory load ( $F(2,58) = 28.6$ ,  $p < 0.001$ ): fearful faces ( $-8.77 \pm 4.35$  V) elicited larger N170 amplitudes than neutral ( $-7.44 \pm 4.33$  V,  $p < 0.001$ ) and disgusting faces ( $-6.76 \pm 4.32$  V,  $p < 0.001$ ). However, under low memory load the emotion effect was not significant ( $F(2,58) < 1$ ; neutral =  $-6.38 \pm 4.33$  V, fear =  $-6.51 \pm 4.60$  V, disgust =  $-6.53 \pm 4.04$  V).

For the parietal P3 component, the main effect of emotion was significant ( $F(2,58) = 12.4$ ,  $p < 0.001$ ,  $\eta^2 p = 0.299$ ), with disgusting faces ( $6.11 \pm 3.07$  V) eliciting larger P3 amplitudes than neutral ( $5.08 \pm 2.46$  V,  $p < 0.001$ ) and fearful faces ( $5.02 \pm 2.68$  V,  $p = 0.002$ ). The main effect of memory load was significant ( $F(1,29) = 15.7$ ,  $p < 0.001$ ,  $\eta^2 p = 0.351$ ), with high memory load ( $5.07 \pm 2.75$  V) eliciting smaller P3 amplitudes than low memory load ( $5.73 \pm 2.79$  V). The interaction between emotion and memory load was significant ( $F(2,58) = 6.20$ ,  $p = 0.004$ ,  $\eta^2 p = 0.176$ ; Figure 3C). The emotion effect was significant under high memory load ( $F(2,58) = 13.7$ ,  $p < 0.001$ ): disgusting faces ( $6.14 \pm 3.04$  V) elicited larger P3 amplitudes than neutral ( $4.51 \pm 2.51$  V,  $p = 0.001$ ) and fearful faces ( $4.56 \pm 2.42$  V,  $p = 0.001$ ). However, under low memory load the emotion effect was not significant ( $F(2,58) = 3.11$ ,  $p = 0.052$ ; neutral =  $5.64 \pm 2.33$  V, fear =  $5.48 \pm 2.89$  V, disgust =  $6.08 \pm 3.14$  V).

**3.2.2 Memory Retention Stage** The ERP in this stage was time-locked to the onset of the four pictures in the encoding stage. Note: A clear “offset response” can be seen in the ERP waveform after 2000 ms, that is, electrical activity evoked by the disappearance of visual stimuli. Since this offset response did not affect the potential change trend of NSW, it is not analyzed here. Additionally, to be consistent with existing literature (Langeslag et al., 2009; Morgan et al., 2008), the analysis time window for NSW in this study spanned both the memory encoding and retention stages.

For the frontal NSW component, the main effect of emotion was significant ( $F(2,58) = 19.0$ ,  $p < 0.001$ ,  $\eta^2 p = 0.396$ ; Figure 4 [Figure 4: see original paper]), with disgusting faces ( $-6.01 \pm 7.85$  V) eliciting more negative NSW than fearful ( $-4.79 \pm 7.16$  V,  $p = 0.026$ ) and neutral faces ( $-3.51 \pm 7.55$  V,  $p <$

0.001). Fearful faces elicited more negative NSW than neutral faces ( $p < 0.001$ ). The main effect of memory load was significant ( $F(1,29) = 13.8$ ,  $p = 0.001$ ,  $2 p = 0.322$ ), with high memory load ( $-5.37 \pm 7.35$  V) eliciting more negative NSW than low memory load ( $-4.17 \pm 7.74$  V).

**3.2.3 Memory Retrieval Stage** For the occipital P1 component, the main effect of emotion was significant ( $F(2,58) = 14.6$ ,  $p < 0.001$ ,  $2 p = 0.336$ ; Figure 5 [Figure 5: see original paper]A), with fearful faces ( $6.07 \pm 3.07$  V) eliciting larger P1 amplitudes than neutral ( $5.66 \pm 2.74$  V,  $p = 0.018$ ) and disgusting faces ( $5.15 \pm 2.84$  V,  $p < 0.001$ ), and neutral faces eliciting larger P1 amplitudes than disgusting faces ( $p = 0.030$ ). The main effect of memory load was significant ( $F(1,29) = 37.8$ ,  $p < 0.001$ ,  $2 p = 0.566$ ), with high memory load ( $6.10 \pm 2.91$  V) eliciting larger P1 amplitudes than low memory load ( $5.15 \pm 2.81$  V).

For the temporo-occipital N170 component, the main effect of emotion was significant ( $F(2,58) = 31.8$ ,  $p < 0.001$ ,  $2 p = 0.523$ ; Figure 5B), with fearful ( $-7.41 \pm 4.32$  V,  $p < 0.001$ ) and disgusting faces ( $-6.85 \pm 3.75$  V,  $p < 0.001$ ) eliciting larger N170 amplitudes than neutral faces ( $-5.20 \pm 4.58$  V). Additionally, fearful faces elicited slightly larger N170 amplitudes than disgusting faces, but this difference was not significant ( $p = 0.081$ ). The main effect of memory load was significant ( $F(1,29) = 42.1$ ,  $p < 0.001$ ,  $2 p = 0.592$ ), with high memory load ( $-5.55 \pm 3.99$  V) eliciting smaller N170 amplitudes than low memory load ( $-7.42 \pm 4.44$  V).

For the parietal P3 component, the main effect of emotion was significant ( $F(2,58) = 16.2$ ,  $p < 0.001$ ,  $2 p = 0.358$ ; Figure 5C), with disgusting faces ( $5.60 \pm 3.02$  V) eliciting larger P3 amplitudes than fearful ( $4.80 \pm 2.87$  V,  $p = 0.017$ ) and neutral faces ( $4.01 \pm 3.32$  V,  $p < 0.001$ ). Fearful faces elicited larger P3 amplitudes than neutral faces ( $p = 0.002$ ). The main effect of memory load was significant ( $F(1,29) = 22.4$ ,  $p < 0.001$ ,  $2 p = 0.436$ ), with high memory load ( $4.23 \pm 3.18$  V) eliciting smaller P3 amplitudes than low memory load ( $5.38 \pm 2.99$  V).

## 4. Discussion

### 4.1 Effects of Disgust and Fear on Memory

Most existing emotional memory studies suggest that emotional memory enhancement effects are caused by the arousal and valence of emotional information. Few studies have examined whether different types of emotional stimuli produce different effects on memory after controlling for these two variables. Using high temporal resolution ERP technology, the present study compared the effects of two high-arousal, withdrawal-related negative emotions—disgust and fear—on memory encoding, retention, and retrieval.

The behavioral results of this study showed that participants had shorter reaction times for negative emotional faces than for neutral faces (Deveney & Deldin,

2004), and higher discrimination index  $d'$  for negative faces than for neutral faces (Langeslag et al., 2009; Xie et al., 2018). More importantly, we found that participants'  $d'$  for disgusting faces was higher than for fearful faces, consistent with existing behavioral research findings (Chapman et al., 2013; Charash & McKay, 2002; Croucher et al., 2011). The stronger memory enhancement effect for disgust than fear may be because disgust signals the “contagious” nature of things, and contagion occurs very easily and often without direct contact. Therefore, only by firmly remembering these disgusting objects or disgust cues (such as faces, voices) can the organism avoid contamination (Marchewka et al., 2016).

In addition to behavioral measures, the ERP data in this study revealed how disgust and fear affect each memory processing stage with high temporal resolution. First, during the memory encoding stage, both negative emotions produced amplitude differences in three ERP components: (1) Compared to neutral conditions, fearful faces elicited larger P1 amplitudes while disgusting faces elicited smaller P1 amplitudes. This result is consistent with the encoding stage findings, as P1 is generally considered to reflect bottom-up, automatic early attention. (2) A similar emotion effect was found in the facial structural encoding time window, with fearful faces eliciting larger N170 than neutral faces, while disgusting faces elicited slightly smaller N170 (not significant). (3) However, the pattern of negative emotion effects on ERP changed during the elaborate processing time window for emotional faces, during which disgusting faces elicited larger P3 than fearful and neutral faces (see also Santos, Iglesias, Olivares, & Young, 2008). These ERP results are extremely similar to those reported in emotional cue dot-probe studies (Liu et al., 2015; Zhang et al., 2017; Zimmer et al., 2015). These studies suggest that, unlike fear and anger emotions that attract attention from the beginning (Cacioppo & Gardner, 1999), disgust emotion inhibits attention in the early processing stage, and then the brain reallocates cognitive resources such as active attention to disgusting stimuli through top-down control mechanisms for in-depth processing (Curtis et al., 2011; Zhang et al., 2017). The reason for this processing pattern is that different types of negative emotions have different evolutionary significance and physiological functions: the purpose of processing fear cues is to avoid acute harm such as being killed or attacked, while the purpose of processing disgust stimuli is to avoid chronic harm such as disease (Neuberg, Kenrick, & Schaller, 2011). Therefore, the brain's processing of fear stimuli is rapid and automatic, while processing of disgust stimuli is slower and more dependent on top-down attentional regulation (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003). P3 (or late positive component) reflects elaborate evaluation of stimuli (Ito, Larsen, Smith, & Cacioppo, 1998). On the one hand, since threatening signals conveyed by disgust emotion do not require urgent processing, the brain's encoding of disgust information is mainly manifested in the P3 time window; on the other hand, since fearful faces have already been adequately processed in earlier cognitive stages (early attention, facial structural encoding), according to the “principles of least effort” (Zipf, 1949), there is no need for repeated processing during the elaborate evaluation

stage (van Hooff, Devue, Vieweg, & Theeuwes, 2013).

Second, during the memory retention stage, this study found significant differences in the negative-going NSW between emotion conditions, manifested as disgusting faces > fearful faces > neutral faces. NSW reflects the maintenance and temporary storage of information in working memory (Ruchkin et al., 1992). People invest more cognitive resources in rehearsing information they pay more attention to. For example, a series of studies by Deldin and Deveney found that during the memory retention stage of emotional information, healthy controls showed NSW amplitudes of: happy faces > sad faces > neutral faces, while with increasing severity of depressive mood in depressed patients, their NSW amplitude increased for sad faces but decreased for happy faces (Deldin et al., 2001; Deveney & Deldin, 2004; Shestiyuk, Deldin, Brand, & Deveney, 2005). Based on this, we speculate that our results indicate healthy adults invested more sustained attention and rehearsal effort in disgusting faces than fearful faces during the memory retention stage. Two studies support this speculation. In a categorization task using disgusting, fearful, and neutral pictures as distractors, participants showed lowest accuracy and longest reaction times in the disgust condition, suggesting disgusting pictures attracted participants' attention more persistently than fearful pictures (Carretié, Ruiz-Padial, López-Martín, & Albert, 2011). Another study examining attention disengagement from emotional pictures found that disgusting pictures attracted participants' attention more persistently than fearful and neutral pictures, as participants' attention remained difficult to disengage from disgusting pictures within 200 ms after picture disappearance (van Hooff et al., 2013).

Finally, during the memory retrieval stage, we found that fearful faces elicited larger P1 than neutral faces, while disgusting faces elicited smaller P1 than neutral faces. This result is consistent with the encoding stage findings. The most important finding in the memory retrieval stage was that not only did negative emotions elicit larger P3 amplitudes than neutral, but disgusting faces also elicited significantly larger P3 amplitudes than fearful faces. The P3 (or late positive component) during memory retrieval is an important indicator of memory recognition, with P3 amplitude showing a positive correlation with memory retrieval success rate (Paller et al., 1995; Wilding & Rugg, 1996), which is also consistent with our behavioral results ( $d'$ ). Some studies have shown that P3 amplitude is related to participants' confidence in memory retrieval, the amount of detail retrieved, and the strength of memory representation (Rugg & Curran, 2007; Weymar, Löw, Melzig, & Hamm, 2009). Emotional memory studies have found that negative stimuli elicit larger P3 amplitudes than neutral stimuli during retrieval (Hauswald et al., 2011; Xie et al., 2018; Zhang et al., 2016). Our finding that disgusting faces elicited larger P3 than fearful faces suggests that disgusting faces may have formed stronger representations in the working memory system, enabling people to recall more details during memory retrieval with increased confidence. Interestingly, N170 amplitude during retrieval was larger under both negative emotion conditions than neutral, a pattern different from the encoding stage (where only fearful faces elicited larger N170). Based

on this, we speculate that N170 during retrieval may be influenced not only by automatic emotional modulation of facial encoding (the mechanism of N170 during encoding) but also by top-down intentional control that highlights emotion information critical for survival (hence the increased N170 for disgust). This speculation is supported by Righi et al. (2012), who in their experiment only presented emotional faces during the encoding stage of memory, but presented neutral faces during retrieval. They found that neutral faces corresponding to previously encoded fearful faces (i.e., the same actor showing fear and the neutral face) elicited larger vertex positive potentials and P3 during retrieval than neutral faces corresponding to previously encoded happy faces.

#### 4.2 Effects of Cognitive Load on Memory

Regarding memory load, the behavioral results of this study showed main effects of load on both reaction time and discrimination index  $d'$ , with high memory load showing lower  $d'$  and longer reaction times than low memory load. Meanwhile, the effect of emotion on  $d'$  was more pronounced under high memory load conditions. These results are consistent with existing literature (Langeslag et al., 2009; Morgan et al., 2008).

ERP results showed that as memory load increased, P3 during encoding and retrieval and N170 during retrieval decreased in amplitude, while N170 during encoding and NSW during retention increased, consistent with our predictions. NSW is typically widely distributed across the scalp and can be observed in frontal, parietal, occipital, and temporal regions (Deldin et al., 2001; Rämä et al., 2000). This study analyzed NSW amplitude in the frontal region because the peak of this component appeared at frontal electrode sites (Löv et al., 1999), and Rämä et al. (2000) found that only frontal (compared to parietal and occipital) NSW amplitude was consistently affected by memory load throughout the retention stage. This study found that P3 amplitudes during both encoding and retrieval decreased with load, but we believe the reasons may differ: during encoding, the negative-going NSW reduced P3 amplitude because the two components overlap in brain regions; during retrieval, more faces occupied more attention and memory retention resources, leaving fewer resources for stimulus evaluation (reflected by P3) (Morgan et al., 2008).

As for why N170 is affected in opposite directions by memory load during encoding and retrieval, we propose the following explanation: during encoding, as the number of faces increases, the brain needs to allocate more resources to encode facial structure, thus eliciting larger N170; during retrieval, similar to P3, more faces occupy more attention and memory retention resources, leaving fewer resources for structural encoding of the test face. Additionally, this study found a main effect of memory load on occipital P1 during retrieval, a result not previously reported in the literature, and P1 increased with load, opposite to the direction of change for N170 and P3. Therefore, we believe this result needs further verification in future studies.

In addition, this study's ERP results showed that the interaction between emotion and memory load existed only during the memory encoding stage, while no significant interactions were found during memory retention and retrieval stages. These results are consistent with existing ERP literature. For example, MacNamara and colleagues reported that the P3 component during memory encoding showed an interaction between emotion and memory load (MacNamara & Proudfit, 2014), while the slow wave component during memory retention did not show an interaction effect (MacNamara, Ferri, & Hajcak, 2011). Additionally, the two ERP studies most relevant to this paper obtained similar results: for memory retrieval ERP, Langeslag et al. (2009) only reported emotion effects, while Morgan et al. (2008) only reported memory load effects, suggesting that these two factors did not interact during memory retrieval. In this study, the emotion by memory load interaction effect on ERP during encoding was consistent with behavioral data ( $d'$ ), showing stronger emotion effects under high memory load. This is because under high load, participants needed to encode three emotional faces simultaneously, so the brain's modulation by emotional information was stronger. During memory retrieval, participants only needed to encode information about one face under both high and low load conditions, so emotion processing at this stage may not be easily modulated by memory load factors.

### 4.3 Summary

This study used ERP technology to examine the effects of different negative emotions (disgust, fear) on the three stages of memory. The results showed that: (1) During the early stage of memory encoding, the brain enhanced attention (P1) and structural encoding (N170) for fearful faces, while processing of disgusting information was suppressed; (2) From the late encoding stage through the entire retention stage, participants' elaborate evaluation of disgusting information (P3 during encoding) and rehearsal maintenance (NSW during retention) were stronger than for fearful information; (3) Compared to fearful faces, disgusting faces may have formed stronger representations in the working memory system, enabling participants to recall more details during memory retrieval with greater confidence (P3 during retrieval). These latter two findings account for the superior behavioral memory for disgusting compared to fearful emotions. This study provides high temporal resolution neural evidence for the notion that "disgust has a stronger memory enhancement effect than fear," thereby further revealing the cognitive mechanisms underlying negative emotional memory enhancement.

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