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Facing Freeze: Social Threat Induces Bodily Freeze in Humans

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Abstract

Freezing is a common defensive response in animals threatened by predators. It is characterized by reduced body motion and decreased heart rate (bradycardia). However, despite the relevance of animal defense models in human stress research, studies have not shown whether social threat cues elicit similar freeze-like responses in humans. We investigated body sway and heart rate in 50 female participants while they were standing on a stabilometric force platform and viewing cues that were socially threatening, socially neutral, and socially affiliative (angry, neutral, and happy faces, respectively). Posturographic analyses showed that angry faces (compared with neutral faces and happy faces) induced significant reductions in body sway. In addition, the reduced body sway for angry faces was accompanied by bradycardia and correlated significantly with subjective anxiety. Together, these findings indicate that spontaneous body responses to social threat cues involve freeze-like behavior in humans that mimics animal freeze responses. These findings open avenues for studying human freeze responses in relation to various sociobiological markers and social-affective disorders.

Keywords

emotional facial expressions, human freeze response, angry faces, posturography, body sway, heart rate

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Freezing is one of the most widely recognized defensive reactions to predator threat in animals. It is characterized by reduced body motion and bradycardia (decreased heart rate) compared with prethreat levels (e.g., Blanchard, Flannelly, & Blanchard, 1986). Despite the use of animal models in human stress research, studies of human freeze responses have been almost exclusively focused on freeze reactions to physical threat or injury. So far, no studies have tested whether threat stimuli of a social nature elicit freeze-like responses in humans. Social threats are a less direct danger to a person's physical integrity than physical threats are, but social threats may prime defensive body reactions, such as freezing, in humans, as they do in animals (e.g., Blanchard et al., 1986; Gazzaniga, 1987; Kalin, 1993; Lang, Bradley, & Cuthbert, 1997; LeDoux, 1996). In this study, we tested the crucial question of whether social threat cues elicit bodily freeze reactions in female participants by using a combination of posturographic, cardiac, and anxiety measures.

Darwin emphasized the evolutionary advantage of closely interacting emotion and motor systems, in which emotions prime adaptive motor behavior needed to cope with the emotion-eliciting context. After encountering a dangerous situation (e.g., an approaching predator), animals freeze when the threat is distant and fear is relatively low (e.g., Blanchard et al., 1986). The freeze response is characterized by bradycardia and a cessation of body motion (immobility), and represents an orienting response during which the animal is hypervigilant to cues priming an appropriate reaction, especially fight-or-flight behaviors (Campbell, Wood, & McBride, 1997; Kalin, 1993; Marks, 1987; Schenberg, Vasquez, & DaCosta, 1993).

This neuromuscular process is thought to involve direct projections from the amygdala to the periaqueductal gray, in which the ventral region mediates freezing and the dorsal region mediates action (Applegate, Kapp, Underwood, & McNall, 1983). On the basis of animal research, Lang et al. (1997) developed a defense cascade model proposing that defensive reactions to a threat stimulus in humans involve a similar sequence of freeze-flight-fight responses (see also Bradley, Codispoti, Cuthbert, & Lang, 2001). Using various psychophysiological measures, including facial electromyography, skin conductance, and heart activity, Lang et al. (1997) and other researchers have collected systematic evidence suggesting that humans' response to viewing

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aversive pictures mimics the postencounter stage of threat response that is observed in animals. In that stage, escape is blocked, and the participant is immobile and vigilant, like a freezing animal (for a review, see Bradley et al., 2001).

Indeed, social threat cues, such as pictures of angry facial expressions, have been shown to facilitate fear-potentiated startle responses and to increase attentional bias and avoidance tendencies, particularly in anxious individuals (e.g., Anokhin & Golosheykin, 2010; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Roelofs, van Peer, et al., 2009; Roelofs et al., 2010). Angry faces are a potent threat stimulus and—when directly gazing at the viewer—are considered to communicate dominance and to induce fear, especially in anxious individuals (e.g., Öhman & Mineka, 2001). However, to validate predictions of the defense cascade model for social threat exposure in humans, a crucial missing link needs to be resolved, namely, whether social threat can indeed elicit body immobility in humans, as is observed in animals. Apart from its theoretical and comparative value, such a finding would open avenues for objectively assessing clinical observations of freeze responses in social-affective disorders, such as social phobia.

A reliable and ecologically valid way to study human freeze reactions is by means of a stabilometric force platform, which enables researchers to assess the amount of spontaneous body sway during picture viewing. During quiet upright standing, the human body exhibits a small amount of spontaneous postural fluctuation in the horizontal plane, and studies have shown that passive viewing of unpleasant pictures causes a reduction in this postural sway. This reduction reflects a neuromuscular response involving cocontraction or stiffening of the muscles around the ankle joint that is indicative of freezing (Azevedo et al., 2005; Facchinetti, Imbiriba, Azevedo, Vargas, & Volchan, 2006; Stins & Beek, 2007). All studies demonstrating this effect used pictures (e.g., of mutilated bodies) that portrayed direct threats to the subject's physical integrity. Social threats may not be physically harmful, but compared with direct physical threats, they are more likely to occur in the majority of human social encounters.

The main purpose of the present research was to test whether exposure to social threat elicits freeze-like behavior in humans. Specifically, we tested whether angry facial expressions (as compared with neutral and happy facial expressions) would induce reduced body sway and decreased heart rate. In addition, we tested whether body sway and heart rate reductions are related to state anxiety. Given the widely recognized gender differences in processing of angry faces (Rotter & Rotter, 1988), this first test of human freeze reactions to social threat was restricted to female participants.

Method

Participants

Fifty female students (mean age = 20.6 years, *SD* = 2.3 years) were included in this study. They were recruited at the VU University Amsterdam and at Leiden University, and they received course credit or cash for their participation. All participants had normal or corrected-to-normal vision and provided written informed consent. The study was approved by the local ethics committee.

Apparatus

Participants stood on a custom-made strain-gauge force plate (1 m × 1 m; sampling frequency: 100 Hz; resolution: 0.28 N/bit; resonance frequency: 30 Hz). Center-of-pressure (COP) excursions in the anterior-posterior (AP) direction and the mediolateral (ML) direction were recorded. Heart rate was registered in beats per minute (bpm) with a standard Polar (Lake Success, NY) band that was attached around the chest at the height of the sternum and was wirelessly transmitted to a receiver and amplifier (Heart Rate Telemetry Systems; Elgo Electric, Rielasingen, Germany) connected to the computer.

Stimuli

The visual stimuli consisted of emotional faces taken from 20 models (10 male and 10 female) in the Karolinska Directed Emotional Faces database (Lundqvist, Flykt, & Öhman, 1998).[1] Each model showed three affective expressions (happy, neutral, and angry), resulting in a total of 60 stimuli. The pictures were gray scale, matched for brightness and contrast values, and displayed against a black background. Faces were cropped to exclude influence from hair and nonfacial features. The stimuli were presented at eye height on a 17-in., height-adjustable computer screen, which was placed approximately 1 m in front of the participant. At this viewing distance, the stimuli subtended a visual angle of 15.5° by 10.8°.

Questionnaire

We assessed state anxiety using the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs 1983), which is a 20-item self-report questionnaire on which participants rate how anxious they feel at present, using a scale ranging from 1 (*not at all*) to 4 (*very much so*). The STAI has high internal consistency (α = .90), good test-retest reliability (r = .70–.76), and concurrent validity with other anxiety measures (Spielberger et al., 1983).

Procedure

Prior to testing, participants attached the Polar band, after which they sat down and watched a short neutral film scene intended to make them feel at ease. Next, they were asked to step onto the force plate and to watch the monitor, on which instructions were displayed. Participants were instructed to stand still and watch the sequence of images on the monitor. Throughout the experiment, participants stood in stocking feet with their arms hanging alongside their body. Their feet were approximately 30 cm apart. It is important to note that this relatively stable position enables a larger range of movement in the AP direction than in the ML direction, and therefore makes AP movements more susceptible than ML movements to affective modulations. The experiment took place in a dimly lit room.

The face stimuli were presented in three blocks. The order of presentation of the three blocks and the order of stimuli within a block were randomized. Each block consisted of 20 images of one type of emotional expression that were presented consecutively for 3 s each, with no intertrial interval. Between blocks, there was a 5-s black screen followed by a 2-s white fixation cross. Following the posturographic measurements, participants completed the STAI and scored the pleasantness of each face on a 9-point Likert scale ranging from *very happy* to *very angry*.

Data analysis

Posturography. Posturographic analysis was performed using the unfiltered time series in MATLAB (The MathWorks, Natick, MA). For each picture, we first calculated the mean position of the COP in the AP direction over the 3-s stimulus interval. Referencing this mean, we then determined the variability in body sway, quantified as the standard deviation of the COP in the AP direction (SD-AP). The standard deviation of the COP in the ML direction was calculated analogously. These standard deviations were then averaged over each block, and these averages yielded our measure of postural mobility.

Heart rate. The mean heart rate in bpm was determined separately for the three stimulus blocks.

Statistical analyses. Valence ratings, postural measures (SD-AP), and heart rate were analyzed using separate repeated measures analyses of variance (ANOVAs) with emotion (happy, angry, neutral) as a within-subjects factor. To investigate the role of anxiety, we included the individual STAI scores as a continuous variable in an analysis of covariance (see Judd, Kenny, & McClelland, 2001). We subsequently calculated Pearson correlations between anxiety scores, body sway, and heart rate. Alpha was set at .05.

Results

Three participants were identified as outliers because of their excessive movements, as reflected in *Z* scores greater than 4 on the body-sway measure.

Picture ratings

An ANOVA for the subjective pleasantness ratings yielded a significant effect of emotion, $F(2, 45) = 983.6$, $p < .01$, $\eta_p^2 = .98$. Separate least significant difference (LSD) comparisons indicated that each emotion category differed significantly from the other two (happy > neutral > angry, all *p*s < .01).

Body sway

An ANOVA for SD-AP yielded a significant effect of emotion, $F(2, 45) = 5.20$, $p = .009$, $\eta_p^2 = .19$.[2] Separate LSD comparisons showed that SD-AP in the angry-faces block differed significantly from SD-AP in both the neutral-faces and the happy-faces blocks ($p = .032$ and $p = .014$, respectively). Figure 1 illustrates that body sway was significantly reduced for angry faces compared with neutral faces and happy faces. The comparison between happy faces and neutral faces was not significant ($p = .939$). Figure 2 provides an individual example of the body-sway path associated with viewing a sequence of emotional faces.

To test whether state anxiety moderated postural responses to the various emotion blocks, we entered STAI total score as a continuous variable in an analysis of covariance; this analysis showed a significant Emotion × Anxiety interaction, $F(2, 44) = 4.60$, $p = .015$, $\eta_p^2 = .17$, that was specific for the contrast between angry faces and neutral faces, $F(1, 45) = 6.71$, $p = .013$, $\eta_p^2 = .13$. Anxiety did not moderate other emotion contrasts ($p > .11$). To investigate the direction of the Emotion × Anxiety interaction, we calculated the correlation between STAI score and the SD-AP difference score for angry faces (SD-AP for angry faces minus SD-AP for neutral faces). A significant negative correlation ($r = −.36$, $p = .013$) indicated that higher state anxiety was associated with greater reduction in body sway for angry faces (relative to body sway for neutral faces; see Fig. 3). SD-AP difference scores for happy faces (SD-AP for happy faces minus SD-AP for neutral faces) showed no such correlation with anxiety ($r = −.011$, $p = .45$).

Heart rate

An ANOVA on mean heart rate measured during the three stimulus blocks, with emotion as a within-subjects factor,

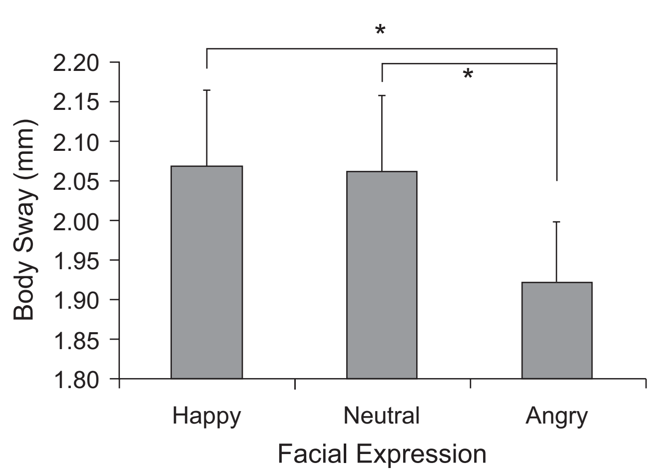

Fig. 1. Mean body sway of all participants when viewing happy faces, neutral faces, and angry faces. Movement is expressed in standard deviation from participants' center of pressure in the anterior-posterior direction. Error bars represent standard errors. Asterisks indicate significant differences between stimulus types (*$p < .05$).

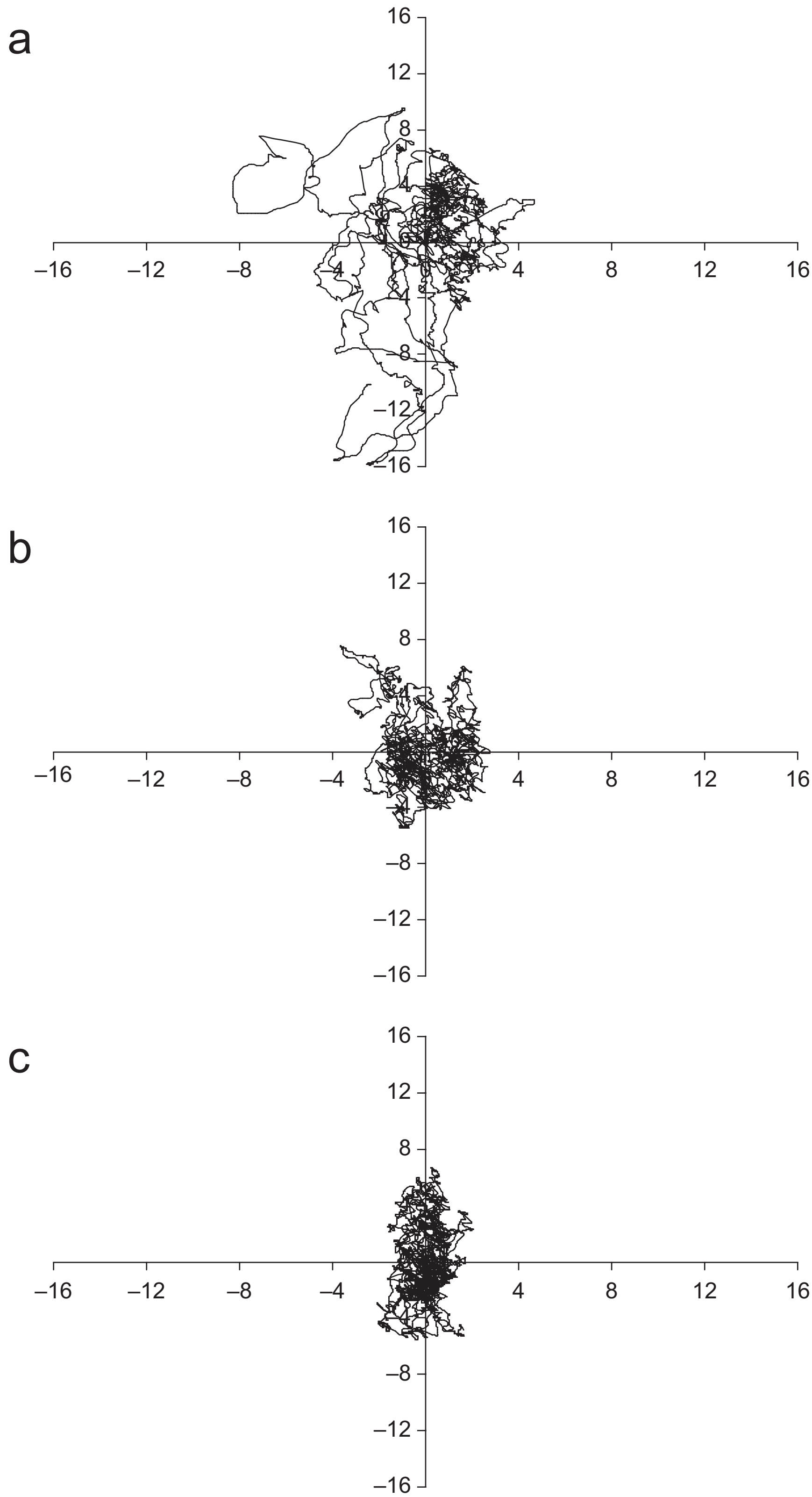

Fig. 2. Body-sway path of a representative participant when exposed to (a) happy faces, (b) neutral faces, and (c) angry faces. The graphs show shifts in the participant's center of pressure, with *x*-axes representing mediolateral excursions (in millimeters) and *y*-axes representing anterior-posterior excursions (in millimeters).

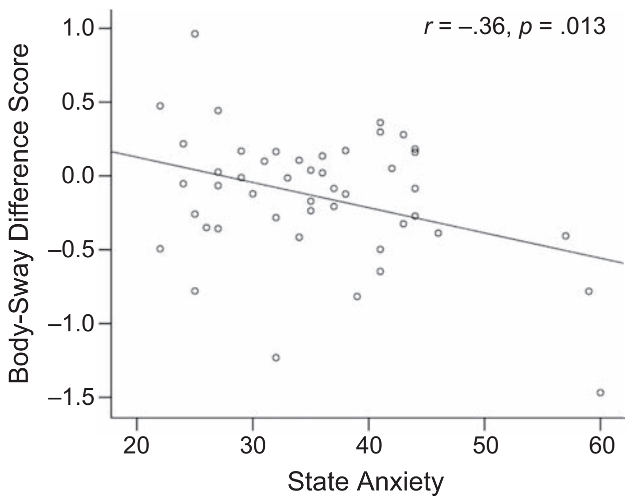

Fig. 3. Scatter plot (with best-fitting regression line) illustrating the correlation between state anxiety and change in body-sway variability (in millimeters) when participants viewed angry faces compared with neutral faces. Change in body-sway variability was calculated by subtracting body-sway variability in the neutral-faces block from the same measure in the angry-faces block.

yielded a nonsignificant trend, $F(2, 45) = 3.14$, $p = .083$, $\eta_p^2 = .10$. The effect of emotion became significant when state anxiety was included as a continuous variable in an analysis of covariance, $F(2, 44) = 3.30$, $p = .049$, $\eta_p^2 = .12$. In addition, a significant Emotion × Anxiety interaction emerged, $F(2, 44) = 3.60$, $p = .036$, $\eta_p^2 = .14$.

An analysis including the happy-faces and angry-faces blocks only revealed that heart rate was significantly reduced during viewing of angry faces (M = 88.51 bpm, SE = 1.91) compared with viewing of happy faces (M = 93.0 bpm, SE = 1.95), $F(1, 45) = 6.24$, $p = .016$, $\eta_p^2 = .12$. This effect was modulated by anxiety, as indicated by a significant Emotion × Anxiety interaction, $F(1, 45) = 7.36$, $p = .009$, $\eta_p^2 = .14$. State anxiety was negatively correlated with heart rate during the angry-faces block ($r = −.30$, $p = .049$) and not during the neutral-faces block ($r = −.16$, $p = .27$) or the happy-faces block ($r = −0.12$, $p = .42$).

Finally, there was a positive correlation between heart rate and body sway in the angry-faces block ($r = .29$, $p = .048$), and this indicated that immobility was related to bradycardia in the social threat condition. A similar correlation between heart rate and body sway was present in the neutral-faces block ($r = .29$, $p = .047$), but not in the happy-faces block ($r = .042$, $p = .78$).

Discussion

The purpose of this study was to test whether social threat elicits freeze-like behavior in humans, using a combination of body motion (posturography), autonomic activity (heart rate), and subjective experience (anxiety scores) measures. Three major findings emerged from this study. First, angry faces induced significant reductions in body sway compared with both happy faces and neutral faces. Second, reduced body sway for angry faces was accompanied by reduced heart rate (bradycardia). Third, reduced body sway, as well as reduced heart rate during viewing of angry faces, correlated with increased subjective anxiety scores. Together, these findings indicate that spontaneous body sway and autonomic responses to social threat cues involve a complex freeze-like pattern of behavior in humans that mimics animal freeze responses.

This is the first study showing that purely social threat cues (without direct reference to physical threat and injury) can induce body-freeze-like reactions in humans. Previous studies with healthy participants using a force platform have found reduced body sway in response to photographs depicting physical threat and injury, such as images of mutilated bodies, compared with photographs of neutral situations (Azevedo et al., 2005; Facchinetti et al., 2006; Stins & Beek, 2007). In a relevant study, Facchinetti et al. (2006) found body-sway reductions in response to physical threat as well as in response to social-affiliative stimuli (smiling babies and families). However, no systematic comparison of social affiliation versus social threat was made. We systematically compared these factors by taking three facial expressions (angry, happy, and neutral) from the same model, and we found less body sway for angry faces compared with both happy faces and neutral faces. Moreover, we found that body sway varied as a function of state anxiety, with greater reductions in body sway in highly anxious individuals than in individuals with lower levels of anxiety. These findings are partly in line with recent findings of reduced body sway in patients with panic disorder compared with healthy control participants (Lopes et al., 2009). However, in the patients with panic disorder, anticipation anxiety predicted body sway at baseline levels, rather than how much sway varied as a function of picture type (emotional picture vs. neutral picture).

The present study is the first to combine anxiety, body sway, and heart rate measures to demonstrate that state anxiety was correlated not only with body sway, but also with heart rate reductions during viewing of angry faces. Heart rate reduction (accompanied by bodily immobility) was previously observed in healthy individuals in response to physical threat (Azevedo et al., 2005) and was taken as an indicator of fear bradycardia. Bradycardia is the organism's immediate attentive reaction to threat at a distance and is consistently observed in both mammals and reptiles (e.g., Graham, 1997). It constitutes a part of the freeze response that is mediated by direct projections from the amygdala to the periaqueductal gray (Applegate et al., 1983).

Our findings of spontaneous freeze-like reactions to angry faces extend previous results showing greater tendencies to avoid angry faces, compared with happy faces and neutral faces, in forced-choice reaction time paradigms (e.g., Roelofs, Minelli, Mars, van Peer, & Toni, 2009; Roelofs, van Peer, et al., 2009; Roelofs et al., 2010). Apparently, when angry faces are presented to anxious individuals who are forced to choose between approach and avoidance responses, these faces facilitate avoidance. However, spontaneous motor reactions to angry faces elicit initial freezing instead of avoidance. Together, these findings fit the defense cascade model (Bradley et al., 2001; Lang et al., 1997), which describes freezing as an early orienting response possibly serving to facilitate detection of information relevant for a subsequent fight-or-flight response involving whole-body movements. We contribute to this knowledge by showing that social threat cues (even without explicit reference to physical threats) are sufficiently potent to trigger this typical response of freeze-like behavior; this fact underlines the relevance of social context in response mechanisms related to human survival. Future studies should include males to test for gender differences. Also, studies involving longer and continuous stimulus presentation are needed to systematically examine timing effects.

In conclusion, social threat stimuli can induce body-freeze reactions in humans. This finding helps to bridge vital animal research and human research by showing, for the first time, that spontaneous reactions to social threat in anxious females mimic freeze reactions generally observed in anxious animals. Freezing is considered an important feature of anxiety disorders, such as posttraumatic stress disorder and social phobia, and the present study opens avenues for assessing psychobiological mechanisms behind freeze-like behavior in various social psychopathologies.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. Stimuli used had the following Karolinska Directed Emotional Faces codes—neutral faces: AF01NES, AF02NES, AF05NES, AF06NES, AF18NES, AF20NES, AF21NES, AF26NES, AF29NES, AF35NES, AM01NES, AM03NES, AM06NES, AM08NES, AM10NES, AM11NES, AM14NES, AM21NES, AM22NES, AM29NES; happy faces: AF01HAS, AF02HAS, AF05HAS, AF06HAS, AF18HAS, AF20HAS, AF21HAS, AF26HAS, AF29HAS, AF35HAS, AM01HAS, AM03HAS, AM06HAS, AM08HAS, AM10HAS, AM11HAS, AM14HAS, AM21HAS, AM22HAS, AM29HAS; angry faces: AF01ANS, AF02ANS, AF05ANS, AF06ANS, AF18ANS, AF20ANS, AF21ANS, AF26ANS, AF29ANS, AF35ANS, AM01ANS, AM03ANS, AM06ANS, AM08ANS, AM10ANS, AM11ANS, AM14ANS, AM21ANS, AM22ANS, AM29ANS.

2. As expected, calculations of the standard deviation of the COP in the ML direction did not show significant emotion-related effects (all *ps* > .31).

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