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RESEARCH ARTICLE

The Modulation of Cardiac Vagal Tone on Attentional Orienting of Fair-Related Faces: Low HRV is Associated with Faster Attentional Engagement to Fair-Relevant Stimuli

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Abstract
The current experiment examined the effect of fair-related stimuli on attentional orienting and the role of cardiac vagal tone indexed by heart rate variability (HRV). Neutral faces were associated with fair and unfair offers in the Ultimatum Game (UG). After the UG, participants performed the spatial cueing task in which targets were preceded by face cues that made fair or unfair offers in the UG. Participants showed faster attentional engagement to fair-related stimuli, which was more pronounced in individuals with lower resting HRV—indexing reduced cardiac vagal tone. Also, people showed delayed attentional disengagement from fair-related stimuli, which was not correlated with HRV. The current research provided initial evidence that fair-related social information influences spatial attention, which is associated with cardiac vagal tone. These results provide further evidence that the difficulty in attentional control associated with reduced cardiac vagal tone may extend to a broader social and moral context.

Keywords : Cardiac vagal tone · Fairness · Attentional orienting · Motivational relevance

Introduction

Fairness is an important social norm that people inherently prefer (Gächter et al., 2017). Fair assessment guides interpersonal relationships and social interaction: people prefer associating with and making business dealings with those who are fair (Gächter et al., 2017; Park et al., 2019). Fair people are more likely to hold and abide by high moral standards, fostering more meaningful and lasting interpersonal relationships (Park et al., 2019). Furthermore, fair consideration plays an important role in shaping cognitive processes, such as economic decision making (Sanfey et al., 2003) and human memory (Park et al., 2019). However, little is known about whether fairness would modulate subsequent attentional orienting. There is emerging evidence that morally relevant concepts influence human perception and attention. The current experiment examined whether and how fairness or unfairness would affect attentional orienting. Furthermore, we explored the role that individual differences in cardiac vagal tone—a physiological proxy of social cognition and cognitive and emotional regulation—would play in attentional bias of socially and morally significant concepts (Park & Thayer, 2014).

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Attentional Orienting

Posner and colleagues developed the spatial cuing paradigm to study different components of covert attention (i.e., an ability to direct attention without eye movement; Posner et al., 1980;Posner & Petersen, 1990 ; Posner & Rothbart, 2007). In the spatial cuing task (Posner & Petersen, 1990; Posner & Rothbart, 2007), a cue is presented and immediately followed by a target. The cue either correctly predicts the location in which a subsequent target will appear (*valid*) or not (*invalid*;Posner & Petersen, 1990 ; Posner & Rothbart, 2007). Generally, people are faster to detect targets on valid compared to invalid trials, which is referred to as the “cue validity" effect (Fox et al., 2001). Based on extensive studies of the spatial cuing task, Posner and others have identified three components involved in attending to a new stimulus: (1) an initial shift of attention to the stimulus; (2) attentional engagement to the stimulus; and (3) attentional disengagement from the stimulus (Posner & Petersen, 1990; Posner & Rothbart, 2007).

It has been well documented that salient emotional stimuli guided and directed attentional orienting (Armony & Dolan, 2002; Fox et al., 2001; Fox et al., 2002; Georgiou et al., 2005; Holmes et al., 2005; Koster et al., 2006; Mogg et al., 2000; Mogg & Bradley, 1999). Utilizing emotionally threatening stimuli (e.g., fearful or angry faces) as cues, researchers have shown that people were faster to detect targets replacing threatening cues in valid trials (attentional *engagement*) and were slower to disengage attention away from them in invalid trials (attentional *disengagement*) compared to neutral cues (Park et al., 2013; Pourtois & Vuilleumier, 2006; see Vuilleumier & Brosch, 2009, for a review). Indeed, emotionally threatening stimuli are detected faster, draw more attention, and are remembered better—a phenomenon termed a negativity bias (Hilgard et al., 2014; Sussman et al., 2016).

According to the evolutionary accounts (Öhman & Mineka, 2001), an organism is evolved to prioritize attention to stimuli critical for survival (Aarts & Dijksterhuis, 2003; Pratto & John, 1991), such as angry faces (Kuhn et al., 2016), or dangerous animals, such as snakes and spiders (Lipp & Derakshan, 2005). The predominant view of the field is that the preferential processing of emotionally negative stimuli—attentional negativity bias—is primarily driven by bottom-up processing that relies on physical salience or attributes of emotionally negative information (Cunningham & Brosch, 2012; Phelps & LeDoux, 2005; Sussman et al., 2016). Note that the perceptual (versus emotional) underpinning of attentional negativity bias is not resolved so far since pure perceptual factors could explain the effect (Mermillod et al., 2009; Purcell et al., 1996). At the neural level, attentional negativity bias is mediated by the "low road" that rapidly conveys signals to the amygdala via the superior colliculi and the thalamus without cortical inputs (Cisler & Koster, 2010; Dolan, 2002; Sussman et al., 2016). Particularly, this low road is known to be sensitive to low spatial frequency information (Park et al., 2013; Vuilleumier et al., 2003). As such, the evolutionary account posited that attentional negativity bias is adaptive for survival and hard-wired, leading to more automatic and robust results (LeDoux, 1996). This attentional negativity bias was more pronounced in individuals with high anxiety: individuals with high anxiety showed significantly faster attentional engagement to and delayed attentional disengagement from emotionally threatening stimuli compared with those with low anxiety (Cisler & Koster, 2010; Koster et al., 2006; Mathews et al., 1997).

However, positive emotion attracts people's attention as well (see Pool et al., 2016 for a meta-analysis). For example, happy faces were detected faster and more accurately than angry faces (Becker et al., 2011). Similar to the negativity bias, the positivity bias was more pronounced in individuals with optimistic personality (Segerstrom, 2001), participants who were primed with positive information (Smith et al., 2006), and participants who were instructed to remember positive sound (Van Dessel & Vogt, 2012). Furthermore, experientially induced optimistic expectancy led to greater attentional prioritization to positive stimuli (Kress et al., 2018).

Circumplex theories explained why positive emotion also draws prioritized attention. The circumplex theories are based on the assumption that emotion can be described in terms of (1) valence, which defines emotion in terms of positivity (or pleasantness) or negativity (or unpleasantness (Kauschke et al., 2019), and (2) arousal, which refers to the extent to which the stimulus evokes the alert and hypervigilant condition of perceivers (Russell, 2003). According to this model, prioritized attentional bias hinges upon arousal, not valence: attention is prioritized to both highly arousing positive and negative stimuli (Anderson, 2005). Indeed, neuroimaging evidence has shown that the greater amygdala activity was triggered in response to emotionally positive as well as threatening stimuli (Hamann et al., 2002; Li et al., 2008; Sander et al., 2003).

Alternatively, appraisal theories posited that attentional prioritization depends on one's appraisal of the motivational relevance of the stimuli to an organism's current state, goals, and needs (see Ellsworth & Scherer, 2003). According to appraisal theories, people appraise each stimulus and prioritize attention when a stimulus is relevant to their current motivational concerns and goals (Frijda, 1988; Sander et al., 2005). For example, a heterosexual woman is more likely to pay attention to an erotic picture of a man, but not a heterosexual man, because the stimulus is relevant to a motivational state, goal, and need of the perceiver (e.g., a heterosexual woman), but not to those of a heterosexual man (Pool et al., 2016). Not only that, but also such motivational state, goals, and needs may vary constantly, which modulates attentional bias accordingly. When a heterosexual woman is looking for a marriage partner, she will show even stronger attentional bias toward an erotic picture of a man than when she is not (Mohanty et al., 2008). As such, attentional bias to motivationally relevant stimuli may depend on not only contexts but also momentary goals, needs, and motivation. Indeed, neuroimaging evidence shows that the activity of brain structures underlying attentional bias flexibly changes as a function of an organism's momentary goals and needs (Cunningham & Brosch, 2012). The amygdala quickly assesses the stimulus relevance, enhances the salience of the relevant stimulus, and makes connections to other brain regions subserving attentional orienting to prioritize attentional resources to the relevant stimulus (Brosch et al., 2007, 2008, 2013; Sander et al., 2003). For example, when participants were hungry, they showed not only significantly faster attentional orienting toward food-related cues but also more neural connectivity between limbic areas (e.g., the amygdala) and parietal attentional regions that subserved attentional shifts, compared to when they were satiated (Mohanty et al., 2008). As such, attentional bias to motivationally relevant stimuli and underlying neural mechanisms can vary as a function of momentary goals, needs, and motivation.

Furthermore, there is growing evidence that moral content modulates human perception and attention. For example, recent research has suggested that the visual system is preferentially tuned to perceive morally relevant stimuli (Gantman & Van Bavel, 2014). When moral and nonmoral words similar in length and frequency were presented close to the threshold of perceptual awareness, people detected moral words (e.g., kill, moral, should) more accurately than non-moral words (e.g., die, useful, could)—a phenomenon termed the "moral pop-out effect" (Gantman & Van Bavel, 2014). However, this moral pop-out effect was reduced when the need for justice was satisfied (Gantman & Van Bavel, 2016). These studies suggest that moral content guides attentional priority because of its motivational relevance to social goals and needs (Brady et al., 2020b; Gantman & Van Bavel, 2016). It is an open question whether stimuli associated with fairness—an important moral construct—may direct and shape attentional orienting.

Fairness/Unfairness in the Ultimatum Game Task

People inherently prefer the fair distribution of resources and express satisfaction when treated fairly from public institutions (e.g., court, police) or during economic decision-making tasks regardless of monetary gain (Fehr & Camerer, 2007; Tabibnia et al., 2008). According to the norm compliance framework, fair consideration has been conceived as a social norm that people inherently favor so far as to be willing to uphold and protect, even at the expense of monetary sacrifice (Gächter et al., 2017). In an economic decision game known as the Ultimatum Game (UG) task, the proposer is given a sum of money, $10, and makes offers to the responder as to how to split the money between themselves (Scheres & Sanfey, 2006). Some offers are fair, such that the money is evenly split between the proposer and the responder ($5:$5). However, other offers are unfair, such that the proposer receives more money and the responder receives less money ($9:$1, $8:$2, or $7:$3). Then, the responder decides whether to accept or reject the offer. When the responder accepts the offer, the money will be split between the two players according to the offer. When the responder rejects the offer, neither receives anything. Therefore, the rational response for the responder is to accept any offer because any monetary reward is preferable to none. However, extensive research has shown that the responders frequently rejected unfair offers ($9:$1, $8:$2, or $7:$3), even if they would not receive anything (Pillutla & Murnighan, 1996; Tabibnia et al., 2008). The rejection of unfair offers was generally construed as "altruistic punishment" for norm violation (Fehr & Rockenbach, 2004; Frith & Singer, 2008). The responders experienced an unpleasant emotion in response to unfair offers and were willing to punish the unfair proposers by stopping them from getting a greater share of the money, even if the decision would result in forfeiting any monetary profit (Fehr & Rockenbach, 2004; Frith & Singer, 2008). As such, fairness is inherently favored and socially normative, as well as highly influential in guiding social and business behavior (Park et al., 2019).

However, there is little known whether fairness or unfairness would shape attentional orienting. We decided to associate neutral faces with fairness or unfairness using the UG and then used those faces as cues in the subsequent spatial cueing task. Converging evidence shows that participants develop attentional bias for stimuli that they learn to associate during an experiment. For example, attention was prioritized to stimuli that participants learned to associate with monetary reward or value in an experiment—a phenomenon termed value-driven attentional capture (Anderson et al., 2011a, 2011b). In one study (Raymond & O'Brien, 2009), participants learned to associate face stimuli with a high or low probability of a monetary win or loss. Then, these faces were used as targets in a subsequent attentional blink task. Participants showed attentional bias favoring facial stimuli associated with reward in a condition where attentional resources were constrained (Raymond & O'Brien, 2009). Similarly, stimuli were associated with high and low rewards in an experiment and then used as targets and nontargets in a subsequent object identification task. Participants were faster to identify stimuli associated with high reward as targets and were slower to reject as distractors, while the opposite pattern was observed for stimuli previously associated with low reward (Della Libera et al., 2011; Della Libera & Chelazzi, 2009). In another study, when neutral face stimuli were randomly assigned to a social in-group or out-group and then were used as cues in a dot-probe task, people showed faster attentional orienting towards faces assigned to the out-group (Brosch & Van Bavel, 2012). As such, prioritized attention can be drawn to stimuli that are endowed with monetary value or group identity through pairing (Brosch & Van Bavel, 2012; Vogt et al., 2020). In this experiment, we utilized the UG, an economic decision-making task, to associate neutral stimuli with fairness or unfairness. After the UG, participants performed the spatial cueing task in which targets were preceded by face cues that made fair and unfair offers in the UG.

However, it is less clear whether fair- or unfair-related faces would draw one's orienting. According to appraisal theories, attentional prioritization depends on one's appraisal of the motivational relevance of the stimuli to an organism's current state, goals, and needs (Ellsworth & Scherer, 2003). Both fair- and unfair-related stimuli might be motivationally salient. However, according to the evolutionary accounts (Öhman & Mineka, 2001), one's attention would be prioritized to unfair-related faces with strong emotionally negative connotations. Also, it is plausible to assume that people would allocate greater attentional resources to stimuli related to fairness. Recent research has shown that perceived fairness asymmetrically biases recognition memory (Park et al., 2019). After performing the UG, participants were given a surprise memory task in which participants saw 48 pictures of male targets, 50% of which had been included in the previous task (i.e., "old" targets), while the remaining 50% were unfamiliar ("new") targets. Their task was to indicate whether a presented target was "old" or "new." Participants showed a better memory for faces that made fair offers during the UG task. These results were further confirmed by signal detection theory. Participants showed higher *d'*—indicating higher recognition—and more conservative decision criterion to fair-related faces compared to unfair-related or new faces. This suggests that perceived fairness influenced and shaped recognition memory. From an ecological perspective, this memory bias favoring fair-related faces makes sense because they are more likely to offer fair business deals in the future and to demonstrate prosocial behaviors (Park et al., 2019). Furthermore, a large body of literature has suggested that attention and memory are interdependent (Chun & Turk-Browne, 2007). Attention monitors and determines what information is processed and encoded into long-term memory (Chun & Turk-Browne, 2007). For example, greater attentional allocation to emotionally arousing stimuli accounted for a better memory of them. Attention highlights information to be selected and activates memory systems to process information further (for more information on the interaction between attention and memory, see Aly & Turk-Browne, 2016; Chun & Turk-Browne, 2007; Wolfe et al., 2007). Thus, enhanced memory of fair-related cues is most likely preceded by preferential attentional allocation towards fair-related information. As such, the current theoretical accounts did not provide a clear indication of whether fair- or unfair-related cues would shape attentional orienting.

Cardiac Vagal Tone as a Physiological Proxy of Social Cognition

There is a growing literature suggesting that HRV may serve as a physiological proxy of social cognition (Okruszek et al., 2016; Quintana et al., 2012; Shahrestani et al., 2015). According to Porges' polyvagal theory (Porges, 1998, 2003, 2007), the phylogenetically more advanced "smart" vagus plays a central role in social engagement, which allows for making flexible and context-appropriate social responses and for managing emotional stress in a social interaction. According to the theory, the smart vagus reduces sympathetic influences on the heart, enabling people to engage with different social situations in an effective and regulatory fashion. However, when fight-or-flight responses are necessary, the smart vagus unleashes its inhibitory controls of the heart, enabling people to act swiftly. As such, the "smart" vagus facilities autonomic function to make context-appropriate responses to given social situations, and we can tap into the social engagement system by measuring its activity at rest. Although Porges' theory was not without its critics (Berntson et al., 2007; Grossman & Taylor, 2007), it sparked a great deal of interest in the relationship between vagal tone and social engagement and emotion regulation.

The neurovisceral integration model further elucidates the neurobiological mechanism of cardiac vagal activity on cognitive, social and emotional regulation (Friedman, 2007; Park & Thayer, 2014; Thayer & Lane, 2000, 2009). Through the vagus nerve, the heart is linked to a neural network mediating cognitive, emotional, and autonomic self-regulation (Friedman, 2007; Park & Thayer, 2014; Thayer & Lane, 2000). Indeed, higher resting HRV is associated with the highly functional prefrontal regulation of the activity of the amygdala, which results in more adaptive patterns of emotional responding and self-regulatory functioning (Friedman, 2007; Park & Thayer, 2014; Thayer & Lane, 2000), prosocial attachment (Porges, 2007), resiliency to stress (Fabes & Eisenberg, 1997), and trait and state experiences of positive emotion (DiPietro et al., 1992). People with higher resting HRV showed more effective inhibitory attention and selective attention (Park et al., 2012a, b, 2013) and adaptive attentional orienting (Park et al., 2013). In contrast, lower resting HRV is associated with hyperactive amygdala that results from reduced prefrontal regulation (see Friedman, 2007; Park & Thayer, 2014; Thayer & Lane, 2009). This leads to poor and maladaptive cognitive function, such as poor working memory capacity and executive function (Hansen et al., 2003), and the difficulty in emotion regulation. Also, cardiac vagal tone predicted differential attentional orienting in response to spatial cues with different affective valence (Park et al., 2013). Specifically, lower resting HRV was associated with a greater cue validity effect in response to fearful faces, rendering significantly faster attentional engagement at low spatial frequency and slower attentional disengagement at high spatial frequency, respectively (Park et al., 2013). This finding is related to previous evidence showing that working memory capacity was related to attentional bias to physically salient stimuli (Fukuda & Vogel, 2009), contingently relevant stimuli (Fukuda & Vogel, 2011), and value-related stimuli (Anderson et al., 2011a, 2011b). Individuals with reduced cognitive function—reduced working memory capacity and poor attentional control—appear be more susceptive to attentional bias. More recently, we have reported that lower cardiac vagal tone is strongly associated with utilitarian moral decisions, which have been linked to outcome-based harm aversion and the willingness to harm few to save more people in moral dilemmas (Park et al., 2016). As such, cardiac vagal activity may serve as a physiological proxy for social and moral cognition and may modulate attentional bias to fair or unfair-related stimuli.

Overview

The primary goal of the current research was to examine whether face stimuli associated with fairness or unfairness would shape attentional orienting. Furthermore, we examined the role that HRV, a potential biomarker of social cognition, played in modulating the attentional orienting of fair- or unfair- related face stimuli. Since the current theoretical accounts did not provide clear clues on what to expect, we hypothesized that either fair- or unfair-related stimuli would lead to prioritized attentional orienting—faster attentional engagement and/or delayed attentional disengagement. We also hypothesized that lower resting HRV would be associated with faster attentional engagement to and/or delayed attentional disengagement from either fair- or unfair-related stimuli (Park et al., 2013).

Method

Participants

According to *G*Power*(Faul et al., 2007), the sample size of 60 was proposed to detect medium effects of about ρ = 0.25. Sixty-two undergraduate students (47 women; mean age = 19.9) successfully completed the experiment for partial course credit.[1] All participants were identified as non-smokers and were asked to refrain from alcohol, drug use, and caffeinated beverages for four hours before participation (Hansen et al., 2003; Park et al., 2012a, b). People with a history of neurological or psychiatric disorders, cardiovascular disorders, or medical conditions such as diabetes were excluded from this experiment. The local ethics committee approved the study, and all participants provided written, informed consent after the procedures had been fully explained per the Declaration of Helsinki.

Procedure

All participants were tested individually in a dimly lit room. Inter-beat intervals for determination of HRV were assessed using a Polar Watch heart rate monitor. Participants were fitted with the chest band. After confirming that inter-beat intervals (IBIs) were being recorded in the watch (which displays beat-to-beat changes in HR), the experimenter moved the watch away from the participant's gaze. A stopwatch was used to time successive 6-minute intervals, during which the participant sat and rested quietly in a partially sound isolated room. After the 6-minute baseline period, participants were given the rules of the ultimatum game and played the game (van't Wout et al., 2010).

The ultimatum game Participants played a modified version of the ultimatum game (UG) which was adapted from van't Wout and Sanfey (2011). The UG was programmed in E-prime software (Psychology Software Tools, Pittsburgh). Before starting the experiment, participants first read the instructions and completed three practice trials to ensure the participants fully understood the game. On each round, participants were first presented with a picture of their human opponent. After the proposal was presented, participants could respond by a button and chose to press accept or reject (the offer). There was a total of 24 rounds that participants played a role as a responder (see Fig. 1 for an example of a full trial). Twenty-four rounds consisted of 6 fair offers ($5 to each player) and 18 unfair offers defined as offering the participant less than half of the money. The unfair set consisted of six offers of $3, six offers of $2 and six offers of $1. We did not include $4 offers because $4 offers are generally perceived as fair and thus frequently accepted. The offers were made by male partners, and the order of partners and the pictures associated with each offer was randomized. Participants were not informed of the total number of rounds in advance. The instructions emphasized that different partners in the game would play the game independently of each other, and participants were told that the games would be played with the set of partners they saw. To encourage participants to make decisions seriously,

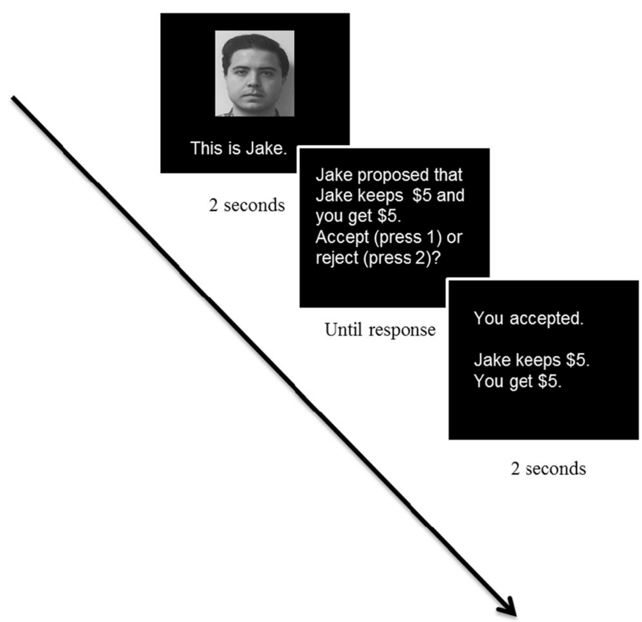

Fig. 1 Sample trial in the ultimatum game task

[1] The behavioral and cardiovascular data from one participant was lost due to equipment failure and a computer error. The data are available online at: https://osf.io/yn9hr/.

participants were told that they would be paid 5% of the total amount of money earned in the game in addition to course credit. On the completion of the game, participants then performed the spatial cueing task (Koster et al., 2004; Koster et al., 2006; Park et al., 2013).

The spatial cueing task On each trial, a white fixation cross ("+") was presented in the middle of the screen, and two gray boxes were presented—one on the left and the other on the right of the fixation point (Fig. 2). These boxes measured 6° horizontally and 6° vertically at a viewing distance of 60 cm. The middle of these boxes was located at a distance of 6° from the fixation point. The target that participants had to detect was a black circle, subtending a visual angle of 0.6° across the diameter. The initial fixation display was presented for 1,000 ms. Then, a face cue was presented either in a left- or right-side gray box for 250 ms. After a 50-ms delay, a target circle appeared at the center of either the left- or right-side boxes until the participants responded (or until 2,000 ms elapsed). There was an intertrial interval of 1,000 ms. All stimuli were presented on a black background. Participants were informed that a cue preceding a target did not predict where the target would appear. Therefore, they should ignore the face cues and keep their eyes focused on the fixation point on the center of the screen. They were instructed to indicate where targets appeared by pressing "Z" for a target on the left box or "M" for a target on the right as quickly and accurately as possible. Each participant completed trials with different

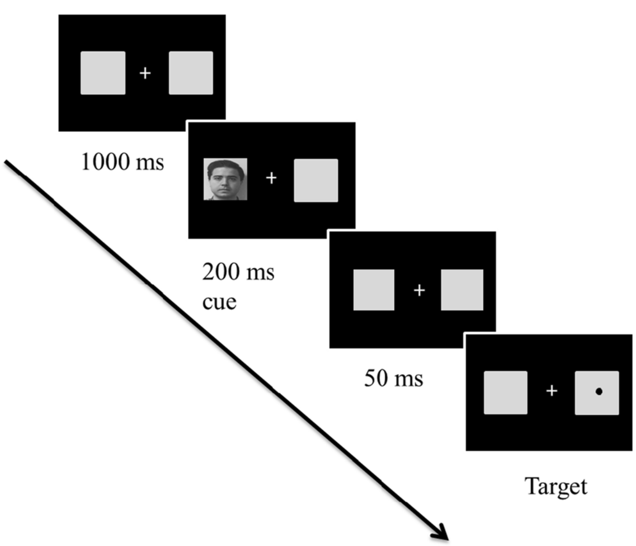

Fig. 2 Sample trial in the cuing task. *Note.* The cues and targets were equally likely to appear on the right or left of fixation. However, 80% of trials were valid (96 trials) and 20% of the trials were invalid (24 trials). The initial fixation display appeared for 1,000 ms. Then, cues, which were fair, unfair, or new faces, appeared for 250 ms. After a 50-ms delay with the initial fixation display, a target circle appeared in the center of the left or right box until the participant responded (or until 2,000 ms elapsed). Stimuli are not drawn to scale

types of face cues (fair, unfair, new). There were 12 practice trials, and 96 experimental trials with faces that made fair (i.e., $5) and unfair (i.e., $1, 2, 3) offers during the UG and new faces that were not used in the UG. There were 48 trials with faces that were used in the UG and 48 trials with faces that were not used in the UG. Two-thirds of the experimental trials were valid (64 trials), and one-third were invalid (32 trials). Fair, unfair, and new face cues appeared 8, 24, and 32 times, respectively, on valid trials and 4, 12, and 16 times, respectively, on invalid trials. Participants were at an approximately 60-cm viewing distance from the computer screen to perform the cueing task.

Physiological measurements HRV can be measured using several time and frequency domain methods (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Simple time-domain measures of HRV can be directly derived from the inter-beat interval (IBI) time series and include: (1) the standard deviation of the time series; (2) the square root of the mean of squared successive IBI differences (RMSSD or MSD); and (3) the percentage of differences between consecutive IBIs that are greater than 50 ms (pNN50). In the frequency domain methods, the HR time series is decomposed into its frequency components, which then can be described in terms of a spectral density function that provides the distribution of power as a function of frequency (Berntson et al., 1997; Task Force, 1996; Thayer & Friedman, 2004). The high-frequency power (HFP) of HRV ranges from 0.15 Hz to 0.4 Hz and is primarily mediated by the vagus nerves (Thayer & Friedman, 2004; Task orce, 1996). The low-frequency band ranges from 0.04 to 0.15 and is thought to reflect both sympathetic and vagal modulation of cardiac activity (Berntson et al., 1997; Task force, 1996; Thayer et al., 1996; Thayer & Friedman, 2004). High-frequency HRV power, root mean square successive differences (RMSSD), and pNN50 are considered to effectively quantify vagal activity (Buchheit et al., 2007; Thayer et al., 1996; Task Force, 1996).

In this research, a Polar RS800cx HR monitor (Polar Electro, Finland; www.polar.fi) was used to record electrocardiographic activity (Park, Moon, Kim, & Lee, 2012c). The RS800cx is a portable heart rate monitor tool that is sampled at 1,000 Hz, which yields time- and frequency-domain estimates of HRV comparable to those obtained via standard 3- or 12-electrode ECG setups (Nunan et al., 2009; Vanderlei et al., 2008). In accordance with the RS800cx instructions, participants wore an elastic band around the chest, just below the sternum. A sensor was attached to the elastic band that detected R spikes and transmitted an infrared signal to the watch, which recorded the time of each R spike. Successive IBIs (in ms) within the baseline period were written in a single text file and analyzed using the Kubios HRV analysis package 2.0 (http://basmig.uku.fk/biosignal), through which time and frequency domain indices of the heart period power spectrum were computed. The Kubios software provides spectral estimates based on the more modern autoregressive algorithm which has numerous advantages over the fast Fourier transform based algorithms (Thayer et al., 2008). We obtained high-frequency HRV power which primarily reflects vagal influences using autoregressive estimates. The time domain methods can be based on the differences between successive normal-to-normal (NN) intervals, which includes the percentage of difference between successive NN intervals greater than 50 ms (pNN50) and the root mean square of success differences in milliseconds (RMSSD; Thayer et al., 1996; Task force, 1996). pNN50 is derived by dividing the number of successive NN interval differences greater than 50 ms by the total number of NN intervals (Task force, 1996). RMSSD is the most commonly used method derived from interval differences and mainly indexes vagally mediated cardiac control (Thayer et al., 1996). For spectral analyses, we used autoregressive estimates following the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (1996) guidelines. In this experiment, we focused on RMSSD as the primary measure of HRV, because they are less affected by respiration HF-HRV derived from spectral analysis (Hill et al., 2009; Penttila et al., 2001). In addition to RMSSD, we also examined pNN50 (Park et al., 2013; Penttila et al., 2001).[2]

Results

The ultimatum game Across all conditions fair offers ($5) were always accepted. As is generally seen in the Ultimatum Game, acceptance rates decreased as the offers became progressively more unfair (van't Wout et al., 2010; Fig. 3): $5-$5: $M = 97.8\%$ ($SD = 7.1$); $7-$3: $M = 61.5\%$ ($SD = 41.7$); $8-$2: $M = 38.7\%$ ($SD = 39.0$); $9-$1: $M = 20.7\%$ ($SD = 33.7$). For the purposes of this study, we considered the $5 offers to be fair and the $3, $2, and $1 offers to be unfair (Destoop et al., 2012; Koenigs & Tranel, 2007). To assess the relationship between individual differences in HRV and the acceptance rates in the UG, we conducted a repeated measure analysis of covariance (ANCOVA) on log-transformed acceptance rates of fair and unfair offers as a within-subjects factor with z-standardized RMSSD (HRV) as a covariate. Z-standardization is mandatory to analyze HRV as a continuous variable in ANCOVA (Schielzeth, 2010). There was a significant main effect of fairness, $F(1, 60) = 80.51$, $p < 0.001$, $\eta_p^2 = 0.57$, such that people accepted more fair offers ($M = 98.12$, $SD = 6.11$) than unfair offers ($M = 39.52$, $SD = 32.74$).

[2] RMSSD was negatively correlated with mean heart rate, $r = -0.60$, $p < 0.001$, but was positively correlated with log-transformed high-frequency HRV power, $r = 0.82$, $p < 0.001$, and pNN50, $r = 0.96$, $p < 0.001$.

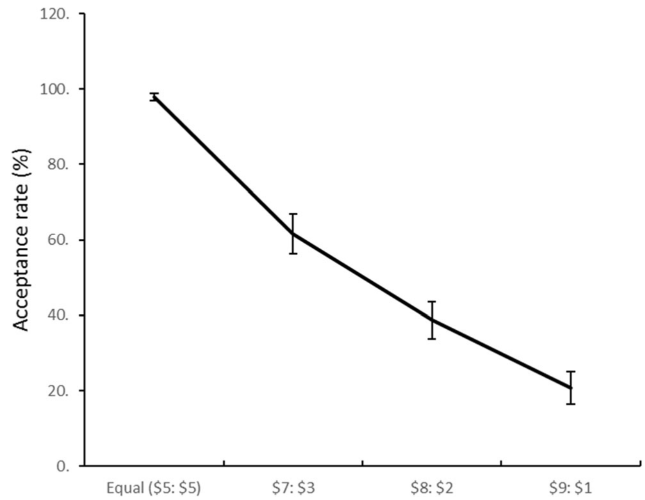

Fig. 3 Percentage of acceptance of the different offers

However, consistent with previous research (Harlé et al., 2010), there was no interaction between HRV and type of offers on acceptance rates in healthy participants ($p = 0.61$).

Spatial cueing task All analyses on reaction times (RTs) excluded incorrect trials and outliers (Fox et al., 2001; Park et al., 2013). RTs of less than 150 ms (anticipatory responding), or more than 1,200 ms or two standard deviations above the mean (delayed responding), were considered outliers (1% of the data). The trimmed RTs were log-transformed and subjected to a 3 (Type of Face Cue: fair-related, unfair-related, new) × 2 (Cue Validity: valid, invalid) repeated measures analysis of covariance (ANCOVA) with z-standardized RMSSD and pNN50 (HRV) scores as a covariate. If the higher-order interactions were significant, we examined cue validity effects. The cue validity effect allows for assessing overall attention for the different types of cues, such that positive scores indicate attention toward a cue, whereas negative scores indicate attention away from the cue (Koster et al., 2006). We computed the cue validity effects by subtracting RTs on valid trials from RTs on invalid trials for fair and unfair cues and then examined the relationship between HRV and the cue validity effects of fair and unfair cues (Koster et al., 2006). Then, to examine our hypotheses related to the specific components of attention, we computed attentional engagement and disengagement scores. In addition, Pearson correlations were used to examine the relationship between HRV as a continuous measure and attentional engagement and disengagement scores.

We hypothesized that: (1) either fair- or unfair-related stimuli would lead to prioritized attentional orienting—faster attentional engagement and/or delayed attentional disengagement, and (2) lower resting HRV would be associated with faster attentional engagement and/or delayed attentional disengagement. Replicating previous research with the cueing task (Koster et al., 2004; Park et al., 2013), there was a

Table 1 Mean correct reaction times (in milliseconds) and mean cue validity (in milliseconds) as a function of types of cues and cue validity (CV) standard deviations and the number of subjects in parentheses

Type	Cue validity	*M*	CVI
New	Valid	372 (64)	22
	Invalid	395 (76)	
Fair	Valid	376 (68)	25
	Invalid	402 (83)	
Unfair	Valid	376 (69)	19
	Invalid	394 (74)	

Note. Cue Validity Index (CVI) is estimated by contrasting the RTs for invalid cues with RTs for valid cues

significant main effect for cue validity, $F(1, 60) = 58.96$, $p < 0.01$, $\eta_p^2 = 0.47$ such that RTs were significantly faster following valid ($M = 376$, $SD = 66$) compared with invalid cues ($M = 399$, $SD = 75$). This main effect was qualified by a significant two-way interaction between RMSSD (HRV) and cue validity, $F(1, 60) = 14.61$, $p < 0.01$, $\eta_p^2 = .20$, which was qualified by a three-way interaction between cue validity, type of face cue, and RMSSD (HRV), $F(2. 120) = 4.07$, $p = 0.02$, $\eta_p^2 = 0.06$ (Table 1).[3]

To decompose the three-way interaction, we examined the main effects and interaction between validity and HRV for fair, unfair, and new cues separately. The trimmed RTs of the fair cue condition were log-transformed and subjected to a 2 (Cue Validity: valid, invalid) repeated measures analysis of covariance (ANCOVA) with a z-standardized RMSSD score as a covariate. There was a significant main effect for cue validity, $F(1, 60) = 26.16$, $p < 0.001$, $\eta_p^2 = 0.30$, such that RTs were significantly faster following valid ($M = 376$, $SD = 68$) compared with invalid cues ($M = 402$, $SD = 83$). This main effect was qualified by a significant two-way interaction between RMSSD (HRV) and cue validity, $F(1, 60) = 15.45$, $p < 0.001$, $\eta_p^2 = 0.21$. The trimmed RTs of the unfair cue condition were log-transformed and subjected to a 2 (Cue Validity: valid, invalid) repeated measures analysis of covariance (ANCOVA) with a z-standardized RMSSD score as a covariate. There was a significant main effect for cue validity, $F(1, 60) = 33.29$, $p < 0.001$, $\eta_p^2 = 0.36$, such that RTs were significantly faster following valid ($M = 376$, $SD = 69$) compared with invalid cues ($M = 394$, $SD = 74$). This main effect was qualified by a significant two-way interaction between RMSSD (HRV) and cue validity, $F(1, 60) = 7.18$, $p < 0.001$, $\eta_p^2 = 0.11$. The trimmed RTs of the new cue condition were log-transformed and subjected to a 2 (Cue Validity: valid, invalid) repeated measures analysis of covariance (ANCOVA) with a z-standardized RMSSD score as a covariate. There was a significant main effect for cue validity, $F(1, 60) = 41.11$, $p < 0.001$, $\eta_p^2 = 0.41$, such that RTs were significantly faster following valid ($M = 372$, $SD = 64$) compared with invalid cues ($M = 395$, $SD = 76$). This main effect was qualified by a significant two-way interaction between RMSSD (HRV) and cue validity, $F(1, 60) = 4.73$, $p = 0.03$, $\eta_p^2 = 0.07$.

We conducted post hoc independent-*t* tests by dividing participants into two groups—high or low HRV—based on the median split of RMSSD ($M = 36$; Park, Van Bavel, Vasey, Egan, & Thayer, 2012a; Park, Van Bavel, Vasey, & Thayer, 2012b). To simplify the analyses, we obtained indices for the cue validity effect ($CV = RT_{invalid\ cue} - RT_{valid\ cue}$) for fair, unfair, and new cues (Waters et al., 2007; Table 1). A positive score indicates faster responses to valid than invalid trials, suggesting that participants maintain attention to where a preceding cue is presented. A negative score indicates faster responses to invalid than valid trials (Posner & Cohen, 1984; Waters et al., 2007). For fair-related face cues, low HRV participants produced significantly greater cue validity scores ($M = 41.52$, $SD = 39.10$) than high HRV participants ($M = 10.03$; $SD = 41.53$), $t(60) = 3.07$, $p = 0.003$, $d = 0.80$. Furthermore, we examined the relationship between HRV and the cue validity effect of fair cues using a Pearson correlation. HRV was negatively correlated with the cue validity effect for fair-related face cues, $r = -0.44$, $p < 0.001$ (Fig. 4). For unfair-related face cues, low HRV participants also produced significantly greater cue validity scores ($M = 28.36$, $SD = 22.51$) than high HRV participants ($M = 10.53$, $SD = 24.46$), $t(60) = 2.98$, $p = 0.004$, $d = 0.77$. HRV also was negatively correlated with the cue validity effect for unfair-related face cues, $r = -0.28$, $p = 0.03$ (Fig. 5). For new face cues, low HRV participants produced marginally significantly greater cue validity scores ($M = 29.65$, $SD = 31.39$) than high HRV participants ($M = 16.09$, $SD = 23.31$), $t(60) = 1.93$, $p = 0.06$, $d = 0.57$. Also, HRV had a marginally significant relationship with the cue validity effect for new cues, $r = -0.25$, $p = 0.051$.

To examine the specific components of attention, attentional engagement and disengagement scores were calculated. We used a variant of Koster et al. (2006) to compute attentional engagement indices for fair (RT_{valid}/new face cue –RT_{valid}/fair cue) and for unfair RT_{valid}/new face cue – RT_{valid}/unfair cue) face cues. We also computed attentional disengagement indices for fair ($RT_{invalid}$/fair cues – $RT_{invalid}$/new cue) and unfair ($RT_{invalid}$/unfair cues – $RT_{invalid}$/new cue) face cues. A positive score on attentional engagement indicates that attention is quickly directed at the location of fair or unfair cues compared with new cues, whereas a negative score indicates an opposite attentional process (Koster et al., 2004, 2006). A positive attentional disengagement score indicates that it takes longer to

[3] We also conducted a 3 (Type of Face Cue: fair-related, unfair-related, new) × 2 (Cue Validity: valid, invalid) repeated measures analysis of covariance (ANCOVA) with z-standardized pNN50 (another measure of vagally-mediated HRV) scores as a covariate. Consistent with RMSSD data, the three-way interaction on the RT data was significant, $F(2, 120) = 4.0$, $p = 0.02$, $\eta_p^2 = 0.06$.

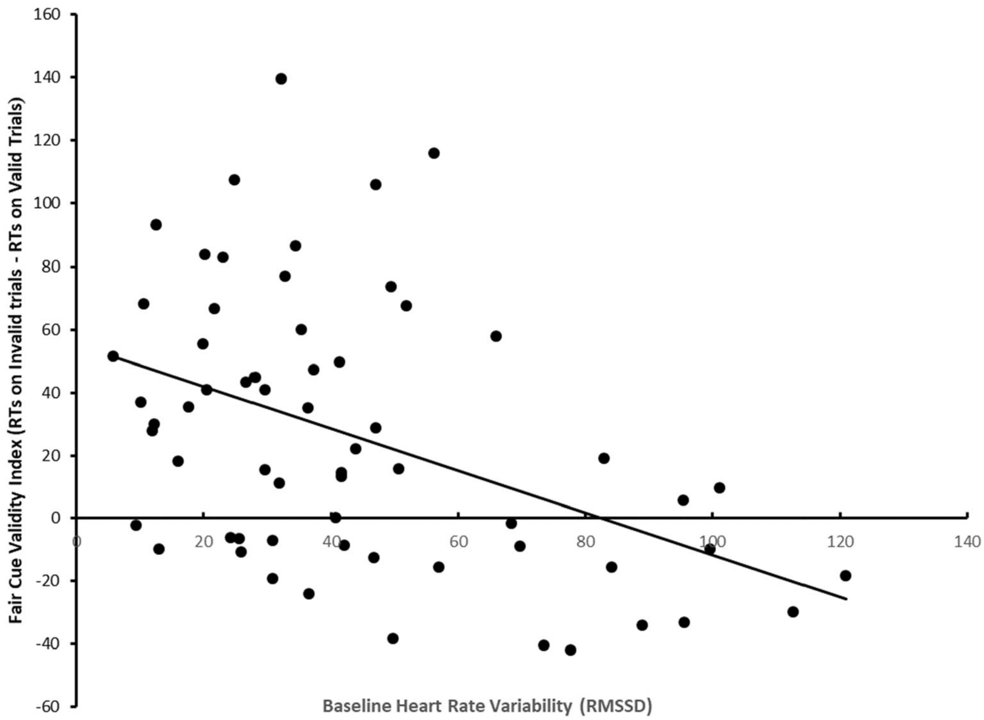

Fig. 4 Scatterplot indicating the correlation between HRV (x-axis) and the cue validity effect (in milliseconds) for fair cues (y-axis), r = −0.44, $p < 0.001$

shift attention away from fair or unfair cues compared with new cues, whereas a negative attentional disengagement score indicates an opposite attentional process (Koster et al., 2004, 2006). Zero score indicates that there is no difference in attentional engagement or disengagement for fair or unfair cues versus neutral cues (Koster et al., 2004, 2006).

To assess whether individual differences in HRV modulated attentional engagement to and disengagement from fair-related face cues, the engagement and disengagement scores were subjected to a 2 (Type of Face Cue: fair-related, unfair-related) repeated measures analysis of covariance (ANCOVA) with z-standardized RMSSD (HRV) scores as a covariate. As

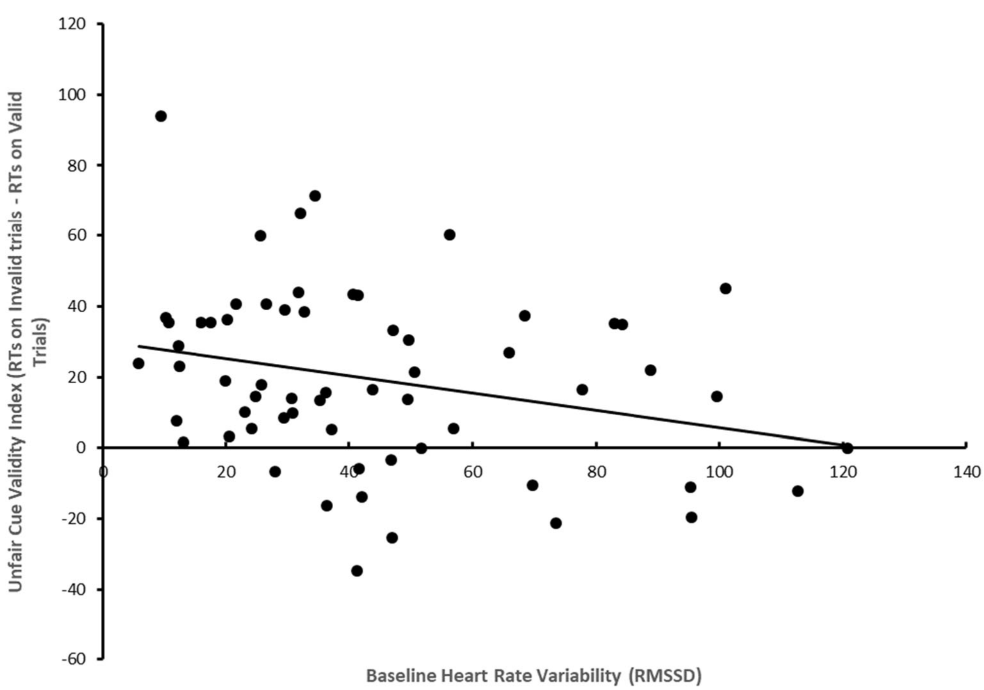

Fig. 5 Scatterplot indicating the correlation between HRV (x-axis) and the cue validity effect (in milliseconds) for unfair cues (y-axis), r = −0.28, p = 0.03

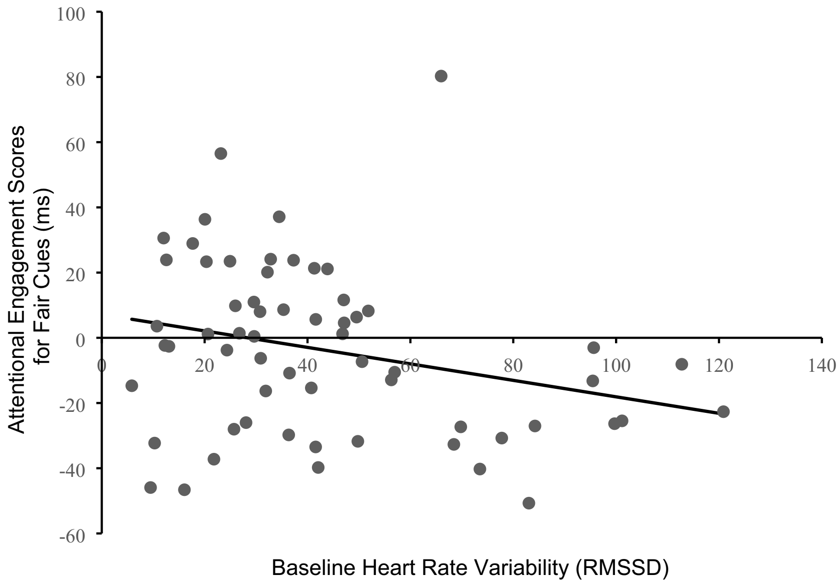

Fig. 6 Scatterplot indicating the correlation between HRV (x-axis) and attentional engagement scores (in milliseconds) for fair cues (y-axis), $r = -0.26$, $p < 0.04$

expected, there was a significant interaction between HRV and type of face cue on engagement scores, $F(1, 60) = 4.06$, $p = 0.048$, $\eta_p^2 = 0.06$. HRV was negatively correlated with attentional engagement scores to fair faces, $r = -0.26$, $p = 0.039$ (Fig. 6). Thus, lower HRV was correlated with faster attentional engagement to fair-related faces, but HRV was not correlated with attentional engagement scores to unfair faces, $r = -0.02$, $p = 0.86$. However, there was no significant main effect of type of face cue ($p = 0.84$).[4] The relationship between resting HRV and attentional disengagement was tested using the same analysis. However, there was no significant interaction between resting HRV and type of face cues in attentional disengagement ($p = 0.27$).[5] However, simple effects indicated that it takes longer to disengage attention away from fair face cues ($M = 6.71$, $SD = 28.80$) compared with unfair face cues ($M = -0.91$, $SD = 21.02$), $F(1, 60) = 3.99$, $p = 0.05$, $\eta_p^2 = 0.02$ (Fig. 7).

Discussion

The experiment provided initial evidence that fair-related stimuli lead to prioritized attentional orienting—faster attentional engagement and slower attentional disengagement. Moreover, lower HRV was associated with faster attentional engagement to fair-related stimuli but not with slower attentional disengagement from fair-related stimuli. Greater attentional allocation to fair-related stimuli may be consistent with memory bias favoring fairness (Park et al., 2019). Recent research has shown that people better recognized faces that made fair offers during the UG task, which was further confirmed by higher *d'*—indicating higher recognition—and more conservative decision criterion (Park et al., 2019). These findings are consistent with the notion that attention and memory are intricately related and that greater attentional allocation leads to better memory (Chun & Turk-Browne, 2007). Neuroimaging evidence has shown that attention increases the activity of brain areas associated with memory (e.g., the medial temporal lobe and the hippocampus; Aly & Turk-Browne, 2016). Moreover, the same brain area (i.e., the posterior parietal cortex) has been identified to mediate both attentional allocation and memory retrieval (Cabeza et al., 2008). Thus, preferential attentional allocation towards fair-related information may have preceded enhanced memory of fair-related information. This enhanced cognitive bias favoring fair-related faces will facilitate effective social interactions and fair business engagements (Park et al., 2019).

A wealth of evidence has shown that attention is prioritized to stimuli with negative as well as positive emotional salience (Öhman & Mineka, 2001; Pool et al., 2016), stimuli with motivational relevance (Cunningham & Brosch, 2012), and stimuli associated with monetary value (Anderson et al., 2011a, 2011b). There is growing evidence that moral content affects human perception and attention (Brady et al., 2020a; Gantman & Van Bavel, 2014, 2016). The results of the current experiment provide additional evidence to the existing literature that social and moral concepts, such as fairness, may modulate attentional orienting as well.

[4] There was also a significant interaction between pNN50 and types of face cues in engagement scores, $F(1, 60) = 5.95$, $p = 0.02$, $\eta_p^2 = 0.09$. pNN50 was negatively correlated with attentional engagement scores to fair face cues, $r = -0.32$, $p = 0.01$, but not unfair face cues ($p = 0.72$).

[5] Consistent with RMSSD, there was no significant interaction between pNN50 and types of face cues in attentional disengagement ($p = 0.35$). However, it takes longer to disengage attention away from fair face cues, $F(1, 60) = 3.99$, $p = 0.05$, $\eta_p^2 = 0.06$ (Figure 6).

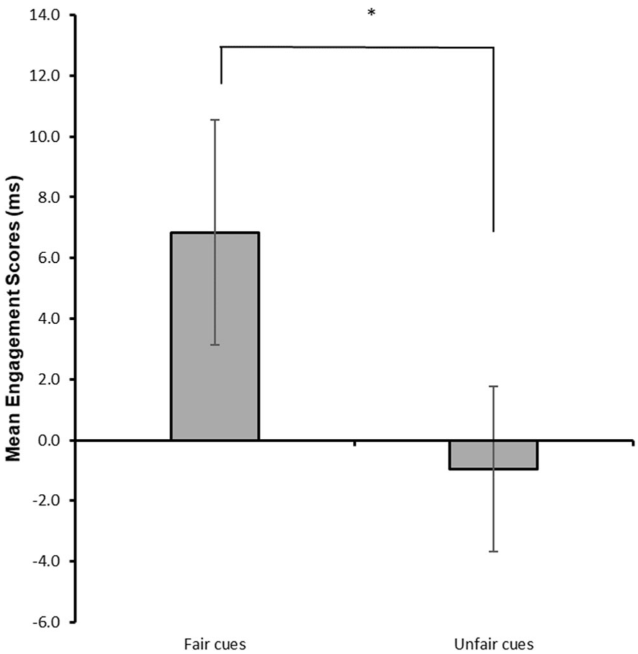

Fig. 7 Mean disengagement scores (in milliseconds) and standard errors of fair and unfair cues. *Note.* *$p \leq 0.05$

Furthermore, we provided evidence that individual differences in cardiac vagal tone plays a role in guiding attentional capture of fair-related stimuli. A growing body of literature suggests that HRV may serve as a physiological proxy of social and moral cognition (Okruszek et al., 2016; Quintana et al., 2012; Shahrestani et al., 2015). Extensive evidence has shown that cardiac vagal tone taps into social engagement systems and neural networks mediating cognitive and emotion self-regulatory systems (Friedman, 2007; Park & Thayer, 2014; Porges, 1998, 2003, 2007; Thayer & Lane, 2000). Being easily drawn to emotionally salient or motivationally relevant stimuli may not be functional and effective in everyday life. When people become highly vigilant to specific types of stimuli, they can be easily distracted and often fail to optimally perform a goal-directed task. Previously, we have reported that lower resting HRV was associated with a greater cue validity effect in response to fearful faces, which rendered significantly faster attentional engagement at low spatial frequency and slower attentional disengagement at high spatial frequency, respectively (Park et al., 2013). Although the relationship between HRV and the cue validity effect in response to positive emotions is yet to be determined, others have shown that the vagal system has implications in more broad social domains, such as political orientation and destructive obedience (Lepage et al., 2019). The current research shows that lower resting HRV was associated with a greater cue validity effect in response to both fair- and unfair-related faces, which rendered significantly faster attentional engagement to fair-related faces, but not unfair-related faces. The current research expands on previous findings that cardiac vagal tone is sensitive to attentional bias of not only emotionally negative stimuli but also a more general social and moral construct, fairness.

At the neural level, many studies have shown that the amygdala plays an important role in attentional bias (Cunningham et al., 2008; Vuilleumier & Brosch, 2009). The amygdala is bidirectionally interconnected with prefrontal cortices, as well as parietal attentional regions that subserve attentional shifts (Brosch et al., 2007, 2008, 2013; Sander et al., 2005; Stefanacci & Amaral, 2000). Previous research has shown that fairness elicited greater activations in brain regions such as the amygdala, ventromedial prefrontal cortex (VMPFC), and orbitofrontal cortex (OFC; Tabibnia et al., 2008). The amygdala, considered as a "relevance detector," assesses and enhances the salience of fair-related faces and mobilizes cognitive and physical resources to make hypervigilant responses to them (Cunningham & Brosch, 2012; Sander et al., 2003). People with lower HRV that are characterized by hyperactive amygdala activity may accentuate the effect of fair-related stimuli on attentional processes. However, to explore this issue more directly, future research should use functional neuroimaging to isolate the specific brain regions implicated in attentional orienting of fairness and cardiac vagal tone.

The current results appear to be contradictory to previous findings showing that cardiac vagal tone was not related to attentional engagement and disengagement of broad spatial frequency faces. Previously, we have reported that participants with lower HRV showed faster attentional engagement to low spatial frequency fearful faces at shorter stimulus-onset asynchronies, which refers to the duration between the onset of a cue and the onset of a target, but showed delayed attentional disengagement from high spatial frequency fearful faces at long stimulus-onset asynchronies compared to those with higher HRV (Park et al., 2013). However, in the present study, participants with lower HRV showed greater attentional engagement to neutral fair-related faces. The discrepancies between the two results can be explained by the fact that two different types of stimuli may have triggered different cognitive processes to direct attentional orienting. Attentional orienting of emotionally threatening stimuli (e.g., fearful faces) in Park et al. (2013) is primarily driven by bottom-up processing that relies on physical attributions and salience of stimuli and their evolutionary significance (Bannerman et al., 2009; Öhman & Mineka, 2001; Sussman et al., 2016). Furthermore, by utilizing spatial frequency information, the study (Park et al., 2013) focused on low-level visual processing that taps directly to the brain structures involved in the bottom-up processing, such as the amygdala.

In contrast, attentional orienting of fair-related stimuli is driven by top-down processing. Top-down processing relies on associative learning, prior knowledge, and experience to prioritize attention to visual stimuli deemed to be highly relevant to goals, contexts, and expectations (Summerfield & Egner, 2009; Sussman et al., 2016). In the present study, participants learned to associate neutral faces with fair or unfair offers in the UG task. Thus, attentional modulation of fair-related stimuli occurs through top-down processing. It can be argued that fair- and unfair-related stimuli may carry emotional positive and negative connotations respectively. However, the fact that participants were presented with all neutral faces during the spatial cuing task rules out the possibility that participants assess emotional valence through bottom-up processing by focusing on physical salience and attributes of the stimuli.

Conclusions

The current research provides initial evidence that fairness modulates visual attention. Attentional capture of fair-related stimuli was more pronounced in people with lower resting HRV; however, slower attentional disengagement was not associated with HRV. The current research expanded on previous research that moral content plays an important role in modulating attentional orienting. Also, we provided evidence that cardiac vagal tone is involved in attentional bias to not only emotionally salient stimuli but also motivationally relevant stimuli.

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