

# The Neural Response to Maternal Stimuli: An ERP Study

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## Abstract

Mothers are important to all humans. Research has established that maternal information affects individuals' cognition, emotion, and behavior. We measured event-related potentials (ERPs) to examine attentional and evaluative processing of maternal stimuli while participants completed a Go/No-go Association Task that paired *mother* or *others* words with *good* or *bad* evaluative words. Behavioral data showed that participants responded faster to *mother* words paired with *good* than the *mother* words paired with *bad* but showed no difference in response to these *others* across conditions, reflecting a positive evaluation of mother. ERPs showed larger P200 and N200 in response to *mother* than in response to *others*, suggesting that *mother* attracted more attention than *others*. In the subsequent time window, *mother* in the *mother + bad* condition elicited a later and larger late positive potential (LPP) than it did in the *mother + good* condition, but this was not true for *others*, also suggesting a positive evaluation of mother. These results suggest that people differentiate *mother* from *others* during initial attentional stage, and evaluative *mother* positively during later stage.

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## Introduction

The mother is important for human beings throughout their lifetime. A mother's physiological and mental state during the pregnancy contributes substantially to her child's physical and psychological health in both early and late infancy (e.g., [1–4]). In early childhood, the mother regulates the physiological state and behaviors of her child [5]. Attachment to their mothers is the start of children's socialization, which facilitates social and affective development [6]. Later, mothers' parenting behavior affects adolescents' emotional regulation ability and problem behaviors [7,8]. Finally, for adults, mothers are still an essential part of individuals' attachment networks [9]. Furthermore, the perceived quality of the parent-child relationship during childhood predicts adults' psychological and physical well-being throughout the lifespan [10,11]. In short, the significance of mothers is difficult to overestimate.

Given this physical and psychological significance, a large number of empirical studies have focused on how stimuli related to the mother, such as a mother's face or name, affect information processing. Findings from studies using behavioral (e.g., [12–14]), electrophysiological (e.g., [15]) and neuroimaging measures (e.g., [16]) show that maternal stimuli affect people's attention and evaluative responses. From the attentional perspective, individuals show a tendency to attend more to maternal stimuli than other kinds of stimuli across different ages. For instance, newborns (4 hours to 72 hours after birth) stare at their mother's face longer than at a stranger's face [12–14,17,18]. Furthermore, an electrophysiological study showed that mothers' faces elicited a larger negative component (Nc, occurring 400 to 800 ms,

indexing attentional response) compared with a stranger's face, indicating that infants allocate increased attention to the mother's face [15]. For adults, the faces of mothers elicited greater activation in facial-specific regions than the faces of others, including strangers, celebrities or even fathers [16]. From an evaluative perspective, maternal stimuli are perceived more positively than other stimuli. For instance, people favor their mother's name [19], show a higher retrieval rate for favorable traits than for unfavorable traits after a mother-reference task [20], and are inclined to interpret their mother's neutral faces as cheerful faces [21].

Although these studies highlight attentional preference and evaluative positivity when processing maternal stimuli, two issues still remain unclear. First, the attentional bias to maternal information usually has been attributed to familiarity [e.g., 15, 16], but a recent study showed that the preference for maternal information was strongly affected by the intense attachment to mother, rather than just reflecting familiarity [21]. However, it is difficult to rule out the familiarity effect because previous studies on the mother/stranger distinction used pictures of mothers and strangers as material. Thus, effectively controlling for the familiarity of material is necessary when evaluating whether the preference for mother is due to the intense attachment. Second, previous studies have found that individuals have positive evaluations of their mothers [19,20,21], but this tendency might be affected by a social desirability bias, influencing participants to show favoritism to their mother over others. However, combining an implicit task with measurements of neural responses that index online mental operations independent of behavioral response

processes would reduce the impact of social desirability bias on maternal evaluations.

The present study sought to examine the attentional and evaluative processing of maternal stimuli using event-related potentials (ERPs). ERPs are particularly well-suited for examining these two processes, because the ERP waveform, measured in response to a stimulus, contains a number of components that are temporally linked to the emergence of different mental operations, including perception, attention, and evaluation [22]. This property of the ERP technique makes it particularly useful for examining attentional and evaluative processes by assessing different components.

Previous research used various types of maternal stimuli, including faces, names, and basic word descriptions (e.g., “mother”) [15,16,19,20]. In the present study, we used words for *mother* and *others* as stimuli. We used words instead of pictures as maternal stimuli because the evaluative dimensions in the task were described by words (good or bad). This effectively eliminated the potential effect of switching between word and picture processing during the experiment. Most importantly, words are more effective for controlling for the familiarity, because the familiarity of word stimuli could be indexed by objective measures such as frequency.

We selected the Go/No-go Association Task (GNAT, [23]) because of its suitability for ERP studies (e.g., [24,25]). More importantly, this paradigm is suitable for examining the attentional and evaluative processing of maternal stimuli by creating contrasts between different experimental blocks. In particular, we used two blocks to explore the processing of maternal stimuli (*mother + good* and *mother + bad*) and two further blocks to explore the processing of non-specific *others* (*others + good* and *others + bad*). For all four blocks, we focused on the behavioral and neural responses to *mother* and *others* stimuli and compared them between the different conditions to test for difference in attentional and evaluative processes. The contrast between *mother* blocks and *others* blocks allowed for examining differences in attentional resource allocation between *mother* and *others*. Furthermore, the evaluative processing of maternal stimuli was examined by contrasting the *mother + good* and *mother + bad* conditions, where the evaluation of *mother* was operationalized as the associative strength of maternal stimuli with positive or negative attributes in the GNATs.

To examine the attentional processing of maternal stimuli, two ERP components, the P200 and N200 were measured and analyzed. Enhanced amplitudes of these two components are assumed to reflect increased attention to information with intrinsic personal relevance, such as self-related information [26,27,28–31]. Thus, we assessed whether participants differentiated *mother* from non-specific *others* at an early attentional stage by examining the amplitudes of these two ERP components across the four conditions. Specifically, we hypothesized that *mother* would draw more attention than *others*, as indicated by increased P200 and N200 components, because of the mother’s critical role in a child’s life.

In addition, to further explore the evaluative processing of maternal stimuli, the late positive potential (LPP) that is generally found to be maximal around the posterior region of the scalp (for reviews, see [32–35]) was examined. This component has been associated with evaluative processing [36–39]. Its peak latency could be used as a neural indicator of the speed of categorization and evaluation (for a review, see [33]). Inconsistency between the current stimulus representation and a previous expectation or evaluation enhances LPP amplitude [36,37]. In the area of social cognition, the LPP has been used to assess the evaluation of

specific social groups. For instance, the LPP amplitude is larger for counter-stereotype associations than stereotype-consistent associations, reflecting a violation of a previously established evaluation and implicit racial attitude [40,41]. Meanwhile, compared with stereotype-consistent information, the LPP latency is longer when counter-stereotype information is processed [40]. In the present study, we hypothesized that the LPP would reflect participants’ evaluations of maternal stimuli. Specially, *mother* words would elicit a larger and later LPP in the *mother + bad* condition than in the *mother + good* condition due to the violation of the positive attitude towards the mother in the former condition. By contrast, people usually hold neutral attitudes towards non-specific others [42,43]. Therefore, we expected that the LPP amplitude or its latency would not differ between the *others + good* and *others + bad* conditions.

In short, we investigated the neural correlates underlying maternal stimulus processing. We hypothesized that the attentional bias for maternal stimuli would be reflected in the P200 and N200 components and the positive evaluation bias for maternal stimuli would be reflected in the LPP.

## Method

### Ethics statement

The experimental protocol was approved by the Institutional Review Board (IRB) at the Institute of Psychology, Chinese Academy of Sciences. We explained the experimental procedure to each participant after he or she arrived at the lab. Moreover, informed written consent was obtained from each participant before the experiment.

### Participants

Twenty-seven college students (19–25 years old, 12 males, all right-handed) participated in this study as paid volunteers. None had a history of neurological or psychiatric disorders. All had normal or corrected-to-normal vision. Data from 4 participants (3 males) were not included in final analysis because of technical problems during data acquisition. As a result, the final sample consisted of twenty-three participants (9 males; age,  $M = 21.8$  years,  $SD = 1.7$  years).

### Materials

We selected 170 Chinese words as stimuli: 5 *mother* words (ma, mother, mama, ama (“阿妈”, means mom) and niang (“娘”, means mom), 5 *others* words (he, him, his, other (“他人”, means other people) and other (“别人”, means other people), 80 *good* or *positive* and 80 *bad* or *negative* attributes. Most attributes were selected from the Chinese version of personal trait words provided by Anderson [44]. The remaining attributes were selected from a Chinese attribute list developed for a prior study examining implicit and explicit self-enhancement [45].

The familiarity of the target category was manipulated from three perspectives. First, all the characters we used are frequently used in daily life (i.e., they were among the top 8% of the 10,241 characters in the “Combined character frequency list of Classical and Modern Chinese, see the link <http://lingua.mtsu.edu/chinese-computing/statistics/char/list.php?Which=TO>). Second, the frequency of *mother* words is not significantly different from that of *others* words (8,001 vs. 321,369,  $t_{(4,002)} = 2.44$ ,  $p = .071$ ) in the Chinese language, according to the word frequency Dictionary of Chinese characters and words (developed by the International R&D Center for Chinese Education, <http://nlp.blcu.edu.cn>). Third, to make sure that participants were familiar with both the *mother* and *others* words before the formal

experiment, we required them to achieve response accuracy higher than 85% in the practice task.

## Procedure

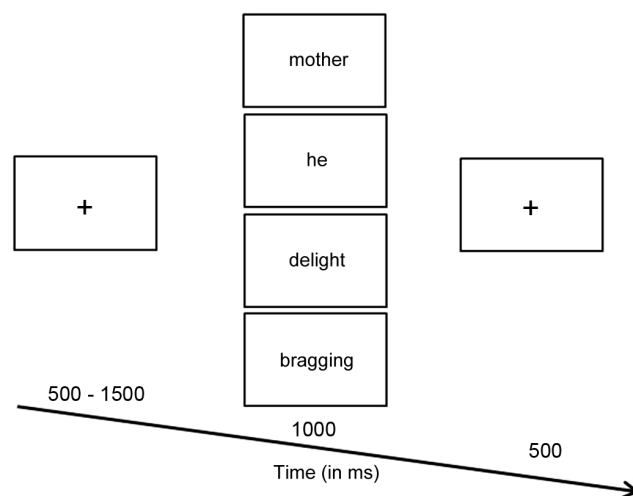
Two GNATs consisted of four blocks: *mother + good*, *mother + bad*, *others + good* and *others + bad*, measuring processing of *mother* (*mother + good* and *mother + bad*) and *others* (*others + good* and *others + bad*), respectively. In each block, four identical types of stimuli were presented randomly on the computer screen one by one. Different blocks, however, required participants to respond to different pairs of stimuli (targets) but ignore other stimuli (distracters). For instance, in the *mother + good* block, participants needed to press the space bar if a stimulus was a *mother* word or a *good* word (e.g., *mother* or *delight*), but did nothing if a stimulus was an *others* word or a *bad* word (e.g., *he* or *bragging*). The order of the blocks was counterbalanced across participants. Before each experimental block, participants worked through pilot trials to become familiar with the task.

Each block included 320 trials. The stimulus presented in each trial was selected from four types of concepts with equal probability. Each of the five target category words (*mother* and *others*) was presented 16 times. The attribute words (*good* and *bad*) were presented without repetition. Therefore, there were 160 trials that presented target category words and the other 160 trials presented attributed words. The ratio of signal to noise was 1:1 in each block.

Figure 1 shows an example of the trial stimulus presentations. Each trial started with a fixation (a cross “+”) on the center of the screen appearing for a random duration between 500 and 1500 ms. After that, the stimulus word was presented on the center of the screen for 1000 ms, and the participants were required to press the SPACE bar if the stimulus word was a target item. Finally, the second fixation was presented for 500 ms. Thereafter, a new trial then started with a fixation.

## EEG Data Recording and Analysis

The continuous electroencephalogram (EEG) was recorded from 64 scalp sites using Ag/AgCl electrodes mounted in an elastic cap (NeuroScan Inc.), with an online reference to the right mastoid and off-line algebraic re-reference to the average of left and right mastoids. The vertical electrooculogram (VEOG) and horizontal electrooculogram (HEOG) were recorded from two pairs of



**Figure 1. Illustration of the experimental procedure.**  
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electrodes, with one placed above and below the left eye, and another 10 mm from the outer canthi of each eye. All interelectrode impedances were maintained below 5 k $\Omega$ . The EEG and EOG were amplified using a 0.05–100 Hz bandpass and continuously sampled at 500 Hz/channel.

During the off-line analysis, the EEG data were digitally filtered with a 30 Hz low-pass filter. Ocular artifacts were removed from the filtered EEG data using a regression procedure implemented in the Neuroscan software [46]. The onsets of the stimuli were set as the zero points, and the continuous EEG data were epoched into periods of 1000 ms including a 200-ms pre-stimulus baseline. Trials with artifacts due to eye blinks, amplifier clipping, and electromyographic (EMG) activity exceeding  $\pm 100 \mu\text{V}$  were excluded from averaging. In addition, trials where a participant had responded incorrectly were excluded from the final averaging. The mean percentage of trials excluded from averaging across the four blocks was less than 2% ( $M = 1.8\%$ ,  $SD = 2.1\%$ ). After that, the ERPs for category words (*mother* or *others*) with a Go response from the four blocks were averaged separately. Finally, two types of ERPs for each of the category words were obtained.

To examine attentional processing of maternal information, two ERP components, the P200 (within 140–210 ms) and N200 (within 250–350 ms), were examined. Previous studies showed that the P200 is generally found to be maximal around the frontal region of the scalp (e.g., [26,27]). Empirical evidence suggests that the anterior N200 may reflect attentional allocation processes, including the attentional selection of salient physical properties of items made by task manipulations [47,48] and the properties of social stimuli that are of inherent motivation/salience, such as out-group membership information (for a review, see [49]). Therefore, the peak amplitudes of P200 and N200 from 9 anterior sites (F3, FZ, F4, FC3, FCZ, FC4, C3, CZ and C4) and analyzed, respectively. These amplitudes from two components were entered into a four-way ANOVA (target category (*mother* vs. *others*)  $\times$  attribute (*good* vs. *bad*)  $\times$  Anterior-Posterior (F vs. FC vs. C)  $\times$  Laterality (left vs. midline vs. right)), respectively.

To examine the evaluative processing of maternal stimuli, the peak latency and mean amplitude of LPP was measured. As this component is generally found to be maximal around the posterior area of the scalp (for reviews, see [32–35]), we selected 12 central parietal sites (C3, CZ, C4, CP3, CPZ, CP4, P3, PZ, P4, PO3, POZ and PO4) to measure its mean amplitude from 400 ms to 600 ms. These peak latencies and mean amplitudes were entered into a four-way ANOVA (target category (*mother* vs. *others*)  $\times$  attribute (*good* vs. *bad*)  $\times$  Anterior-Posterior (C vs. CP vs. P vs. PO)  $\times$  Laterality (left vs. midline vs. right)), respectively.

Additionally, to check the physical properties differences between maternal stimuli and *others* stimuli, P100 and anterior N100 were assessed and analyzed. Peak amplitude of P100 (within 80–120 ms) was measured from 3 occipital sites (O1, OZ and O2) and then entered into a three-way ANOVA (target category (*mother* vs. *others*)  $\times$  attribute (*good* vs. *bad*)  $\times$  Laterality (left vs. midline vs. right)). Meanwhile, peak amplitude of N100 (within 90–130 ms) were measured from 9 anterior sites (F3, FZ, F4, FC3, FCZ, FC4, C3, CZ and C4) and then submitted into a four-way ANOVA (target category (*mother* vs. *others*)  $\times$  attribute (*good* vs. *bad*)  $\times$  Anterior-Posterior (F vs. FC vs. C)  $\times$  Laterality (left vs. midline vs. right)).

For all the analyses listed below, the significance level was set at 0.05. Greenhouse–Geisser correction was used to compensate for sphericity violations when appropriate. Post-hoc analyses were conducted to explore the interaction effects. Partial eta-squared ( $\eta^2$ ) was reported to demonstrate the effect sizes of significant results in the ANOVA tests.

## Results

### Behavioral Results

To examine whether attentional and evaluative factors contribute to the behavioral response, we performed an ANOVA on accuracy and reaction time to *mother* and *others* words in Go trials with target category (*mother* vs. *others*) and attribute (*good* vs. *bad*) as two within-subject factors, respectively. Regarding accuracy, participants performed at 96.63% accuracy in four conditions, and no significant difference was found across conditions, all  $F_s < 0.11$  and all  $p_s > .35$ . Regarding reaction time, the category effect was not significant,  $F_{(1, 22)} = 2.31$ ,  $p = .143$ ,  $\text{partial } \eta^2 = 0.095$ , but the attribute effect was significant,  $F_{(1, 22)} = 5.48$ ,  $p = .029$ ,  $\text{partial } \eta^2 = 0.20$ . Targets paired with *good* words elicited faster responses ( $M = 474$  ms,  $SD = 44$ ) than targets paired with *bad* words ( $M = 490$  ms,  $SD = 52$ ). More importantly, the interaction between category and attribute was highly significant,  $F_{(1, 22)} = 12.76$ ,  $p = .002$ ,  $\text{partial } \eta^2 = 0.37$ . Participants responded faster to *mother* words in the *mother + good* condition ( $M = 461$  ms,  $SD = 41$ ) than in *mother + bad* condition ( $M = 492$  ms,  $SD = 50$ ),  $t_{(22)} = -4.13$ ,  $p < .001$ , but the reaction times for *others* words, between *others + good* ( $M = 488$  ms,  $SD = 47$ ) and *others + bad* ( $M = 487$  ms,  $SD = 54$ ), were not significantly different,  $t_{(22)} = .07$ ,  $p = .945$ . These findings suggested that participants had positive attitudes to *mother*, which is consistent with previous findings [19–21].

### ERP Results

**P100 and N100 amplitude.** No significant difference was detected in peak amplitudes of the P100 (peaks at 98.33 ms) and anterior N100 (peaks at 98.50 ms), all  $F_s < 3.90$ , and all  $p_s > .05$ . Therefore, we concluded that *mother* and *others* words were processed similarly in terms of physical properties, thus not affecting early visual processing.

**P200 amplitude.** The peak amplitudes of the P200 (peaks at 165.62 ms) within 140–210 ms were entered into a four-way ANOVA. Main effect of target category was significant,  $F_{(1, 22)} = 30.46$ ,  $p < .001$ ,  $\text{partial } \eta^2 = 0.58$ , with *mother* words eliciting larger P200 ( $M = 8.14$   $\mu\text{V}$ ,  $SD = 4.45$ ) than *others* words ( $M = 6.34$   $\mu\text{V}$ ,  $SD = 3.72$ ) (see Figure 2). Neither the main effect of attribute nor the interaction effect was significant,  $F_{(1, 22)} = 1.06$ ,  $0.61$ ,  $p = .315, .442$ ,  $\text{partial } \eta^2 = 0.05$ ,  $0.03$ , respectively.

**N200 amplitude.** The peak amplitudes of the anterior N200 (peaks at 279.67 ms) within 250–350 ms were entered into a four-way ANOVA. Main effect of target category was significant,  $F_{(1, 22)} = 14.86$ ,  $p = .001$ ,  $\text{partial } \eta^2 = 0.40$ , with *mother* words eliciting larger N200 ( $M = -1.92$   $\mu\text{V}$ ,  $SD = 4.80$ ) than *other* words ( $M = -0.53$   $\mu\text{V}$ ,  $SD = 4.71$ ) (see Figure 2). Neither the main effect of attribute nor the interaction effect was significant,  $F_{(1, 22)} = 0.01$ ,  $0.52$ ,  $p = .932, .481$ ,  $\text{partial } \eta^2 = 0.001, .023$ , for valence and interaction, respectively.

**LPP amplitude.** The grand averaged ERPs to *mother* and *others* words from Go trials are shown in Figure 3a and Figure 3b, respectively. Mean amplitude of LPP was measured and submitted to a four-way ANOVA. The main effect of target category was significant,  $F_{(1, 22)} = 20.41$ ,  $p < .001$ ,  $\text{partial } \eta^2 = 0.48$ , with *mother* words eliciting larger LPP than *others* words (*mother*:  $M = 10.24$   $\mu\text{V}$  vs. *others*:  $M = 8.90$   $\mu\text{V}$ ). The main effect of attribute was not significant,  $F_{(1, 22)} = 1.79$ ,  $p = .195$ ,  $\text{partial } \eta^2 = 0.08$ . The interaction effect for category and attribute was significant,  $F_{(1, 22)} = 8.86$ ,  $p = .007$ ,  $\text{partial } \eta^2 = 0.29$ . Further analyses showed that *mother* in the *mother + bad* condition ( $M = 10.90$   $\mu\text{V}$ ) elicited larger LPP than in the *mother + good*

condition ( $M = 9.59$   $\mu\text{V}$ ),  $F_{(1, 22)} = 7.21$ ,  $p = .014$ ,  $\text{partial } \eta^2 = 0.25$ . By contrast, no significant difference was found in LPP mean amplitude between the *others + bad* ( $M = 8.75$   $\mu\text{V}$ ) and *others + good* conditions ( $M = 9.06$   $\mu\text{V}$ ),  $F_{(1, 22)} = 0.49$ ,  $p = .493$ ,  $\text{partial } \eta^2 = 0.02$ .

**LPP latency.** Peak latencies of LPP were measured and submitted to a four-way ANOVA. The main effect of target category was not significant,  $F_{(1, 22)} = 2.73$ ,  $p = .113$ ,  $\text{partial } \eta^2 = .11$ . The main effect of attribute was significant,  $F_{(1, 22)} = 6.22$ ,  $p = .021$ ,  $\text{partial } \eta^2 = .22$ , with target category words paired with *good* words eliciting an earlier LPP ( $M = 428$  ms) than those paired with *bad* words ( $M = 441$  ms). The category by valence interaction was significant,  $F_{(1, 22)} = 13.15$ ,  $p = .001$ ,  $\text{partial } \eta^2 = 0.37$ . Further analyses showed that *mother* in the *mother + bad* condition ( $M = 447$  ms) elicited a later LPP than in the *mother + good* condition ( $M = 414$  ms),  $F_{(1, 22)} = 26.26$ ,  $p < .001$ ,  $\text{partial } \eta^2 = .54$ . By contrast, no significant difference was found in LPP latency between the *others + bad* ( $M = 435$  ms) and *others + good* conditions ( $M = 442$  ms),  $F_{(1, 22)} = 0.54$ ,  $p = .471$ ,  $\text{partial } \eta^2 = 0.024$ .

### Results of the two gender neutral "others" items

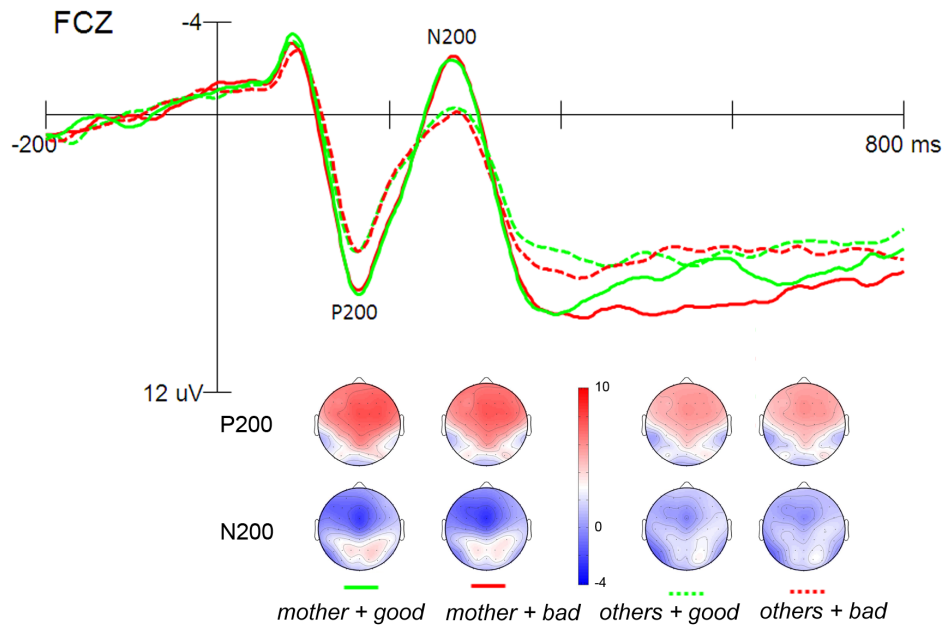
One potential concern with the current results was the “woman are wonderful” effect, in which both males and females have a general tendency to associate women with more positive attributes and expectations than men [50]. It is possible that the *mother/others* manipulation was confounded with female/male in our findings, seeing that three of the *others* stimuli were masculine (he, him, his). One way to rule out this possibility was to directly compare the *mother* stimuli with the two non-masculine *others* stimuli. Specifically, we selected the trials elicited by the two gender-neutral words (“他人” and “别人”) under *others + bad* and *others + good* conditions, respectively. Then, we compared the reaction time and the ERP components elicited by *mother* words with those elicited by these two *others* words, respectively. The results were similar to those reported above. Specifically, participants showed positive bias to *mother* at behavioral level. ERP results showed that they allocated more attentional resources to maternal stimuli, and they held positive evaluations of *mother*. The detailed results are listed below.

### Behavioral result

The result showed that participants made faster responses to *mother* words ( $M = 476$  ms,  $SD = 42$ ) than to *others* words ( $M = 500$  ms,  $SD = 50$ ),  $F_{(1, 22)} = 8.04$ ,  $p = .01$ ,  $\text{partial } \eta^2 = 0.27$ . More importantly, the category  $\times$  attribute interaction effect was significant,  $F_{(1, 22)} = 11.13$ ,  $p = .003$ ,  $\text{partial } \eta^2 = 0.34$ . Further tests showed that participants responded faster to *mother* words in the *mother + good* condition ( $M = 461$  ms,  $SD = 41$ ) than in the *mother + bad* condition ( $M = 492$  ms,  $SD = 50$ ),  $t_{(22)} = -4.13$ ,  $p < .001$ ; whereas the reaction times for *others* words, between *others + good* ( $M = 501$  ms,  $SD = 47$ ) and *others + bad* ( $M = 499$  ms,  $SD = 63$ ), were not significantly different,  $t_{(22)} = .168$ ,  $p = .868$ .

### ERP results

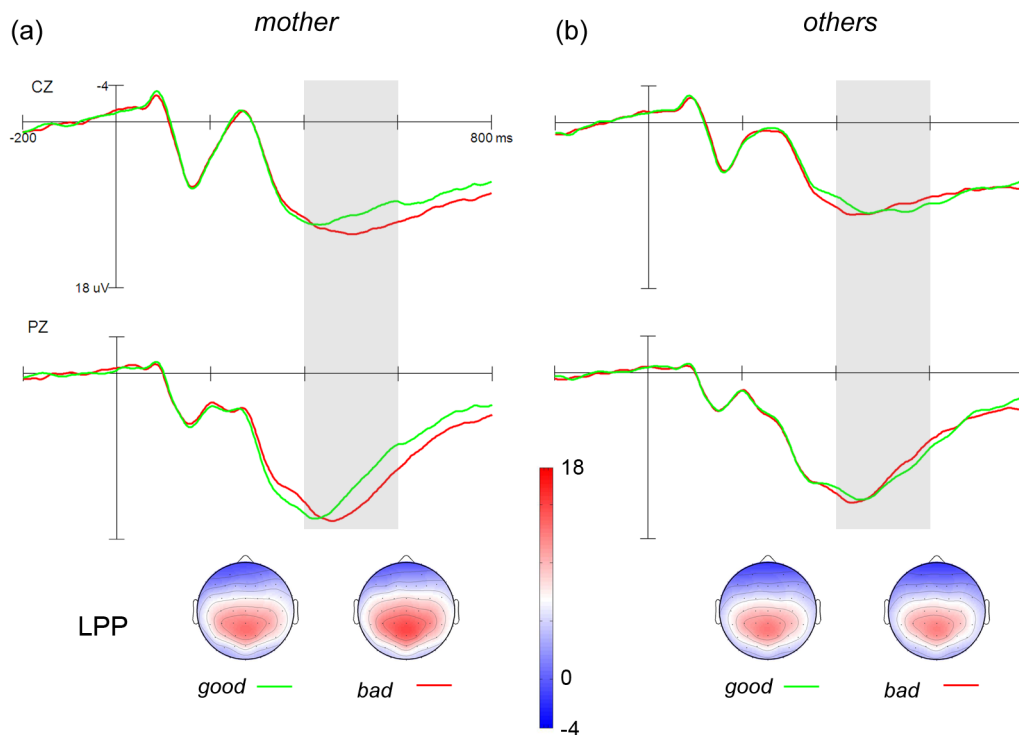
**P200.** The peak amplitudes of the P200 within 140–210 ms were entered into a four-way ANOVA. The main effect of category was significant,  $F_{(1, 22)} = 20.23$ ,  $p < .001$ ,  $\text{partial } \eta^2 = 0.479$ , with *mother* words eliciting larger P200 than *others* words (*mother*:  $M = 8.14$   $\mu\text{V}$  vs. *others*:  $M = 6.70$   $\mu\text{V}$ ). Neither the main effect of attribute nor the interaction effect were significant,  $F_{(1, 22)} = 0.465$ ,  $0.716$ ,  $p = .503, .406$ ,  $\text{partial } \eta^2 = 0.021$ ,  $0.032$ , respectively.



**Figure 2. Grand averaged ERPs for target category words.** The scalp topographies at peak latency for P200 and N200 of each condition are presented beneath.  
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**N200.** The peak amplitudes of the anterior N200 within 250–350 ms were entered into a four-way ANOVA. Main effect of target category, main effect of attribute, and the Category × Attribute interaction were not significant, all  $F_s < 1.8$ , all  $p_s > .2$ . However, a significant Category × Laterality interaction effect was

found,  $F_{(2, 44)} = 8.88, p = .001, \text{partial } \eta^2 = .29$ . Further analysis showed that the category effect was only significant over left area,  $F_{(1, 22)} = 5.63, p = .027, \text{partial } \eta^2 = .204$ , with *mother* words eliciting larger N200 than *others* words in this area.



**Figure 3. Grand averaged ERPs for target category words.** The light gray shaded areas indicate the time window for the detection of the LPP component. The scalp topographies of each condition are presented beneath.  
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**LPP.** Mean amplitude of LPP was measured and submitted into a four-way ANOVA. The main effect of target category was significant,  $F_{(1, 22)} = 19.41, p < .001, \text{partial } \eta^2 = 0.47$ , with *mother* words elicited larger LPP than *others* words (*mother*:  $M = 10.24 \mu\text{V}$  vs. *others*:  $M = 8.47 \mu\text{V}$ ). The main effect of attribute was not significant,  $F_{(1, 22)} = 1.40, p = .25, \text{partial } \eta^2 = 0.06$ . The category by attribute interaction was significant,  $F_{(1, 22)} = 5.92, p = .024, \text{partial } \eta^2 = 0.21$ . Further analyses showed that *mother* in the *mother + bad* condition elicited a larger LPP ( $M = 10.90 \mu\text{V}$ ) than in the *mother + good* condition ( $M = 9.59 \mu\text{V}$ ),  $F_{(1, 22)} = 7.21, p = .014, \text{partial } \eta^2 = 0.25$ . By contrast, no significant difference was found in LPP mean amplitudes between the *others + bad* ( $M = 8.34 \mu\text{V}$ ) and *others + good* conditions ( $M = 8.61 \mu\text{V}$ ),  $F_{(1, 22)} = 0.20, p = .66, \text{partial } \eta^2 = 0.009$ .

In addition to the *mother/others* manipulation, since the majority of the sample were female and the “women are wonderful” effect is stronger in females than males [51], the gender ratio (female: male = 14:9) might have confounded the result. To rule it out, we averaged the data of female and male participants separately and then re-analyzed the original behavioral and ERPs result with gender (female vs. male) as a group factor. If the findings indeed reflected the maternal/others effect, then there should be no significant gender difference. Otherwise, if the findings were confounded with the “women are wonderful” phenomenon, a gender effect should manifest on behavioral and/or neural response. The result showed that the gender effect was not significant after being entered into ANOVA tests. Moreover, adding this factor to analyses does not affect our major findings of either the behavioral or the ERPs results (including the P200, N200, and LPP components), which suggested that the gender factor did not affect the behavioral and neural response.

## Discussion

The present study aimed to investigate attentional and evaluative processing of maternal stimuli. We examined whether there was an attentional preference to maternal information after controlling for familiarity, and we sought to reduce social desirability in the evaluations of maternal stimuli by using an implicit evaluative task and measuring electrophysiological responses. The behavioral data in the formal experiment, including accuracy and response time, supported the experimental control of stimulus familiarity. Target category effects were not significant for either measure, which would be difficult to explain if *mother* words were more familiar than the *others* words. Thus, the neural response to *mother* words likely reflects the specificity of maternal stimulus processing instead of stimulus familiarity.

The behavioral results also suggested that participants indeed had a positive attitude towards maternal stimuli, which was consistent with previous findings [19–21]. That is, participants responded faster when *mother* words were grouped with *good* attributes than when they were grouped with *bad* attributes; whereas no significant difference was found between *others* paired with *good* or *bad* attributes.

The ERP results revealed two major findings. First, *mother* words garnered more attention than non-specific *others* words in both the early and late stages of processing. The P200/N200 and the LPP, respectively, were larger in amplitude for *mother* than for *others* words. Second, the positive attitude towards maternal stimuli emerged in the evaluative stage. The LPP amplitude was larger for the *mother + bad* than *mother + good* condition.

Previous research has consistently demonstrated that maternal stimuli, such as participants’ mothers’ faces, receive more attentional resources and deeper processing compared with *others*

stimuli, as shown by indexes such as looking time [17,18] and blood-oxygen-level-dependent (BOLD) signals [16]. Such preferences were usually attributed to familiarity. However, the present study extends this literature by showing that this kind of phenomenon occurs even after controlling for the level of familiarity. We believe that the selectively deep processing of maternal information was due to the critical role of mothers in human life and the relationships between the participants and their respective mothers.

The current study also revealed the temporal course for this attentional bias using ERPs. Compared with *others*, *mother* elicited larger P200 and N200 components, suggesting that maternal information received considerable attention at an early stage of stimulus processing. Additionally, the augmented LPP amplitude for *mother* compared with *others* also reflected greater attentional resources allocation to *mother* during later cognitive processing stages. Because the five items of maternal stimuli were specific and concrete, whereas the *others* items are non-specific and abstract, it is possible that the attentional preference to maternal stimuli resulted from the concreteness of the words. However, we do not think so. Several empirical studies have shown that concrete words differ from abstract words at a late processing stage, with concrete words eliciting a larger N400 (between 300 and 550 ms) and a larger N700 (between 550 and 800 ms) than abstract words post stimulus onset, but not at the attentional stage (e.g., refs [52,53]). Therefore, the LPP difference to maternal stimuli indexes attention allocation to *mother* and does not index the differences in word concreteness. Additionally, the attentional bias we observed is consistent with the results of previous studies where stimulus salience was operationalized as a function of the degree of self-relevance [31,54–58].

In the present study, the evaluative processing of mother was operationalized by the association between *mother* words and evaluative attributes. Behavioral results from this study and other studies (e.g., refs [19–21]) suggest that people evaluate mother positively. In the *mother + bad* condition, *mother* words were assigned to negative attributes, which was incompatible with the intrinsic positive attitude towards the mother [19–21]. This evaluative incompatibility in the present study resulted in an augmented LPP. This finding was in line with earlier findings that the LPP reflects people’s evaluations of social targets, such as people of different races or genders [40,41,59]. Additionally, the LPP latency was longer when incompatible evaluative information (*mother + bad*) is processed compared with the compatible evaluative information (*mother + good*), which is also in line with previous findings [41]. Our study shows that the evaluative processing of maternal stimuli occurs during a later stage of processing. For *others* stimuli, however, the LPP amplitudes and latency were not significantly different between the *others + bad* and *others + good* conditions, which was consistent with earlier claims that people hold a neutral attitude towards non-specific others [42,43].

Given that the RTs in the *mother + bad* condition were significantly longer than those in the *mother + good* condition, two other potential factors might account for the ERP differences between these two conditions: overt motor response speed and task difficulty. We have two reasons for disagreeing with the former issue. First, participants carried out the same key-pressing responses to identical stimuli (*mother* words) in both the *mother + bad* and *mother + good* conditions. Second, if the LPP amplitude difference was caused merely by the speed difference of the same motor response, there would be no significant difference in the amplitude of the ERP wave before a response between these two conditions. To directly test this hypothesis, we set the response

point as the time zero and then measured and analyzed the amplitude of the ERP wave before the motor response over the centro-parietal area. The results revealed that the ERP wave in the *mother + bad* condition was larger than that in the *mother + good* condition, and no significant difference between the *others + bad* and *others + good* conditions. These results suggest that the differences in LPP amplitudes did not result from differences in overt motor response speed (please refer to Text S1 and Figure S1 for details).

Concerning the issue of task difficulty, the behavioral and neural findings between *mother + bad* and *mother + good* conditions might be due to differences in task difficulty. However, the source of this difficulty is worth noting. In the field of experimental psychology, task difficulty has been manipulated in several ways, including the stimulus characteristics [60,61], the physical effort required in the task [62], the understandability of the stimulus content [63], the length of time allotted to make a response [64,65], the number of cognitive operations needed to complete the task [66], the complexity of mental operations (e.g., [67]), and the strength of the inconsistency between different response tendencies [68,69]. In the current study, the differences in difficulty levels were not caused by the stimulus characteristics or the mental steps necessary for response implementation, but they varied as a function of the degree of mental inconsistency. That is, asking participants to respond to *mother* and *bad* words, the *mother + bad* condition creates a scenario in which automatic evaluation (i.e., associating maternal stimuli with positive descriptions) strongly conflicts with task-demand evaluation. This may have increased the task difficulty, thus leading to longer response times and larger LPP amplitudes compared to the *mother + good* condition, with no significant differences between *others + good* and *others + bad* conditions. Thus, even though our major findings might be interpreted in terms of task difficulty, we argue that these differences in difficulty levels between the *mother* conditions were the result of the internal positive attitude towards maternal stimuli.

Although the current study aimed to examine the maternal/other effect, it is possible that the “women are wonderful” effect [51], rather than the maternal/other effect, might explain our results. First, three of the five “*others*” items were masculine. Second, because the sample of the present study largely consisted of female participants and the “women are wonderful” effect is stronger in females than males [50], the gender ratio (female: male = 14:9) of the sample might have affected the result. However, we re-analyzed the data in order to rule out the potential effect of masculine words and the gender ratio of the sample. The first analysis showed that when we selectively made comparison between *mother* words and two gender-neutral *others* words, the results were essentially the same. Although the effect of category on the N200 amplitude was only significant over left hemisphere, we suggest this asymmetry may disappear in a larger sample. Alternatively, the attention to maternal information might depend more on left hemisphere, but we believe that this is unlikely because the contrast of N200 between *mother* words and all five *others* words did not show a left asymmetry. Regarding the low spatial resolution of ERP technique, future brain-imaging studies would be more appropriate for clarifying this issue. With respect to the gender ratio, a second analysis showed that the gender effect was not significant, i.e., it did not moderate the behavioral or the ERPs results. Thus, the results from these analyses both did not challenge our initial findings and interpretations.

The results suggest that both attentional and evaluative components are involved in processing maternal stimuli. The attentional distinction of *mother* from non-specific *others* occurs immediately after stimulus presentation, which is in line with the proposal that people spontaneously group their perceptions of others by relationship status [70]. The evaluative components contributed to the later processing of the maternal stimuli. The initial recognition and later evaluation of maternal stimuli probably jointly contribute to constructions of a complex representation of the mother, which in turn affects participants’ cognition, emotion, motivation, and behaviors.

One limitation of the present study was that we only compared *mother* and *others* stimuli. We do not know whether such responses are specific to the mother or could be generalized to significant others, such as the father. The father’s role as attachment figure has been emphasized recently (for a review, see [71]). It is likely that the processing of paternal stimuli involves cognitive and affective components similar to the processing of maternal stimuli. Future studies could extend our findings by adding another target, such as *father*, to the task design.

Another limitation was that we only tested adults. Thus, we could not test whether the current findings and conclusions can be generalized across different ages. Given that for most children, mothers are the primary attachment figures, whereas for adults the mother is generally ranked lower than romantic partners [9], it is possible that the processing of maternal stimuli is different between children and adults. However, this may not be the case, since there is some evidence that the neural activation evoked by maternal information is not modulated by age [72]. Thus, the response to the mother observed in the present study may also be generalizable to younger people. Future studies that examine the behavioral and neural response to maternal stimuli in children could help clarifying this issue.

In conclusion, our results indicate that maternal stimuli affect people’s attentional and evaluative processing in a short time interval (less than one second). Such attentional preference and evaluative processing were not a result of stimulus familiarity or social desirability bias, but they were driven by the critical role of mother in human life. Moreover, we found that instead of using stimuli directly related to participants’ own mother, such as the mother’s face, just presenting symbolic stimuli that describe the mother elicits biased processing. This suggests that a more abstract, general, and typical mother concept—not just concrete and specific maternal information—can receive instant processing.

## Supporting Information

### Text S1 Response-locked ERP analysis for *mother* and *others* words with Go response.

(DOCX)

### Figure S1 Grand averaged ERPs for target category words.

The light gray shaded areas indicate the time window for the detection of the LPP component.

(TIF)

## Author Contributions

Conceived and designed the experiments: LLW. Performed the experiments: LLW. Analyzed the data: LLW RLG. Wrote the paper: LLW RLG. Revised the paper: RLG JXZ HJC YLLL.

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