Automatic Processing of Facial Width-to-Height Ratio

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Abstract

Research has found that high and low facial width-to-height ratio (fWHR) differ in their representation of actual aggressiveness in male individuals and in predicting others' evaluations of aggressive behavior; individuals with high fWHR not only exhibit stronger aggressiveness but are also perceived by others as having higher aggressive tendencies. However, the underlying neural mechanisms remain unclear, particularly the processing mechanisms of the two under non-attentional conditions. Therefore, this study employed visual mismatch negativity (vMMN) as an indicator to investigate the neural mechanisms of high and low fWHR processing under non-attentional conditions. In Experiment 1, faces with neutral expressions were presented to participants, who were required to perform a fixation point size detection task. The results revealed that high fWHR elicited vMMN at 200–500 ms, whereas low fWHR elicited vMMN at 200–250 ms and 300–350 ms, with the vMMN for high fWHR being larger than that for low fWHR at 300–350 ms. Experiment 2 presented angry and fearful faces; the results showed that high fWHR in angry faces elicited vMMN at 200–250 ms and 300–400 ms, while low fWHR in fearful faces elicited vMMN in the left hemisphere at 250–400 ms. Comparison between Experiments 1 and 2 revealed that angry emotion reduced the vMMN for high fWHR compared to neutral emotion. These results indicate that the automatic processing of fWHR, which is closely related to perceived individual aggressiveness levels, may be influenced by emotional information; angry emotion facilitates the automatic processing of high fWHR, whereas fearful emotion facilitates the automatic processing of low fWHR; however, possibly due to the influence of automatic emotional processing, angry emotion reduces the degree of automatic processing of high fWHR relative to neutral emotion.

Full Text

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Abstract

Previous research has demonstrated that facial width-to-height ratio (fWHR) differs in representing actual aggression in male individuals and in predicting how others evaluate their aggressive behavior. Individuals with high fWHR not only exhibit stronger aggression but are also perceived by others as having higher aggressive tendencies. However, the underlying neural mechanisms remain unclear, particularly regarding how high and low fWHR are processed under non-attentional conditions. Therefore, the present study used visual mismatch negativity (vMMN) as an index to investigate the neural mechanisms of high and low fWHR processing under non-attentional conditions. In Experiment 1, participants were presented with neutral emotional faces while performing a fixation cross size detection task. The results revealed that high fWHR elicited vMMN between 200–500 ms, whereas low fWHR elicited vMMN during 200–250 ms and 300–350 ms. Critically, high fWHR evoked larger vMMN than low fWHR during the 300–350 ms window. Experiment 2 presented angry and fearful faces and found that angry high fWHR elicited vMMN during 200–250 ms and 300–400 ms, while fearful low fWHR elicited vMMN in the left hemisphere during 250–400 ms. Comparing Experiments 1 and 2 revealed that angry emotion reduced vMMN for high fWHR relative to neutral emotion. These results suggest that the automatic processing of fWHR, which is closely related to perceived aggression levels, may be influenced by emotional information: angry emotion facilitates automatic processing of high fWHR, whereas fearful emotion facilitates automatic processing of low fWHR. However, due to the automatic processing of emotion itself, angry emotion appears to weaken the degree of automatic processing of high fWHR compared to neutral emotion.

Keywords: face, facial width-to-height ratio, emotion, vMMN, automatic processing

The facial width-to-height ratio (fWHR) refers to the ratio of facial width to height, where width is defined as the distance between the outermost points of the left and right zygion, and height as the distance between the brow center and the upper lip (Geniole & McCormick, 2015; Haselhuhn et al., 2015). Previous research has primarily focused on how fWHR influences individual psychological states and social behavior perception (Zheng et al., 2017). Studies have found significant gender differences in fWHR, with male individuals exhibiting larger ratios than females (Weston et al., 2007; Wong et al., 2011). Moreover, research on female fWHR has failed to yield significant relationships with social behavior (Goetz et al., 2013; Haselhuhn & Wong, 2012). Consequently, most fWHR studies have utilized male faces. A substantial body of evidence indicates that male fWHR serves as a reliable predictor of perceived antisocial behavior (Geniole et al., 2015; Haselhuhn et al., 2015). Compared to men with low fWHR, those with high fWHR are perceived as more threatening (Hehman, Leitner, & Gaertner, 2013), less trustworthy (Costa et al., 2017), and more likely to be evaluated as lacking cooperative spirit during intragroup competition (Stirrat et al., 2012).

The theoretical foundation for these findings primarily stems from Carré and McCormick's (2008) discovery of a correlation between fWHR and aggressive behavior, where higher fWHR is associated with stronger actual aggression. Researchers further observed that men with high fWHR are also rated as more behaviorally aggressive than their low fWHR counterparts (Carré et al., 2009), a pattern confirmed by subsequent studies (Costa et al., 2017; Geniole et al., 2015; Geniole et al., 2012; Lefevre et al., 2014). This relationship may be linked to testosterone, a physiological marker of aggression. Research has demonstrated a significant positive correlation between testosterone and actual aggressive behavior (Carré et al., 2011), and fWHR is considered a reliable external indicator of testosterone levels (Hehman, Leitner, Deegan & Gaertner, 2013; Lefevre et al., 2013). Thus, increased testosterone secretion may simultaneously enlarge fWHR and enhance aggressive behavior, suggesting that testosterone may constitute the physiological basis for the covariation between fWHR and aggression. Additionally, actual aggression levels correlate highly with perceived aggression (Carré et al., 2009), implying that testosterone may also contribute to higher perceived aggression in high fWHR individuals. However, this explanation fails to clarify the processing differences between high and low fWHR information, particularly regarding the temporal dynamics of their neural mechanisms.

Furthermore, researchers have proposed that these findings may arise from the close relationship between fWHR and facial emotion. Studies show that when presented with neutral faces, observers tend to interpret high fWHR as expressing anger and low fWHR as expressing fear. When faces display angry, fearful, or happy emotions, participants can quickly and accurately identify anger in high fWHR faces and fear/happiness in low fWHR faces (Deska et al., 2018), indicating that fWHR conveys emotional information independent of the face's actual emotion. Recent work confirms this: as fWHR increases, perceived anger intensity increases while perceived fear intensity decreases (Merlhiot et al., 2021). Merlhiot et al. (2021) also measured fWHR across emotions in the same individuals, finding that expressed emotion affects actual fWHR values. Specifically, compared to neutral expressions, anger and fear respectively lower and raise the brow center while raising and lowering the upper lip, thereby decreasing and increasing facial height without affecting width. Consequently, anger increases fWHR while fear decreases it. Moreover, angry expressions signal impending aggressive behavior, whereas fearful expressions signal detection of environmental threat (Adams et al., 2003), potentially making angry expressions perceived as more directly threatening than fearful ones. Thus, high and low fWHR appear closely linked to anger and fear, respectively. These findings suggest that anger and fear information conveyed through fWHR may serve as important cues underlying the relationship between fWHR and aggressive behavior (Carré et al., 2009).

Despite extensive research examining the relationship between fWHR and perceived aggression, little is known about the processing mechanisms of fWHR itself, particularly its automatic processing mechanisms—knowledge crucial for understanding how individuals rapidly identify threat signals. The human brain can rapidly and automatically process external information, especially socially significant information vital for survival (Haselton & Funder, 2006; Kovarski et al., 2017). In event-related potential (ERP) research with high temporal resolution, visual mismatch negativity (vMMN) serves as an index of preattentive automatic processing. vMMN refers to the ERP difference wave between infrequent task-irrelevant stimuli (deviants) and frequent task-irrelevant stimuli (standards) over posterior parieto-occipital regions, characterized by more negative amplitudes for deviants (Stefanics et al., 2014). Numerous studies have demonstrated vMMN elicitation by visual stimuli ranging from simple features (color, orientation; Czigler et al., 2002; Fu et al., 2003) to complex socially significant information such as facial emotion, gender, and age (Stefanics et al., 2012; Kecskés-Kovács et al., 2013; Csizmadia et al., 2021). This indicates that the brain can both rapidly detect simple visual features and automatically process complex visual stimuli. However, as a reliable indicator of actual aggression and predictor of perceived aggressive tendencies, the automatic processing mechanisms of fWHR remain unclear. Therefore, this study uses vMMN to investigate the automatic processing mechanisms of fWHR, aiming to provide evidence and new perspectives on how fWHR represents actual aggression and predicts perceived aggressive behavior.

Additionally, this study examines the sensitivity of early P1 and N170 components to fWHR. While P1 is sensitive to physical stimulus properties, recent research shows it reflects changes in facial perceptual information, with second-order configural information (e.g., interocular distance, nose-mouth distance) eliciting larger P1 amplitudes than featural information (Wang et al., 2015, 2016, 2020; Wang & Fu, 2018). The N170 component, known for its sensitivity to faces, primarily reflects structural encoding and is sensitive to configural changes (Eimer, 2011). Since both high and low fWHR represent configural information, we predicted no amplitude differences in P1 or N170. However, research shows N170 can distinguish neutral from specific emotional faces (Luo et al., 2010) and is sensitive to eye region information (Itier et al., 2006), which is crucial for recognizing anger and fear (Smith et al., 2005). Thus, whether N170 sensitivity to fWHR varies across emotions remains unclear. Furthermore, although the spatiotemporal distribution of N170 resembles early vMMN elicited by facial emotion, researchers suggest early vMMN reflects visual refractoriness, while late vMMN (post-200 ms) reflects automatic information processing (Kimura et al., 2009). Therefore, analyzing N170 sensitivity to probabilistic fWHR stimuli is necessary.

In summary, this study primarily uses vMMN to investigate the neural mechanisms of fWHR during preattentive processing, leveraging ERP's high temporal resolution to reveal the temporal dynamics of automatic processing for high and low fWHR. Experiment 1 employed neutral faces to examine automatic processing of high and low fWHR without specific emotional context. Previous research shows that second-order configural information—critical for identity, race, and emotion processing—elicits vMMN in occipitotemporal regions (Wang et al., 2022). Based on this, we expected both high and low fWHR, as configural information, to elicit vMMN. From an evolutionary perspective, rapidly detecting threatening, high-aggression signals is crucial for survival (Haselton & Funder, 2006). Thus, based on previous findings that high fWHR is perceived as more aggressive than low fWHR (Carré et al., 2009), we further predicted that high fWHR would elicit larger and longer-lasting vMMN than low fWHR. This prediction is also supported by behavioral findings that neutral high and low fWHR faces tend to be identified as angry and fearful, respectively (Deska et al., 2018), with anger conveying more direct threat than fear (Adams et al., 2003). Experiment 2 used angry and fearful faces to clarify emotion's role in the fWHR-aggression relationship. Given that high and low fWHR are respectively associated with anger and fear (Deska et al., 2018; Merlhiot et al., 2021), if emotion indeed mediates fWHR's prediction of perceived aggression, we expected angry expressions to facilitate automatic processing of high fWHR and fearful expressions to facilitate processing of low fWHR. Finally, comparing Experiments 1 and 2 allowed us to examine how explicit emotional cues affect the degree of automatic processing for high and low fWHR.

2.1 Method

2.1.1 Participants

Using G*Power (Faul et al., 2007), we calculated that a minimum of 33 participants (^{2}p = 0.06, power = 80%, $\alpha = 0.01$; Wang et al., 2022) were required for our 2 (fWHR: high vs. low) × 2 (stimulus type: standard vs. deviant) within-subjects design to detect vMMN differences between high and low fWHR faces. We ultimately recruited 41 participants (19 females, mean age = 21.05 ± 1.70 years). All participants were healthy with normal or corrected-to-normal vision and provided informed consent before the experiment. The study was approved by the Ethics Research Committee of the School of Psychology at Shandong Normal University.

2.1.2 Materials

Facial stimuli were selected from the Chinese Facial Affective Picture System (CAFPS; Gong et al., 2011). We used ImageJ (National Institutes of Health open-source software) to measure fWHR in 113 male neutral-expression faces (labeled as "calm" in the database)—calculating the distance between left and right zygion (width) and between brow center and upper lip (height; Carré & McCormick, 2008; Weston et al., 2007). Width divided by height yielded a mean fWHR of 1.620 ± 0.080. Following previous research (Carré et al., 2013), faces more than one standard deviation above the mean were classified as high fWHR, and those more than one standard deviation below as low fWHR. We selected three high fWHR faces (fWHR: 1.744, 1.745, 1.781) and three low fWHR faces (fWHR: 1.436, 1.520, 1.520; [Figure 1: see original paper]), with high fWHR values significantly exceeding low fWHR, $t(4) = 8.669$, $p = 0.001$, Cohen's $d = 0.962$.

According to database information, the emotion recognition rates for high and low fWHR neutral faces were 80.073% ± 5.362% vs. 76.087% ± 8.490%, respectively, with intensity ratings of 5.775 ± 0.075 vs. 5.608 ± 0.138 (1 = weakest, 9 = strongest). No significant differences emerged in emotion recognition or intensity ($ps \geq 0.466$), indicating that differences in emotional intensity and recognition were controlled and would minimally impact our primary fWHR analyses. We processed the faces using Photoshop CC 14.0 (Adobe Systems), resizing them to 6.6° × 7.7° (170 × 198 pixels).

[Figure 1: see original paper] Example of experimental stimuli. Neutral faces were used in Experiment 1; angry and fearful faces were used in Experiment 2.

2.1.3 Procedure

Experiment 1 employed a reverse oddball paradigm similar to previous studies (Stefanics et al., 2012; Wang et al., 2014; Wang et al., 2022). In this paradigm, the same stimulus serves as both deviant and standard across different blocks, allowing examination of vMMN elicited by physically identical stimuli while minimizing effects of low-level physical properties. The formal experiment comprised two blocks, each containing 300 trials: 240 standard stimuli (80%), 30 deviant stimuli (10%), and 30 target stimuli (10%). The fixation cross was size 24 for standards and deviants, and size 32 for targets, though target faces were always standard stimuli. All stimuli were presented randomly within each block, with block order counterbalanced across participants. In one block, high fWHR served as deviant and low fWHR as standard and target (10 and 90 presentations each, respectively). In the other block, low fWHR served as deviant and high fWHR as standard and target (90 and 10 presentations each).

Each trial began with a 200 ms fixation cross "+", followed by a 300 ms high or low fWHR stimulus, then a 450 ms response screen, and finally a random 600–800 ms inter-trial interval. The fixation cross remained onscreen throughout. Participants detected size changes in the cross during face presentation, pressing the F or J key when it enlarged (from size 24 to 32). Response timing began at stimulus onset, with response keys counterbalanced across participants. All stimuli were presented using E-Prime 2.0 (Pittsburgh, PA, USA) on a 19-inch Dell monitor (resolution: 1024 × 768 pixels; refresh rate: 60 Hz) positioned 60 cm from participants.

2.2 EEG Recording and Processing

EEG data were recorded using a Neuroscan system. Participants wore a 64-channel cap with vertical EOG (VEOG) recorded from electrodes above and below the left eye and horizontal EOG (HEOG) from electrodes 1.5 cm lateral to each eye. Impedance was maintained below 10 kΩ, sampling rate was 500 Hz, and filtering was set to 0.05–100 Hz. The physical reference electrode was positioned between CZ and CPZ. Raw data were preprocessed using letswave7 (https://letswave.cn), a MATLAB (R2015a, The MathWorks, Natick, MA) toolbox. We applied a 0.1–30 Hz band-pass filter, re-referenced to the average of all electrodes, and used independent component analysis to remove ocular artifacts. Epochs were segmented from −200 to 600 ms relative to face onset, with artifacts rejected using a $±$75 V threshold. Trial counts were: high fWHR deviant = 23.44 ± 3.96, high fWHR standard = 208.34 ± 37.66, low fWHR deviant = 24.29 ± 3.73, low fWHR standard = 218.78 ± 35.44.

Based on previous research (Kecskés-Kovács et al., 2013) and our topographical maps, we selected posterior electrodes P3/4, PO5/6, and PO7/8 for analysis. We conducted a 2 (fWHR: low, high) × 2 (stimulus type: deviant, standard) × 3 (electrode: P3/P4, PO5/PO6, PO7/PO8) × 2 (hemisphere: left, right) repeated-measures ANOVA on P1 (90–120 ms) and N170 (130–200 ms) amplitude (peak-to-baseline: vertical distance from highest/lowest point to baseline) and peak latency, as well as mean vMMN amplitude. Statistical analyses used SPSS Statistics 21.0 (Armonk, NY: IBM Corp). Greenhouse-Geisser correction was applied for non-sphericity, and Bonferroni correction for multiple comparisons and post-hoc tests.

Before conventional vMMN analysis, we conducted exploratory cluster-based permutation tests to determine temporal analysis windows and control for multiple comparisons. While conventional ERP analysis focuses on specific time windows at single or small electrode clusters, cluster-based permutation tests construct a null distribution assuming no difference between conditions (Maris & Oostenveld, 2007), enabling comparison of ERP amplitudes across all electrodes and time points (Sassenhagen & Draschkow, 2019). Although our design was two-factor, we performed paired t-tests comparing: (1) standard vs. deviant within high fWHR; (2) standard vs. deviant within low fWHR; and (3) vMMN (deviant minus standard) between high and low fWHR. This approach was adopted because cluster-based permutation tests may not guarantee ANOVA validity (Groppe et al., 2011), and previous studies using this method have employed paired t-tests (Vormbrock et al., 2023; Zochowska et al., 2021). We selected 0–600 ms post-stimulus as the permutation test window. Data points significant at $p < 0.05$ that were temporally and spatially adjacent formed clusters. The cluster-level statistic was the sum of t-values within each cluster, with significance tested via Monte Carlo simulation ($\alpha = 0.05$, 2000 randomizations).

2.3 Results

2.3.1 Behavioral Results

Paired t-tests on accuracy and reaction time (RT) showed no significant difference in accuracy between high fWHR targets (98.79% ± 0.25%) and low fWHR targets (98.96% ± 0.13%; p = 0.366). However, RTs were significantly faster for low fWHR targets (544 ± 7 ms) than high fWHR targets (563 ± 7 ms), t(40) = –5.851, p < 0.001, Cohen's d = 0.816, 95% CI = [–28.158, –12.454].

2.3.2 ERP Results

P1 Amplitude showed a significant main effect of hemisphere, F(1, 40) = 4.109, p = 0.049, ^{2}p = 0.093, but no significant main effect of fWHR (p = 0.825). **P1 Latency** revealed a significant main effect of stimulus type, F(1, 40) = 20.569, p < 0.001, ^{2}p = 0.340. A significant fWHR × stimulus type × electrode × hemisphere interaction emerged, F(2, 80) = 6.189, p = 0.005, ^{2}p = 0.134. High fWHR deviants elicited earlier P1 than standards at PO5/6 and PO7/8 (PO5: 113 ± 1 vs. 117 ± 1 ms, p = 0.024, 95% CI = [–0.006, –0.000]; PO6: 113 ± 1 vs. 115 ± 1 ms, p = 0.041, 95% CI = [–0.004, –0.001]; PO7: 110 ± 2 vs. 116 ± 1 ms, p = 0.001, 95% CI = [–0.009, –0.003]; PO8: 112 ± 1 vs. 115 ± 1 ms, p = 0.017, 95% CI = [–0.004, –0.000]). Low fWHR deviants also elicited earlier P1 than standards at PO8 (110 ± 2 vs. 114 ± 1 ms, p = 0.011, 95% CI = [–0.007, –0.001]).

N170 Amplitude showed a significant main effect of stimulus type, F(1, 40) = 11.128, p = 0.002, ^{2}p = 0.206, with deviants eliciting more negative N170 than standards (–1.419 ± 0.372 vs. –0.972 ± 0.551 V, 95% CI = [–0.717, –0.177]). The fWHR × stimulus type interaction was significant, F(1, 40) = 17.125, p < 0.001, ^{2}p = 0.285: high fWHR deviants elicited more negative N170 than standards (–1.717 ± 0.589 vs. –0.571 ± 0.534 V, p < 0.001, 95% CI = [–1.588, –0.703]), whereas low fWHR deviants did not differ from standards (p = 0.242). **N170 Latency** revealed a significant stimulus type × hemisphere interaction, F(1, 40) = 5.037, p = 0.027, ^{2}p = 0.117, with standards eliciting earlier N170 than deviants in the right hemisphere (168 ± 3 vs. 170 ± 3 ms, p = 0.048, 95% CI = [–0.004, –0.000]).

Cluster-based permutation tests revealed widespread spatiotemporal differences between standards and deviants for both fWHR levels. For high fWHR, deviants were more negative than standards across occipitotemporal regions (except P1, P2, PZ) from 228–600 ms post-stimulus. Conversely, for low fWHR, deviants were more positive than standards from 300–600 ms in occipitotemporal regions (P1, P3, PZ, PO3, PO4, PO5, PO7, PO8, POZ). Critically, comparing high vs. low fWHR vMMN revealed significant differences in occipitotemporal regions (P1, P3, P4, P5, P6, P7, P8, PO3, PO4, PO5, PO6, PO7, PO8, POZ) from 254–600 ms, with high fWHR vMMN significantly larger than low fWHR ([Figure 2: see original paper]). Based on these permutation results and previous vMMN analyses (200–440 ms, Wang et al., 2022), we selected 200–500 ms as our vMMN analysis window.

[Figure 2: see original paper] Experiment 1 cluster-based permutation test results. Topographic maps of p-values for clusters showing significant differences between high and low fWHR vMMN.

200–500 ms Analysis revealed a significant main effect of stimulus type, F(1, 40) = 52.173, $p < 0.001$, ^{2}p = 0.566, with deviants more negative than standards (2.576 ± 0.471 vs. 3.323 ± 0.449 V, 95% CI = [–0.955, –0.538]), confirming vMMN. The fWHR × stimulus type interaction was significant, F(1, 40) = 21.588, $p < 0.001$, ^{2}p = 0.351, as was the three-way interaction with electrode, F(2, 80) = 7.493, p = 0.004, ^{2}p = 0.158. Post-hoc tests showed high fWHR deviants were more negative than standards at P3/4, PO5/6, and PO7/8 (ps < 0.001; P3/4: 2.463 ± 0.386 vs. 3.282 ± 0.395 V, 95% CI = [–1.178, –0.460]; PO5/6: 2.617 ± 0.614 vs. 4.382 ± 0.585 V, 95% CI = [–2.276, –1.255]; PO7/8: 1.506 ± 0.545 vs. 3.463 ± 0.548 V, 95% CI = [–2.495, –1.420]). Low fWHR deviants did not differ from standards (ps $\geq$ 0.456), indicating that high fWHR elicits automatic processing.

Previous research suggests temporal dynamics in automatic processing of facial configural information (Wang et al., 2022). Our cluster-based permutation results also indicated temporal differences in vMMN between high and low fWHR. High fWHR vMMN emerged continuously from 228 ms post-stimulus at electrodes of interest (P3/4, PO5/6, PO7/8), whereas low fWHR vMMN appeared intermittently in 16–124 ms segments (mean = 50.44 ms) at P3, PO5, and PO7/8. To examine vMMN time courses more precisely, we conducted segmented analyses in 50 ms windows ([Figure 3: see original paper]), a approach used in previous facial vMMN studies (Kreegipuu et al., 2013; Wang et al., 2022; Wang et al., 2014). If significant interactions involving stimulus type emerged, particularly fWHR × stimulus type, with simple effects showing vMMN (deviants more negative than standards) for both high and low fWHR, we planned further vMMN analyses (deviant minus standard) to compare automatic processing strength.

[Figure 3: see original paper] Experiment 1 ERP waveforms (A) and 300–350 ms topographic maps (B). Difference waves represent ERPs elicited by deviants minus standards. (A) Shaded areas indicate time windows where deviants were more negative than standards (vMMN). (B) Yellow dots indicate electrodes where deviants were more negative than standards (P3/4, PO5/6, PO7/8).

200–250 ms showed a significant main effect of stimulus type, F(1, 40) = 23.502, $p < 0.001$, ^{2}p = 0.370, with deviants more negative than standards (4.117 ± 0.591 vs. 4.685 ± 0.582 V, 95% CI = [–0.804, –0.331]). The stimulus type × hemisphere interaction was significant, F(1, 40) = 4.537, p = 0.039, ^{2}p = 0.102, with vMMN present in both hemispheres (ps $\leq$ 0.003; left: 3.749 ± 0.622 vs. 4.137 ± 0.621 V, 95% CI = [–0.633, –0.143]; right: 4.485 ± 0.664 vs. 5.233 ± 0.654 V, 95% CI = [–1.079, –0.416]). vMMN was larger in the right hemisphere (p = 0.039, 95% CI = [–0.700, –0.018]).

250–300 ms revealed a significant main effect of stimulus type, F(1, 40) = 55.353, p < 0.001, ^{2}p = 0.581, with deviants more negative than standards (3.513 ± 0.552 vs. 4.496 ± 0.531 V, 95% CI = [–1.250, –0.716]). Critically, the fWHR × stimulus type interaction was significant, F(1, 40) = 11.149, p = 0.002, ^{2}p = 0.218: high fWHR deviants were more negative than standards (3.273 ± 0.562 vs. 4.869 ± 0.553 V, p < 0.001, 95% CI = [–2.043, –1.150]), while low fWHR deviants did not differ (p = 0.119). The stimulus type × hemisphere interaction was also significant, F(1, 40) = 4.733, p = 0.036, ^{2}p = 0.106, with larger right-hemisphere vMMN (p = 0.036, 95% CI = [–0.733, –0.027]).

300–350 ms showed a significant main effect of stimulus type, F(1, 40) = 72.457, p < 0.001, ^{2}p = 0.644, with deviants more negative than standards (2.368 ± 0.511 vs. 3.313 ± 0.490 V, 95% CI = [–1.168, –0.720]). The fWHR × stimulus type interaction was significant, F(1, 40) = 16.713, p < 0.001, ^{2}p = 0.295: high fWHR deviants were more negative than standards (2.026 ± 0.532 vs. 3.725 ± 0.510 V, p < 0.001, 95% CI = [–2.114, –1.284]), while low fWHR deviants did not differ (p = 0.405). The fWHR × stimulus type × hemisphere interaction was significant, F(1, 40) = 6.436, p = 0.015, ^{2}p = 0.139. In the left hemisphere, high fWHR deviants were more negative than standards (1.820 ± 0.544 vs. 3.490 ± 0.535 V, p < 0.001, 95% CI = [–2.115, –1.224]). In the right hemisphere, both high and low fWHR deviants were more negative than standards (ps ≤ 0.009; high: 2.231 ± 0.628 vs. 3.959 ± 0.591 V, 95% CI = [–2.217, –1.240]; low: 2.563 ± 0.648 vs. 3.256 ± 0.588 V, 95% CI = [–1.207, –0.179]). vMMN analysis revealed larger vMMN for high than low fWHR in the right hemisphere (–1.728 ± 0.242 vs. –0.693 ± 0.254 V, p = 0.010, 95% CI = [–1.804, –0.266]).

350–400 ms showed a significant main effect of stimulus type, F(1, 40) = 21.817, p < 0.001, ^{2}p = 0.353, with deviants more negative than standards (2.654 ± 0.454 vs. 3.236 ± 0.418 V, 95% CI = [–0.834, –0.330]). The fWHR × stimulus type interaction was significant, F(1, 40) = 32.146, p < 0.001, ^{2}p = 0.446: high fWHR deviants were more negative than standards (2.104 ± 0.483 vs. 3.692 ± 0.443 V, p < 0.001, 95% CI = [–2.064, –1.113]), while low fWHR standards were more negative than deviants (2.780 ± 0.419 vs. 3.205 ± 0.470 V, p = 0.037, 95% CI = [–0.823, –0.027]). The stimulus type × hemisphere interaction was significant, F(1, 40) = 8.960, p = 0.005, ^{2}p = 0.183, with larger right-hemisphere vMMN (p = 0.005, 95% CI = [–0.862, –0.167]).

400–450 ms revealed a significant main effect of stimulus type, F(1, 40) = 31.429, p < 0.001, ^{2}p = 0.440, with deviants more negative than standards (1.764 ± 0.449 vs. 2.453 ± 0.421 V, 95% CI = [–0.913, –0.426]). The fWHR × stimulus type interaction was significant, F(1, 40) = 30.727, p < 0.001, ^{2}p = 0.434: high fWHR deviants were more negative than standards (1.163 ± 0.463 vs. 2.936 ± 0.431 V, p < 0.001, 95% CI = [–2.231, –1.316]), while low fWHR deviants did not differ (p = 0.077).

450–500 ms showed a significant main effect of stimulus type, F(1, 40) = 34.891, p < 0.001, ^{2}p = 0.466, with deviants more negative than standards

(0.991 ± 0.452 vs. 1.722 ± 0.422 V, 95% CI = [–0.981, –0.481]). The fWHR × stimulus type interaction was significant, F(1, 40) = 36.899, $p < 0.001$, ^{2}p = 0.480: high fWHR deviants were more negative than standards (0.331 ± 0.449 vs. 2.231 ± 0.434 V, $p < 0.001$, 95% CI = [–1.889, –0.752]), while low fWHR standards were more negative than deviants (1.212 ± 0.431 vs. 1.651 ± 0.497 V, $p < 0.001$, 95% CI = [–1.392, –0.646]).

In summary, analyses of the 200–500 ms window revealed that fWHR elicits vMMN. Specifically, high fWHR evoked vMMN across the entire window, whereas low fWHR only elicited vMMN during 200–250 ms and 300–350 ms. Although low fWHR showed significant differences during 350–400 ms and 450–500 ms, these reflected standards being more negative than deviants—a pattern termed visual mismatch positivity (vMMP; Sulykos & Czigler, 2011) rather than vMMN. Notably, vMMN analysis revealed larger vMMN for high than low fWHR during 300–350 ms. These results indicate that, compared to low fWHR, high fWHR undergoes longer and stronger automatic processing.

3.1 Method

3.1.1 Participants

G*Power analysis (Faul et al., 2007) indicated that at least 22 participants (^{2}p = 0.06, power = 80%, $\alpha = 0.01$) were needed to detect the interaction in a 2 (emotion: angry vs. fearful) × 2 (fWHR: high vs. low) × 2 (stimulus type: standard vs. deviant) repeated-measures design. Twenty-five participants (13 females, mean age = 20.56 ± 1.635 years) completed Experiment 2. All were healthy with normal or corrected-to-normal vision and provided informed consent. The study was approved by the Ethics Research Committee of the School of Psychology at Shandong Normal University.

3.1.2 Materials

We selected 37 male fearful and 37 male angry faces from the CAFPS database. Using ImageJ, we measured fWHR for fearful faces (mean = 1.760 ± 0.152) and angry faces (mean = 1.690 ± 0.153). Faces exceeding one standard deviation above the mean were classified as high fWHR, and those below one standard deviation as low fWHR. This yielded six high fWHR angry faces (fWHR = 1.949 ± 0.147), six high fWHR fearful faces (fWHR = 2.000 ± 0.135), six low fWHR angry faces (fWHR = 1.505 ± 0.058), and six low fWHR fearful faces (fWHR = 1.558 ± 0.067; [Figure 1: see original paper]). High fWHR values were significantly greater than low fWHR for both angry, t(10) = 6.262, $p < 0.001$, Cohen's d = 0.874, and fearful expressions, t(10) = 6.568, $p < 0.001$, Cohen's d = 0.885. According to database information, emotion recognition rates for high vs. low fWHR angry faces were 81.313% ± 12.218% vs. 75.597% ± 15.152%, with intensity ratings of 6.305 ± 1.658 vs. 6.153 ± 1.285. For fearful faces, recognition rates were 73.232% ± 7.498% vs. 72.317% ± 9.425%, with intensity ratings of 6.003 ± 0.762 vs. 6.354 ± 1.189. Separate 2 (fWHR: high, low) × 2 (emotion: angry, fearful) ANOVAs on recognition rates and intensity revealed no significant differences (ps $\geq$ 0.359), indicating that emotional intensity and recognition were controlled and would not substantially affect our primary fWHR analyses.

3.1.3 Procedure

Experiment 2 used the same reverse oddball paradigm as Experiment 1, comprising four blocks: two with angry faces and two with fearful faces. Each block contained 600 trials: 420 standards (70%), 120 deviants (20%), and 60 targets (10%). The fixation cross was size 24 for standards and deviants, and size 32 for targets, which always displayed standard faces. Other parameters matched Experiment 1. For angry faces, one block presented high fWHR angry faces as deviants and low fWHR angry faces as standards and targets (20 and 80 presentations each), while the other block reversed these roles (80 and 20 presentations). The same structure applied to fearful faces.

3.2 EEG Recording and Processing

EEG recording and analysis methods were identical to Experiment 1. Trial counts were: high fWHR angry deviant = 110.44 ± 18.29, low fWHR angry standard = 390.08 ± 61.45, low fWHR angry deviant = 106.16 ± 17.76, high fWHR angry standard = 366.40 ± 64.78; high fWHR fearful deviant = 107.72 ± 16.87, low fWHR fearful standard = 379.76 ± 54.76, low fWHR fearful deviant = 112.32 ± 13.15, high fWHR fearful standard = 392.52 ± 47.23. We conducted a 2 (fWHR: low, high) × 2 (stimulus type: deviant, standard) × 2 (emotion: angry, fearful) × 3 (electrode: P3/P4, PO5/PO6, PO7/PO8) × 2 (hemisphere: left, right) repeated-measures ANOVA on P1 (90–120 ms) and N170 (130–200 ms) amplitude (peak-to-baseline) and latency, as well as vMMN mean amplitude. Greenhouse-Geisser and Bonferroni corrections were applied as in Experiment 1. Cluster-based permutation tests used paired t-tests comparing: (1) standard vs. deviant differences; (2) vMMN differences between angry and fearful conditions for high fWHR; and (3) vMMN differences between angry and fearful conditions for low fWHR.

3.3 Results

3.3.1 Behavioral Results

Accuracy for angry high fWHR, angry low fWHR, fearful high fWHR, and fearful low fWHR target faces was 99.19% ± 0.17%, 99.38% ± 0.11%, 99.32% ± 0.13%, and 99.36% ± 0.12%, respectively. RTs were 580 ± 12 ms, 582 ± 12 ms, 570 ± 12 ms, and 567 ± 12 ms. Separate 2 (fWHR: low, high) × 2 (emotion: angry, fearful) ANOVAs showed no significant effects on accuracy (ps $\geq$ 0.092). For RTs, a significant main effect of emotion emerged, $F(1, 24) = 10.437$, $p = 0.004$, $^2p = 0.303$, with angry faces eliciting slower responses than fearful faces

(581 ± 12 vs. 568 ± 12 ms, 95% CI = [4.593, 20.840]). No other effects were significant (ps ≥ 0.485).

3.3.2 ERP Results

P1 Amplitude showed a significant main effect of stimulus type, F(1, 24) = 7.006, p = 0.014, ^{2}p = 0.226, with deviants eliciting more positive P1 than standards (3.698 ± 0.236 vs. 3.572 ± 0.217 V, 95% CI = [0.028, 0.225]). The fWHR main effect was not significant (p = 0.188). The emotion × fWHR interaction was significant, F(1, 24) = 5.892, p = 0.023, ^{2}p = 0.197, as was the emotion × fWHR × hemisphere interaction, F(1, 24) = 5.781, p = 0.024, ^{2}p = 0.194. In the left hemisphere, high fWHR fearful faces elicited larger P1 than angry faces (3.295 ± 0.240 vs. 3.002 ± 0.210 V, p = 0.004, 95% CI = [0.102, 0.485]).

P1 Latency revealed a significant main effect of emotion, F(1, 24) = 6.820, p = 0.015, ^{2}p = 0.221, and an emotion × hemisphere interaction, F(1, 24) = 5.041, p = 0.034, ^{2}p = 0.174. In the right hemisphere, angry faces elicited earlier P1 than fearful faces (114 ± 1 vs. 116 ± 1 ms, p = 0.007, 95% CI = [–0.002, –0.000]).

N170 Amplitude showed a significant emotion × fWHR × hemisphere interaction, F(1, 24) = 5.646, p = 0.026, ^{2}p = 0.190. In the right hemisphere, angry high fWHR elicited more negative N170 than low fWHR (–3.355 ± 0.703 vs. –3.057 ± 0.697 V, p = 0.008, 95% CI = [–0.444, –0.229]). No other differences were significant (ps ≥ 0.161).

N170 Latency revealed significant main effects of emotion, F(1, 24) = 9.276, p = 0.006, ^{2}p = 0.279, and fWHR, F(1, 24) = 26.999, p < 0.001, ^{2}p = 0.529, with high fWHR eliciting earlier N170 than low fWHR (180 ± 2 vs. 182 ± 2 ms, 95% CI = [–0.003, –0.001]). The emotion × fWHR interaction was significant, F(1, 24) = 5.122, p = 0.033, ^{2}p = 0.176, as was the three-way interaction with electrode, F(2, 48) = 4.904, p = 0.018, ^{2}p = 0.170. At PO5/6, both angry and fearful expressions showed earlier N170 for high vs. low fWHR (angry: 180 ± 2 vs. 184 ± 2 ms, p = 0.002, 95% CI = [–0.006, –0.002]; fearful: 183 ± 2 vs. 184 ± 2 ms, p = 0.004, 95% CI = [–0.003, –0.001]). At PO7/8, angry high fWHR elicited earlier N170 than low fWHR (178 ± 2 vs. 182 ± 2 ms, p < 0.001, 95% CI = [–0.005, –0.002]).

[Figure 4: see original paper] Experiment 2 ERP waveforms. A: Angry faces. B: Fearful faces. Difference waves represent deviants minus standards; shaded areas indicate vMMN time windows.

Cluster-based permutation tests revealed that across frontal, central, and parietal regions (AF4, F2, F4, F6, FC1, FC2, FC4, CZ, C1, C2, C4, C6, CPZ, CP1, CP2, CP4, CP6, PZ, P1, P2, POZ), standards were more negative than deviants from 194–430 ms post-stimulus. No differences in vMMN between high and low fWHR across emotions were found. Although permutation tests did not detect vMMN at our electrodes of interest (P3/4, PO5/6, PO7/8), we used the same time window and electrodes as Experiment 1 for comparative purposes.

200–500 ms Analysis showed a significant main effect of stimulus type, F(1, 24) = 7.422, p = 0.012, ^{2}p = 0.236, with deviants more negative than standards (1.186 ± 0.424 vs. 1.328 ± 0.392 V, 95% CI = [–0.249, –0.034]), confirming vMMN. The fWHR main effect was significant, F(1, 24) = 70.097, p < 0.001, ^{2}p = 0.745, with high fWHR eliciting more positive amplitudes than low fWHR (1.402 ± 0.408 vs. 1.112 ± 0.407 V, 95% CI = [0.218, 0.361]). The emotion × fWHR × hemisphere interaction was significant, F(1, 24) = 6.287, p = 0.019, ^{2}p = 0.208. In both hemispheres, angry high fWHR elicited more positive amplitudes than low fWHR (left: 1.130 ± 0.368 vs. 0.754 ± 0.358 V, p ≤ 0.046, 95% CI = [0.259, 0.493]; right: 1.461 ± 0.529 vs. 1.315 ± 0.507 V, 95% CI = [0.003, 0.288]). The same pattern held for fearful faces (left: 1.179 ± 0.331 vs. 0.883 ± 0.349 V, 95% CI = [0.133, 0.459]; right: 1.839 ± 0.502 vs. 1.496 ± 0.514 V, 95% CI = [0.192, 0.493]).

To clarify vMMN time courses for angry and fearful high and low fWHR faces, we conducted segmented 50 ms analyses ([Figure 4: see original paper]) as in Experiment 1. Our prediction would be supported by significant emotion × fWHR × stimulus type interactions, with simple effects showing vMMN for both angry and fearful high and low fWHR faces, enabling further vMMN comparisons.

200–250 ms showed a significant main effect of stimulus type, F(1, 24) = 5.909, p = 0.023, ^{2}p = 0.198, with deviants more negative than standards (1.417 ± 0.462 vs. 1.555 ± 0.433 V, 95% CI = [–0.256, –0.021]). The fWHR main effect was significant, F(1, 24) = 118.363, p < 0.001, ^{2}p = 0.831. Critically, the emotion × fWHR × stimulus × electrode × hemisphere interaction was significant, F(2, 48) = 3.832, p = 0.032, ^{2}p = 0.138. At P4/PO8, angry high fWHR deviants were more negative than standards (P4: 2.291 ± 0.547 vs. 2.694 ± 0.542 V, p = 0.039, 95% CI = [–0.784, –0.022]; PO8: 1.298 ± 0.669 vs. 1.966 ± 0.664 V, p = 0.011, 95% CI = [–1.166, –0.169]). No other conditions differed (ps ≥ 0.119).

250–300 ms revealed a significant main effect of stimulus type, F(1, 24) = 12.851, p = 0.001, ^{2}p = 0.349, with deviants more negative than standards (2.041 ± 0.551 vs. 2.237 ± 0.530 V, 95% CI = [–0.309, –0.083]). The fWHR main effect was significant, F(1, 24) = 89.960, p < 0.001, ^{2}p = 0.789. The emotion × fWHR × stimulus × electrode × hemisphere interaction was significant, F(2, 48) = 3.488, p = 0.044, ^{2}p = 0.127. At PO6, angry low fWHR deviants were more negative than standards (2.467 ± 0.808 vs. 2.957 ± 0.820 V, p = 0.040, 95% CI = [–0.955, –0.024]). At PO5, fearful low fWHR deviants were more negative than standards (1.484 ± 0.600 vs. 1.911 ± 0.551 V, p = 0.026, 95% CI = [–0.797, –0.056]).

300–350 ms showed a significant main effect of stimulus type, F(1, 24) = 8.056, p = 0.009, ^{2}p = 0.251, with deviants more negative than standards (1.101 ± 0.489 vs. 1.291 ± 0.463 V, 95% CI = [–0.329, –0.052]). The fWHR main effect was significant, F(1, 24) = 86.854, p < 0.001, ^{2}p = 0.783. The emotion × fWHR × stimulus × electrode × hemisphere interaction was significant, F(2, 48) = 4.101, p = 0.025, ^{2}p = 0.146. At P3/PO5/PO8, angry high fWHR deviants were more negative than standards (P3: 1.068 ± 0.361 vs. 1.492 ± 0.291 V, p = 0.009, 95% CI = [–0.731, –0.116]; PO5: 0.689 ± 0.580 vs. 1.097 ± 0.525 V, p = 0.044, 95% CI = [–0.804, –0.012]; PO8: 0.775 ± 0.636 vs. 1.348 ± 0.702 V, p = 0.049, 95% CI = [–1.143, –0.002]). At PO5, fearful low fWHR deviants were more negative than standards (0.239 ± 0.538 vs. 0.820 ± 0.510 V, p = 0.022, 95% CI = [–1.069, –0.092]). vMMN analysis at PO5 showed no difference between angry high fWHR and fearful low fWHR, t(24) = 0.649, p = 0.522, 95% CI = [–0.376, 0.722].

350–400 ms revealed a significant main effect of stimulus type, F(1, 24) = 6.866, p = 0.015, ^{2}p = 0.222, with deviants more negative than standards (0.965 ± 0.411 vs. 1.121 ± 0.380 V, 95% CI = [–0.279, –0.033]). The fWHR main effect was significant, F(1, 24) = 15.172, p = 0.001, ^{2}p = 0.387. Although the emotion × fWHR × stimulus × electrode × hemisphere interaction was not significant, F(2, 48) = 2.515, p = 0.098, ^{2}p = 0.095, the effect size was medium and main effects indicated vMMN. Follow-up analyses revealed that at P3 and PO8, angry high fWHR deviants were more negative than standards (P3: 0.613 ± 0.307 vs. 0.979 ± 0.229 V, p = 0.031, 95% CI = [–0.696, –0.036]; PO8: 0.730 ± 0.553 vs. 1.343 ± 0.587 V, p = 0.035, 95% CI = [–1.180, –0.047]). At PO5, fearful low fWHR deviants were more negative than standards (0.657 ± 0.435 vs. 1.109 ± 0.390 V, p = 0.035, 95% CI = [–0.870, –0.035]).

400–450 ms showed a significant fWHR main effect, F(1, 24) = 4.318, p = 0.049, ^{2}p = 0.152, and fWHR × hemisphere interaction, F(1, 24) = 6.225, p = 0.020, ^{2}p = 0.206, with high fWHR more positive than low fWHR in the left hemisphere (1.153 ± 0.341 vs. 0.950 ± 0.339 V, p = 0.004, 95% CI = [0.071, 0.334]). The stimulus type × electrode interaction was significant, F(2, 48) = 5.981, p = 0.016, ^{2}p = 0.199, with deviants more negative than standards only at PO7/8 (1.049 ± 0.446 vs. 1.282 ± 0.388 V, p = 0.044, 95% CI = [–0.460, –0.007]). No other differences were significant (ps ≥ 0.199).

450–500 ms revealed a significant fWHR main effect, F(1, 24) = 9.170, p = 0.006, ^{2}p = 0.276, with high fWHR more positive than low fWHR (0.682 ± 0.361 vs. 0.543 ± 0.536 V, 95% CI = [0.044, 0.234]).

In summary, fWHR elicited vMMN across 200–450 ms. Specifically, angry high fWHR evoked vMMN during 200–250 ms and 300–400 ms, angry low fWHR evoked vMMN in the right hemisphere during 250–300 ms, and fearful low fWHR evoked vMMN in the left hemisphere during 250–400 ms. No differences emerged between angry high fWHR and fearful low fWHR vMMN in overlapping time windows and electrodes. These findings suggest that angry emotion primarily facilitates automatic processing of high fWHR faces, while fearful emotion facilitates processing of low fWHR faces, with no difference in facilitation magnitude. Notably, the overall 200–500 ms analysis did not reveal the predicted emotion × fWHR × stimulus type interaction, which only emerged in segmented analyses. This suggests that automatic processing of emotional fWHR information may have distinct temporal windows, possibly because emotion processing itself varies across time windows (Zeng et al., 2021), which may influence the automatic processing of fWHR as perceptual information.

4 Experiment 1 vs. Experiment 2

Although some studies found that angry expressions increase fWHR and fearful expressions decrease it compared to neutral (Merlhiot et al., 2021), a 2 (fWHR: low, high) × 3 (emotion: neutral, angry, fearful) ANOVA on fWHR values from our experiments revealed no emotion effect, F(2, 4) = 1.119, p = 0.411. This discrepancy may stem from our use of different identity faces across experiments. However, this lack of difference enhances the validity of cross-experiment vMMN comparisons, as differences in automatic processing between neutral and emotional fWHR are less likely confounded by physical fWHR differences. A 2 (fWHR: low, high) × 3 (emotion: neutral, angry, fearful) ANOVA on behavioral data revealed only a significant fWHR × emotion interaction for RTs, F(2, 88) = 5.864, p = 0.004, ^{2}p = 0.118. Follow-up tests showed faster RTs for neutral than angry high fWHR targets (p = 0.020), with no other differences (ps $\geq$ 0.307). Additionally, ANOVAs on emotion intensity and recognition rates showed no significant differences (ps $\geq$ 0.232).

To further examine how explicit emotional cues affect automatic processing of high and low fWHR, we compared vMMN between neutral and angry high fWHR faces and between neutral and fearful low fWHR faces. For high fWHR, both neutral and angry faces elicited vMMN at overlapping electrodes and time windows: 200–250 ms at P4; 300–350 ms at P3/PO5/PO8; and 350–400 ms at P3/PO8 (). Independent samples t-tests revealed larger vMMN for neutral than angry faces at PO5/PO8 during 300–350 ms (PO5: t(64) = –3.654, p = 0.001, Cohen's d = 0.272, 95% CI = [–2.180, –0.639]; PO8: t(64) = –3.455, p = 0.001, Cohen's d = 0.289, 95% CI = [–2.581, –0.690]) and at PO8 during 350–400 ms (t(64) = –3.279, p = 0.002, Cohen's d = 0.305, 95% CI = [–2.538, –0.617]). For low fWHR, neutral and fearful faces showed no overlapping vMMN time windows or electrodes (), precluding further analysis. These results demonstrate that explicit emotional cues affect automatic processing of high fWHR: angry emotion weakens automatic processing compared to neutral emotion.

Time windows for vMMN elicited by neutral and angry high fWHR faces. Note: Values represent p-values for conditions where deviants were more negative than standards.

Time windows for vMMN elicited by neutral and fearful low fWHR faces. Note: Values represent p-values for conditions where deviants were more negative than standards.

General Discussion

This study investigated vMMN elicited by high and low fWHR to provide new perspectives on how fWHR represents actual aggression and predicts perceived aggression during preattentive processing. Experiment 1 used neutral faces and found that high fWHR elicited vMMN from 200–500 ms, whereas low fWHR only elicited vMMN during 200–250 ms and 300–350 ms. Critically, high fWHR evoked larger vMMN than low fWHR during 300–350 ms, indicating that the brain distinguishes high and low fWHR during preattentive processing with greater automatic processing of high fWHR. Experiment 2 presented angry and fearful faces, revealing that angry high fWHR elicited vMMN during 200–250 ms and 300–400 ms, angry low fWHR elicited right-hemisphere vMMN during 250–300 ms, and fearful low fWHR elicited left-hemisphere vMMN during 250–400 ms. These findings suggest that angry and fearful emotions respectively facilitate automatic processing of high and low fWHR, with angry high fWHR processing occurring earlier than fearful low fWHR processing. Comparing experiments revealed that angry emotion weakened automatic processing of high fWHR relative to neutral emotion.

Consistent with previous findings that facial configural information undergoes automatic processing (Wang et al., 2022), our study demonstrates that fWHR—a type of configural information—also elicits vMMN. More importantly, Experiment 1 revealed that high and low fWHR differ not only in temporal windows but also in processing strength. Specifically, for neutral faces, high fWHR showed longer automatic processing windows and greater strength during 300–350 ms, aligning with our predictions. This may relate to perceived aggression levels, as high fWHR is perceived as more aggressive than low fWHR (Carré et al., 2009), leading to stronger and longer automatic processing of threat-related high fWHR.

This pattern may also reflect emotion cues conveyed by fWHR. Emotion research shows P1 and N170 are sensitive to angry and fearful expressions, respectively (Batty & Taylor, 2003), suggesting different processing time courses for these emotions. A meta-analysis of emotional face vMMN revealed that while few studies directly compare angry and fearful vMMN (Zeng et al., 2021), separate studies show angry vMMN across 100–500 ms (Kovarski et al., 2017) and fearful vMMN during 180–220 ms (Chen et al., 2020), indicating temporal differences. Meanwhile, behavioral research shows neutral high fWHR is perceived as angry and low fWHR as fearful (Deska et al., 2018; Merlhiot et al., 2021). Thus, the anger and fear cues represented by high and low fWHR may explain our Experiment 1 results.

Furthermore, differences in vMMN between high and low fWHR may relate to different types of threat signals conveyed by anger and fear. Anger signals impending aggressive behavior, while fear signals detection of environmental threat (Adams et al., 2003), making angry expressions potentially more directly threatening and eliciting stronger, longer automatic processing than fear. This aligns with findings that emotional faces elicit vMMN through emotional category information rather than basic visual features (Li et al., 2012; Stefanics et al., 2012). Consistent with this emotion-cue interpretation, Experiment 2 demonstrated that angry and fearful expressions respectively facilitated automatic processing of high and low fWHR, suggesting emotion plays an important role in how fWHR represents aggression during preattentive processing. Because angry expressions convey direct threat, angry low fWHR also elicited some vMMN.

Based on research highlighting emotion's role in fWHR's prediction of perceived aggression (Carré et al., 2009), we expected angry high fWHR to show stronger automatic processing than neutral high fWHR. However, cross-experiment comparisons revealed the opposite: neutral faces enhanced late (300–400 ms) automatic processing of high fWHR compared to angry faces. This may reflect automatic processing of facial emotion itself. Although faces were task-irrelevant, their central presentation may have captured attention, particularly for socially significant emotions (Zeng et al., 2021). Research shows angry and fearful expressions undergo early and prolonged automatic processing (Chen et al., 2020; Kovarski et al., 2017). Our behavioral results support this: angry faces slowed fixation detection, and cross-experiment comparisons showed slower RTs for angry than neutral high fWHR targets. This suggests that directly threatening angry faces captured more attention, potentially reducing automatic processing of fWHR as perceptual information. Alternatively, this pattern may relate to our control of fWHR across emotions. While Merlhiot et al. (2021) found angry expressions increase fWHR, our cross-experiment comparison showed no difference between neutral and angry high fWHR values, potentially reducing perceived aggression and weakening automatic processing. This aligns with Geniole et al. (2015) in suggesting that whether fWHR's prediction of perceived aggression depends on facial emotion requires further investigation.

Additionally, Experiment 1's difference in automatic processing between neutral high and low fWHR emerged relatively late (300–350 ms), possibly reflecting emotion processing time courses. Studies show later components like P3 (350–500 ms) and N300 (250–350 ms) in occipitotemporal regions distinguish specific facial emotions (Luo et al., 2010). In contrast, while Experiment 2 found both angry high fWHR and fearful low fWHR elicited vMMN at PO5 during 300–350 ms, their magnitudes did not differ. This may also reflect emotion capturing attention and reducing fWHR automatic processing. Although debate exists over whether N170 differences between deviants and standards reflect refractoriness or automatic processing (Kimura et al., 2009), Experiment 1's N170 results showing more negative amplitudes for high fWHR deviants were not replicated in Experiment 2, suggesting emotional fWHR automatic processing may be reduced by emotion processing. Regarding potential confounds from fWHR's physical properties, early P1 analyses in both experiments showed no differences between high and low fWHR, consistent with our prediction that configural information does not differ at P1. N170 sensitivity to fWHR varied by emotion, with high fWHR only showing enhanced sensitivity during angry expressions, possibly because this condition predicts higher perceived aggression. Experiment 1 also revealed right-hemisphere dominance in fWHR automatic processing across multiple time windows, consistent with right-lateralized configural processing for neutral faces (Wang & Fu, 2018).

Notably, cluster-based permutation tests in both experiments revealed standard-deviant differences across broader spatiotemporal regions, supplementing our ERP results. Experiment 1's permutation results aligned well with ERP findings, showing that high fWHR elicited vMMN across broader regions and time windows than low fWHR, with larger vMMN across occipitotemporal, frontal, and central regions. Frontal and central automatic processing of high fWHR may relate to these regions' involvement in aggressive response processing (Peterson et al., 2008). However, Experiment 2's permutation results differed from ERP findings, showing no role of anger and fear in facilitating high and low fWHR automatic processing. This discrepancy may reflect methodological differences: ERP analysis focuses on specific electrodes and time windows, while permutation tests compare signals across all electrodes and time points (Sassenhagen & Draschkow, 2019). Experiment 2's interaction effects were localized to few electrodes and time points, which permutation tests are less likely to detect (Groope et al., 2011). Furthermore, Sassenhagen and Draschkow (2019) note that cluster significance only indicates where cluster statistics fall in the distribution, not precise spatiotemporal localization, and can bias latency estimates. Permutation tests are superior for confirming effect existence rather than localization (Groope et al., 2011), so we treated them as exploratory.

This study has several limitations. First, although many facial vMMN studies present task-irrelevant faces centrally (Kecskés-Kovács et al., 2013; Kovarski et al., 2017), this may not ensure complete non-attention, especially for emotional faces that may automatically capture attention and influence fWHR processing. Future studies should present faces peripherally to increase non-attention likelihood. Second, following previous research (Carré & McCormick, 2008; Carré et al., 2009, 2010; Stirrat et al., 2012), we only used male faces; whether our conclusions apply to female faces remains unclear. Finally, stimulus proportions differed between experiments. Based on G*Power calculations, Experiment 2 required fewer participants, so we increased deviant proportion from 10% (Experiment 1) to 20% (Experiment 2) to obtain stable waveforms. Both proportions are common in facial vMMN research (Kecskés-Kovács et al., 2013; Stefanics et al., 2012; Wang et al., 2022), and no evidence suggests proportion affects vMMN (Stefanics et al., 2014), though using identical proportions would strengthen cross-experiment comparisons.

In conclusion, this study demonstrates that fWHR information undergoes automatic processing, with high fWHR showing longer duration and greater strength than low fWHR. This may relate to their respective perception as angry and fearful emotions when representing aggression. We further found that angry and fearful expressions facilitate automatic processing of high and low fWHR, respectively, but angry emotion weakens automatic processing of high fWHR compared to neutral emotion. Overall, these results suggest emotion plays an important role in the preattentive processing of facial width-to-height ratio.

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Automatic processing of facial width-to-height ratio

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Note: Figure translations are in progress. See original paper for figures.