Aggression differentially modulates brain responses to fearful and angry faces: an exploratory study

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Aggression is reported to modulate neural responses to the threatening information. However, whether aggression can modulate neural response to different kinds of threatening facial expressions (angry and fearful expressions) remains unknown. Thus, event-related potentials were measured in individuals (13 high aggressive, 12 low aggressive) exposed to neutral, angry, and fearful facial expressions while performing a frame-distinguishing task, irrespective of the emotional valence of the expressions. Highly aggressive participants showed no distinct neural responses between the three facial expressions. In addition, compared with individuals with low aggression, highly aggressive individuals showed a decreased frontocentral response to fearful faces within 250–300 ms and to angry faces within 400–500 ms of exposure. These results indicate that fearful faces represent a more threatening signal requiring a quick cognitive response during the early stage of facial processing, whereas angry faces elicit a stronger response during the later processing stage because of its eminent emotional significance. The present results represent the first known evidence that aggression is associated with different neural responses to fearful and angry faces. By exploring the distinct temporal responses to fearful and angry faces modulated by aggression, this study more precisely characterizes the cognitive characteristics of aggressive individuals. ***NeuroReport*** **26:663–668**

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Introduction

The prevalence of violence in the world has driven scientists to explore predictors and causes of aggressive behavior. Many studies have reported that aggression is associated with a susceptibility to negative emotional events and abnormalities in emotion regulation [1,2]. Among the emotional stimuli, facial expression is an important part of nonverbal communication used in everyday life [3]. Exploration of neural responses to negative facial expressions that are modulated by aggression could elucidate mechanisms of cognitive processing and emotion regulation in highly aggressive individuals. Such studies may further contribute toward decreases in aggressive behavior and crime rates.

Among negative emotional facial stimuli, fearful and angry expressions are most closely related to aggression. Although both fearful and angry facial expressions are negative, their social signals differ. A fearful face is considered to represent an ambiguous threat in the environment. In contrast, an angry face is often used in face-to-face encounters to exert dominance [4]. To escape from danger and increase the chance for survival, humans theoretically respond with an attack (anger) or flight (fear) when encountering threatening events in the environment. Thus, the goal of anger is to remove an obstacle and the goal of fear is to avoid the menace.

Previous event-related potentials (ERP) and functional MRI studies have shown that aggression is associated with particular neural responses to angry expressions in prefrontal brain regions [4]; however, there is no neural evidence to suggest that aggression relates to specific responses to fearful expressions. Thus, in the current study, we first explored how aggression modulates neural responses to fearful and angry faces. We further explored the different temporal characteristics associated with these responses using electroencephalography (EEG).

Previous EEG studies have shown sensitivity to various emotional expressions during early processing stages (N2 or N300) and later evaluate processing stages (P300) in the responses of the frontal and frontocentral scalp regions. N300 should be more negative in response to negative facial information in the anterior regions [5–8]. For example, Bar-Haim *et al.* [8] found that fearful facial expressions elicited larger N300 potentials than did angry and neutral facial expressions over the frontocentral area. Previous studies have also shown that P300 amplitude

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reflects the essentiality of an affective stimulus, which elicits larger P300 amplitudes compared with neutral stimuli [9,10]. In addition, it is important to note that this emotion-specific ERP effect is not merely an amplitude modulation of a specific ERP peak as it typically overlaps with several successive peaks in ERP waveforms.

Highly aggressive individuals are reported to have callous-unemotional traits [11,12], and previous studies have indicated that such individuals tend to show deficits in processing negative stimuli. For instance, individuals with callous-unemotional traits have been reported to show emotional deficits in response to distressing stimuli [13] and display selective impairments in response to sad and fearful faces [14]. Moreover, these individuals show an early processing deficit in response to fearful facial expressions [2]. In addition, previous evidence showed that a specific frontocentral response is decreased within 200–300 ms of viewing an angry face in highly aggressive individuals [4]. Specifically, an increased aggression score correlated positively with amygdala activity, which is considered to reflect increased negative affect and vigilance, and negatively with prefrontal activity, considered to reflect decreased inhibition control [4]. On the basis of this evidence, we hypothesized that highly aggressive individuals would not distinguish between negative and neutral stimuli in the process of facial processing. Furthermore, compared with low aggression individuals, highly aggressive individuals would show reduced frontal responses to both fearful and angry facial expressions. On the basis of a study showing that angry faces evoke larger negative ERPs in the frontal area within 300–600 ms than do fearful faces [15] and evidence that fear signals are prioritized in neural processing [16], with more intense expressions eliciting a larger ERP response amplitude [17], we reasoned that responses evoked by fearful and angry faces would differ. Specifically, we hypothesized that aggression would be associated with earlier inhibition to fearful faces and later inhibition to angry faces during facial processing.

To investigate the temporal properties of the interaction between aggression and the frontal response to angry faces, we recorded ERPs in individuals with high ($N=13$) and low ($N=12$) aggression scores on the Buss questionnaire [18] while they viewed angry, fearful, and neutral expressions. In real-world situations, emotional responses are often triggered by unpredictable stimuli in a nonemotional cognitive context [19]; therefore, the current study used an implicit emotional task that did not require the participants to evaluate the emotionality of the expressions.

Materials and methods

Participants

Twenty-five paid healthy undergraduate students (mean age $=20.7\pm1.38$ years) participated in this experiment. All participants were right-handed, with normal or corrected to normal vision. Individuals with symptoms or a history of psychiatric care, neurological disease, or head injury were excluded. Before EEG recordings, participants completed the Buss questionnaire [18], which is one of the most widely used methods to assess hostility. The Buss questionnaire consists of four scales: Physical Aggression, Verbal Aggression, Anger, and Hostility. In addition, the coefficient of internal consistency was 0.55–0.94 and the retest reliability was 0.81. The score of the questionnaire indicated the extent of aggression, with a higher score indicating stronger aggression. On the basis of these scores, participants were divided into two groups: high aggression and low aggression. The highly aggressive group included 13 participants (seven women and six men, mean score $=95.5\pm7.7$, mean age $=21.15\pm1.69$), culled from those who scored among the top 10% of all students ($N=400$). The low aggression group included 12 participants (eight women and four men, mean score $=55.1\pm3.6$, mean age $=20.17\pm0.83$) who scored in the bottom 10% of all students. The high and low Buss score groups were matched for age and emotional state measured by the Positive and Negative Affect Schedule.

Materials and procedure

The participants sat in a sound-attenuated room in front of a computer screen that was placed at a viewing distance of 130 cm, with the horizontal and vertical visual angles below 6°. Stimuli were images of emotional faces that displayed neutral, angry, and fearful expressions. These stimuli were posed by different individuals (two women and two men, 12 faces in total) selected from the native Chinese Affective Picture System [20] to avoid cultural bias. The experiment included four experimental blocks of 96 trials each. Three different facial expressions were presented in a random order, with equal probability. Before the experiment, participants were told that the task was to respond to the presented facial expressions. They were required to judge whether the frame of the expressions was thick or thin. At the end of each block, accuracy rates were provided to the participants as a feedback of their performance. Ten practice trials were performed before the experimental procedure. All participants achieved 100% accuracy rates on practice trials before the formal experiment. The faces used in the practice trials were never presented in formal trials. Each trial began with a central fixation cross for 500 ms, followed by facial expressions for 1000 ms. Participants were instructed to press the '1' key on the keyboard if they judged that the frame was thick and to press the '2' key if they judged that the frame was thin. Response hand was counterbalanced across participants. Facial expressions were terminated by key pressing or when 1000 ms had elapsed. Thus, participants were informed that their responses must be made within 1000 ms after the expression onset. Each response was followed by 1500 ms of a blank screen before the next trial began.

EEG recording

EEGs were recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products, Gilching, Germany), with the average reference on the left and right mastoids and a ground electrode on the medial frontal aspect. Vertical electrooculograms (EOGs) were recorded supraorbitally and infraorbitally at the left eye. The horizontal EOG was recorded from the left versus right orbital rim. EEGs and EOGs were amplified using a DC ~ 100 Hz bandpass and sampled continuously at 500 Hz/channel. All interelectrode impedance was maintained below 5 kΩ. Averaging of ERPs was computed off-line; trials with EOG artifacts (mean EOG voltage exceeding ± 80 μV) and those contaminated with artifacts because of amplifier clipping, peak-to-peak deflection exceeding ± 80 μV, were excluded from averaging. EEG activity for a correct response in each emotional condition was overlapped and separately averaged. ERP waveforms were time-locked to the onset of stimuli and the average epoch was 1200 ms, including a 200 ms prestimulus baseline.

Previous EEG studies have found specific neural responses evoked by different emotional facial expressions at early processing stages (120–300 ms) over frontal and frontocentral regions [21], and this emotion-specific ERP effect typically overlaps with several successive peaks in ERP waveforms, such as N1 and P2 [4]. The amplitude differences among the three emotional conditions emerged from ~ 250 to 300 ms, which were also present at 400–500 ms in the frontal and frontocentral sites. Thus, we analyzed the two intervals by selecting the following 10 electrode sites: frontal (F1, F2, F3, F4, Fz) and frontocentral (FC1, FC2, FC3, FC4, FCz) for statistical analyses. In addition, we measured and analyzed the peak latencies and amplitudes of the P1 (80–130 ms) components at the occipital sites (O1, and O2). Similar analyses were carried out for the mean amplitudes at electrodes PO7 and PO8 in a time window centered on the face-sensitive N170 peak amplitude (130–200 ms). A repeated-measures analysis of variance (ANOVA) on the amplitude and latency of each component was performed with emotion (three levels: angry, fearful, neutral) and electrode sites as within-subject factors and group (high and low aggression) as the between-subject factor. The latency analyses of these components were not reported because no significant effect was produced by the emotion or group factor. The degrees of freedom of the F-ratio were corrected according to the Greenhouse–Geisser method.

Results

False responses or missed trials were rare as all of the participants achieved more than 97% accuracy rates in this experiment. The repeated-measures ANOVA of the ACC (accuracy rates) data, with emotion (neutral, fearful, angry) as the repeated factor and group (high and low aggression) as the between-subject factor, showed significant main effects of emotion [$F(2,46)=3.1$, $P<0.05$]. Pairwise comparisons for the main effect of emotion showed that ACCs were faster under angry conditions than under fearful conditions [$F(1,24)=5.81$, $P<0.05$]. However, both the interaction between emotion and group and the main effects of group failed to reach statistical significance [$F(2,46)=0.62$, $P=0.54$; $F(1,23)=0.15$, $P=0.70$]. With respect to response times, no significant effect or interaction emerged for the emotion and group factors.

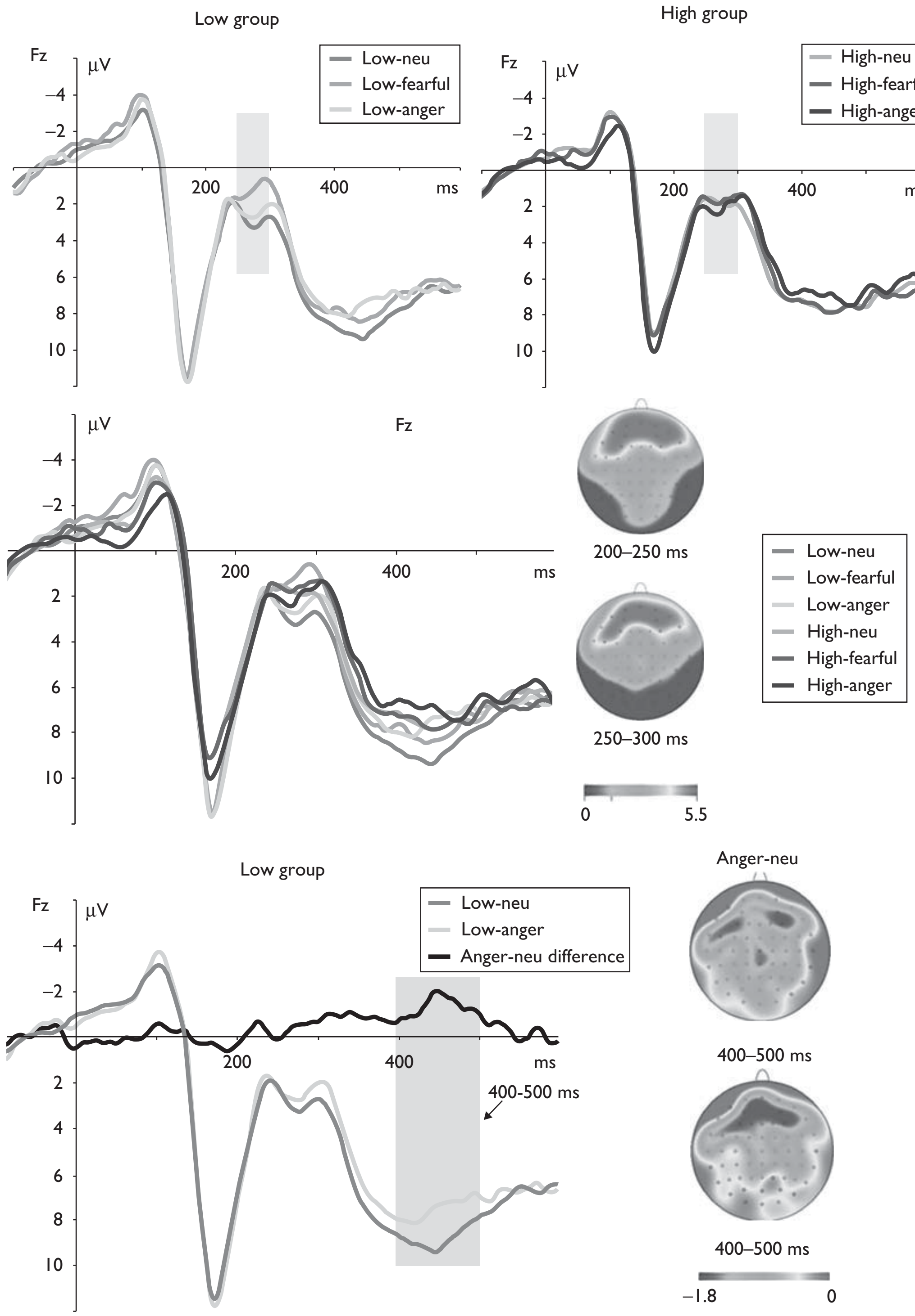
The significant main effects of emotion on mean ERP amplitudes were recorded at O1, O2, and Oz in the P1 time window (80–130 ms) for emotion [$F(2,46)=3.50$, $P<0.05$]. Pairwise comparison for the emotion main effect showed an enhanced amplitude for fearful compared with neutral conditions [$F(1,24)=5.62$, $P<0.05$]. Moreover, both the interaction between emotion and group and the main effects of group failed to reach statistical significance [$F(2,46)=3.07$, $P=0.06$; $F(1,23)=0.36$, $P=0.55$].

A main effect of emotion [$F(2,46)=3.49$, $P<0.05$] was observed for the mean ERP amplitudes recorded at PO7 and PO8 in the N170 time window (130–200 ms poststimulus), which reflected enhanced N170 amplitudes for angry compared with fearful [$F(1,24)=5.38$, $P<0.05$] and neutral [$F(1,24)=5.97$, $P<0.05$] faces, whereas angry versus neutral faces failed to achieve significance. There was no main effect or interaction involving the group factor.

In the 250–300 ms time window, there was a significant main effect of emotion over frontal/frontocentral electrodes [$F(2,46)=3.61$, $P<0.05$], which reflected enhanced amplitudes to fearful relative to neutral faces [$F(1,24)=6.41$, $P<0.05$]. Moreover, there was no significant main effect of group [$F(1,23)=0.11$, $P=0.78$]. It is noteworthy that there was a significant emotion × group interaction [$F(2,46)=3.45$, $P<0.05$]. Repeated-measures ANOVAs were analyzed separately in each group. These results indicated that fearful faces elicited enhanced negative amplitudes compared with neutral [$F(1,11)=13.19$, $P<0.01$] and angry [$F(1,11)=5.34$, $P<0.05$] faces in the low aggression group (Fig. 1), whereas there was no effect involving the emotion factor in highly aggressive individuals. These comparisons showed that ERP differences between fearful and other expressions were significantly smaller in highly aggressive participants compared with participants with low aggression.

In the 400–500 ms time window, the main effect of emotion reached significance [$F(2,46)=5.49$, $P<0.01$]. Pairwise comparison for the emotion main effect showed reduced positive amplitudes for angry faces compared with the neutral [$F(1,24)=10.05$, $P<0.01$] and fearful conditions [$F(1,24)=6.63$, $P<0.05$]. Both the group main

Fig. 1



Top: grand average ERP responses to angry (light grey), fearful (dark grey), and neutral (black) faces in the low aggression group ($N=12$) and to angry (black), fearful (dark grey), and neutral (light grey) faces in the highly aggressive group ($N=13$). Selected electrodes showed the early posterior negativity (EPN) and early frontal positivity at Fz. Middle: average ERP responses to six conditions at Fz. The topographical map of voltage amplitudes is also shown for the two time windows of interest (200–250, 250–300 ms) for the average ERP to show the general distribution of emotional expression effects. Bottom: average ERP responses to angry (light grey), neutral (dark grey) faces, and the angry minus neutral (black) difference waves at Fz. The topographical map of voltage amplitudes for the angry-neutral difference waves in the 400-ms to 500-ms interval. ERP, event-related potential.

effect and interaction between the two factors failed to achieve significance; however, an electrode × emotion × group interaction was found [$F(18,414) = 1.68$, $P < 0.05$], which reflected reduced positive ERP amplitudes for angry compared with fearful [$F(1,11) = 7.71$, $P < 0.05$] and neutral [$F(1,11) = 20.61$, $P < 0.001$] faces only for participants with low aggression, which was significant at Fz [$F(2, 46) = 3.98$, $P < 0.05$] (Fig. 1).

Discussion

Using an implicit emotional paradigm in the frame-distinguish task, the current study explored the temporal characteristics of different neural responses to angry and fearful expressions in aggression of individual difference. Consistent with our hypothesis, highly aggressive individuals did not show any significant differences in the specific neural response between angry and fearful faces in either time interval. In other words, compared with participants with low aggression, highly aggressive participants showed reduced negative amplitudes to fearful faces compared with angry and neutral faces at 250–300 ms as well as decreased negative amplitudes in response to angry faces compared with other expressions at 400–500 ms after the stimulus onset in frontal areas.

Importantly, because of the callous-unemotional traits of highly aggressive individuals [11,12], they are prone to deficits in processing negative stimuli [2,13,14]. Consistent with our hypothesis, highly aggressive participants did not show any distinct neural responses between the three different emotional conditions during either component. A previous study reported that aggression could modulate early frontocentral ERPs to angry faces at 200–300 ms after stimulus [4]. The current study presented new findings that aggression can modulate frontocentral ERPs to both fearful and angry faces during the early and later stages of facial processing, respectively. A series of studies carried out by Calder and colleagues [4] confirmed the modulatory function of the frontocentral region in negative emotion among high-aggression individuals. To be specific, the higher the degree of aggression, the less the activation in the ventral anterior cingulate region and the greater the activation observed in the amygdala [4]. Moreover, it has been shown that the extensive frontal region comprises many different cytoarchitectonic frontal areas, which contribute in distinct ways toward higher order control processes and modulate information in different ways [22]. It remains to be established in future studies how these areas contribute toward the modulation of emotional faces by low and highly aggressive individuals. At present, we propose that highly aggressive individuals show reduction of prefrontal activation and accordingly increase amygdala response, which makes these individuals more vigilant and more easily provoked. More importantly, the present study expands previous findings by providing evidence that aggression is associated with a reduced prefrontal neural response to threat-related expressions, which include both fearful and angry faces. These results confirmed our hypothesis that, compared with angry facial expressions, fearful faces are of more biologically and emotional salient significance, and thus induce an eminent response during the early stage of facial expression encoding. In contrast, angry faces elicit distinct neural responses during the later stage of facial processing when vigilant stimuli have been previously perceived and responded to.

Consistent with our hypothesis, aggression was associated with earlier inhibition by fearful faces and later inhibition by angry faces in the prefrontal area during facial processing. Compared with participants with low aggression, highly aggressive participants showed reduced negative amplitudes to fearful faces compared with angry and neutral faces at 250–300 ms in frontal areas. This finding was supported by a previous study, which reported strong prefrontal evoked fear-specific ERP responses at 220–280 ms after stimulus [16]. The negative response evoked at 250–300 ms in the prefrontal area matched the archetype of the N300 component and was most pronounced over the frontal cortex, which is aroused by negative-related stimuli [5,23]. Moreover, the anterior distribution of N300 may reflect an arousal dimension of the affective characteristics for visual stimuli [5–7]. Williams *et al.* [16] found that fear signals were prioritized in neural processing systems, such that the processing of positive signals may be suppressed until vigilance for potential danger is complete. In addition, the fear-specific response was consistent with the negativity bias [9,24], and negative stimuli with higher valence were prioritized during processing over other stimuli [17]. Thus, compared with angry faces, fearful expressions represented a stronger salient valence of negative emotion and thus reduced negative amplitude during the 250–300 ms interval in the anterior area of highly aggressive participants.

However, highly aggressive participants showed relatively decreased negative amplitudes for angry faces compared with other expressions at 400–500 ms after the stimulus onset. The 400–500 ms component fits the archetype of P300, which represents the higher-level phases of cognitive processing, such as the evaluation of information related to the affective valence of a face and inhibition control [9,10]. Previous studies have also shown that the P300 amplitude reflects the essentiality of an affective stimulus, which elicits larger P300 amplitudes compared with neutral stimuli. Cognitive evaluation plays an important role in producing and modulating emotion, and the P300 component is closely associated with cognitive evaluation of the meaning and importance of emotion [10]. Because the task required implicit emotion assessment, the emotional responses were considered irrelevant information and were involved in cognitive inhibition, most likely contributing toward the smaller amplitudes of P300 components during angry faces than during other expressions in low aggressive participants [23]. Moreover, the angry faces elicited more negative amplitudes during 400–500 ms in the frontocentral area, which is consistent with a previous similar study [15].

To further explore the neural mechanisms evoked by different negative facial expressions, a series of behavioral and ERP studies are necessary using different kinds of stimuli, paradigms, and participants with various personalities. This would considerably contribute toward our understanding of how aggression modulates different emotional responses to threatening information. Moreover, further research exploring the relationship between aggression and facial gaze direction is recommended.

Conclusion

In summary, consistent with our hypothesis, this study showed that aggression was associated with a decreased frontocentral response to fearful faces during 250–300 ms and to angry faces during 400–500 ms after stimulus. By exploring the distinct temporal characteristics of fearful and angry faces modulated by aggression, this study helped further knowledge of the detailed cognitive processes in aggressive individuals. A rapid automatic detection of danger is vital to quickly prepare the 'fight, flight, or freeze' response and enhance survival [4], and this frontal-related activation likely reflects the inhibition of emotional distraction to ensure that individuals appropriately allocate cognitive resources, with obvious implications for evolutionary functions. The implication of this result may be that certain social signal values are perceived differentially, not merely as negative.

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Conflicts of interest

There are no conflicts of interest.

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