Cardiac deceleration following positive and negative feedback is influenced by competence-based social status.

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Abstract

Previous studies indicate that neurophysiological signatures of feedback processing might be enhanced when participants are assigned a low-status position. Error commission and negative feedback can evoke responses in the peripheral (autonomic) nervous system including heart rate deceleration. We conducted an exploratory study to investigate whether such activity can be modulated by the participant's social status in a competence-based hierarchy. Participants were engaged in a cooperative time estimation task with two same-gender confederates. On each trial, they were provided with positive or negative feedback depending on their time estimation performance. Their social status varied during the task, so that they were either at the top (high-status) or at the bottom (low-status) of the hierarchy in different blocks. Results showed that cardiac deceleration was significantly modulated by feedback valence in the high-status but not in the low-status condition. We interpret this result as an increased activation of the performance monitoring system elicited by the desire to maintain a high-status position in an unstable hierarchy. In this vein, negative feedback might be processed as an aversive stimulus that signals a threat to the acquired status.

Introduction

Human societies and groups are characterized by unequal distribution of privileges among individuals and attaining a low versus high-status position has implications for health, well-being and longevity (Sapolsky, 2005; Marmot, 2006). For example, people who rank themselves as low social status show higher basal heart rate (Adler et al., 2000), higher cortisol levels (Wright & Steptoe, 2005) and reduced habituation of cortisol responses to psychological stressors (Adler et al., 2000). Nevertheless, other studies on both human and non-human primates indicate that being at the top of an unstable hierarchy (i.e., where the relation of forces can change at any time) can increase stress levels (Sapolsky, 2005; Knight and Mehta; 2016). It has been traditionally assumed that low-status individuals are more likely to experience social threat and to receive negative evaluation than high-status individuals, leading to enhanced performance monitoring across domains (Boksem et al., 2011). Consistent with this notion, one experimental study using electroencephalography (EEG) showed that participants assigned to a low-status position showed an enhanced medial frontal negativity (MFN), an event-related potential reflecting performance monitoring, when they received negative feedback during a cooperative task (Boksem et al., 2011). Conversely, when participants are presented with high-status neutral faces, they show an enhancement of the error-related negativity (ERN, Gehring et al., 1993) when committing an error (Fondevila et al., 2021).

Besides the well-known EEG signatures including the ERN, MFN, positivity error (Pe, Hermann et al., 2004) and feedback-related negativity (FRN, Hajcak et al., 2006), performance monitoring and feedback also evoke specific changes in bodily physiology via the activity of the autonomic nervous system (ANS). Such changes can be detected from the heart rate (HR), pupil diameter and skin conductance response (SCR) (Hajcak et al., 2004; 2003; O’Connell et al., 2007; Critchley et al., 2005; Fiehler et al., 2004; van der Veen et al., 2004; Crone et al., 2003). Neuroimaging studies have further shown that both error processing (Carter et al., 1998; Kiehl et al., 2000) and autonomic changes (Matthews et al., 2004; Critchley, 2005) activate visceromotor regions within dorsal anterior cingulate cortex (ACC), a “hub-like” brain structure interconnected with several cortical and subcortical networks (Critchley et al., 2000; 2001; 2005; Matthews et al., 2004; Cavanagh & Frank, 2014). A reciprocal relationship is observed with dorsal ACC and ventromedial prefrontal cortex (VMPFC) in the generation of autonomic arousal in the context of social threat (Wager et al., 2009; Gianaros et al., 2007), while activity in the ACC predicted the magnitude of baroreflex sensitivity suppression during a stress-evoking task (Gianaros et al., 2012). In addition, using a conjunction analysis Critchley and colleagues (Critchley et al., 2005) demonstrated that a dorsal subregion of the ACC was jointly activated by both error processing and error-related autonomic arousal. Overall, these findings indicate that the the cognitive and emotional aspects of error processing are integrated with the generation of an associated autonomic response in the ACC.

Building on the finding that the assignment of low social status hyper-activates neural substrates of performance monitoring (Boksem et al., 2011), in the present study we explored whether the autonomic response to negative feedback will also be modulated by individuals’ social status. To this end, we recorded the cardiac activity of participants engaged in a status-inducing procedure within a social game played with two other players. Previous research has established that the presentation of negative feedback during cognitive tasks induces a transient bradycardic response, namely a brief cardiac deceleration followed by a phase of acceleratory recover (Somsen et al., 2000; Crone et al., 2003; van der Veen et al., 2004, Gunter-Moor et al., 2010). Phasic cardiac deceleration is a well-known, parasympathetically mediated (Campbell et al., 1997) response that can be observed following the presentation of negative/threatening stimuli (Klorman et al., 1977; Bradley et al., 2000) or unpleasant sounds (Bradley et al., 2001) and is typically associated with an amplification of reactive attention towards potentially threatening stimuli (Sokolov, 1990; Porges, 1992; Wessel et al., 2011). Errors and negative feedback are indeed processed as aversive stimuli (Hajcak and Foti, 2008; Cavanagh & Shackman, 2015) and previous research has established that error-related central and peripheral signals are modulated by contextual, emotional and personality variables. Individuals with high levels of anxiety and patients with obsessive-compulsive disorder display exaggerated EEG responses to errors, conflict and negative feedback (Cavanagh & Shackman, 2015; Santamaria-Garcia et al., 2017). Moreover, individuals with higher levels of negative affect display exaggerated autonomic responses after error commission (Hajcak et al., 2004). Similar patterns are observed in patients with obsessive-compulsive disorder (Hajcak & Simons, 2002) and depression (Tucker et al., 2003). Importantly, also the social context will modulate this response, such that the magnitude of cardiac deceleration following negative feedback is enhanced in a 'social' condition, when feedback reflects peer rejection (Gunter-Moor et al., 2010).

In the present study, we explored whether that attaining a low- or-high status position in an interactive, cooperative game would differentially modulate the participants' cardiac responses to negative and positive feedback (i.e., cardiac deceleration). Previous studies have tested the effects of social status on both brain activity and behaviour by engaging participants in interactive games where they were requested to compete with other players for a (virtual or real) reward. This approach has produced a variety of important findings on how the relative social status of a target modulates the neural correlates of face perception (Breton et al., 2015; Feng et al., 2015, even at the earliest stages of processing: Santamaría-García et al., 2015), error monitoring (Santamaría-García et al., 2018) and differently engages brain networks related to attentional and emotional processing (Zink et al., 2008). For the present study, however, we decided to inform our participants that each player's score would be added to a common account, making the task cooperative in nature. Although status has been often discussed in relation to dominance and competition, recent studies have highlighted that people who chose to benefit the group over themselves (Hardy and Van Vugt, 2006), contribute to collective actions (Willer, 2009) and display virtuous behaviours beyond the conformity to norms (Bai et al., 2020) are afforded high status by group members. Therefore, in our experiment status was operationalized as competence but inherently linked to each player's contribution to collective gain or, in other words, to how much each player was helping the group. In this vein, when our participants were in the low-status condition, they were not only the worst player but also the one who was making the group lose money. The same approach has been used in previous studies (Boksem et al., 2011; Boukarras et al., 2020; Boukarras et al., 2021) and has proven effective in inducing a competence-based hierarchy.

Low-status individuals are reported to display reduced levels of heart rate variability (HRV), an index of parasympathetic-sympathetic balance that is also considered an indicator of an adaptive, well-regulated organism (Marmot et al., 1991; Thayer et al., 2009). When social status is experimentally manipulated, changes in HRV can also be observed. For example, when participants are required to compare themselves to someone of higher social status, they show a reduction in HRV relative to baseline (Pieritz et al., 2016). Based on these findings, in the present study, we also measured HRV during the high and low-status blocks of the game. Given the lack of pre-registration before data collection, this study should be considered as exploratory.

Methods

Participants

Twenty-four (24) participants (6 M, age = 20 ± 2.53 years) were recruited from September to November 2019 using leaflets and mailing lists from students attending the

University of Sussex campus. We tested 24 participants before the data collection was stopped due to the COVID-19 pandemic outbreak. The sample size (N = 24) is comparable to other studies using a similar paradigm (Crone et al. 2003; Van Der Veen & Sahibdin, 2011; Gunter-Moor et al., 2010), but in which no between-subjects factor was included. For that reason, we report in the main text only the analyses concerning the interaction between *induced* status, feedback valence and heartbeat. Additional analyses taking into account the interaction with *subjective* social status should be considered as exploratory and are reported in the Supplementary Materials. Participants' exclusion criteria were: Medication intake and/or a self-declared ongoing or history of psychiatric disorders, neurodevelopmental conditions or cardiac issues. All participants had normal or corrected-to-normal vision. The study was approved by the Brighton and Sussex Medical School Research Governance and Ethics Committee and all participants gave written informed consent. The study involved deception, since participants were told that they were to play with other individuals while the other players' scores were artificially generated by a computer. This procedure was approved by the Ethics Committee and participants were debriefed at the end of the experiment and given the opportunity to retract from the study.

General Procedure

Participants were each informed that they would individually play a cooperative time estimation game with two other players located in nearby rooms within the same building and connected by computer. They were also informed that their physiological activity would be recorded during the game and that some aspects of the study would be disclosed only at the end of the experiment, as clearly also stated in the participant information sheet. A photo of the participant was taken and uploaded into the computer running the game. Correspondingly during the game, the participant's photo and those of two same-gender confederates were displayed on the screen (see Fig. 1). In fact, during the game the participant was the only active player, while the scores of the other two players were artificially manipulated to and presented to the participant as a performance-based hierarchy. Participants were told that the game was cooperative in nature, specifically that the score obtained by each player would be added to a shared account. They were also informed that, at the end of the game, the collective score would be split into three equal parts and distributed equally among the players in the form of a small monetary reward (which will be equal for all participants). After a 2-min physiological recording designed to assess baseline measures of cardiac activity, participants were provided with instructions concerning the time estimation task and were given the opportunity to perform a practice block. Participants then completed the Mac Arthur Subjective Social Status scale (SSS, Adler et al., 2000 – see Supplementary Materials) and started the task, while their cardiac activity was recorded continuously. At the end of the experiment, participants underwent a final debriefing procedure to determine if they had any suspicion about the cover story. The experimenter started this debriefing with a broad question (i.e., "Do you have any idea about what the purpose of this experiment may be?") before getting more detailed: "Did you ever wonder whether the other players really existed"? Participants were then debriefed and offered the opportunity to retract from the study (i.e. their data being deleted) if they felt uncomfortable with the actual goal of the study. The total time of the experiment was around 1 hour.

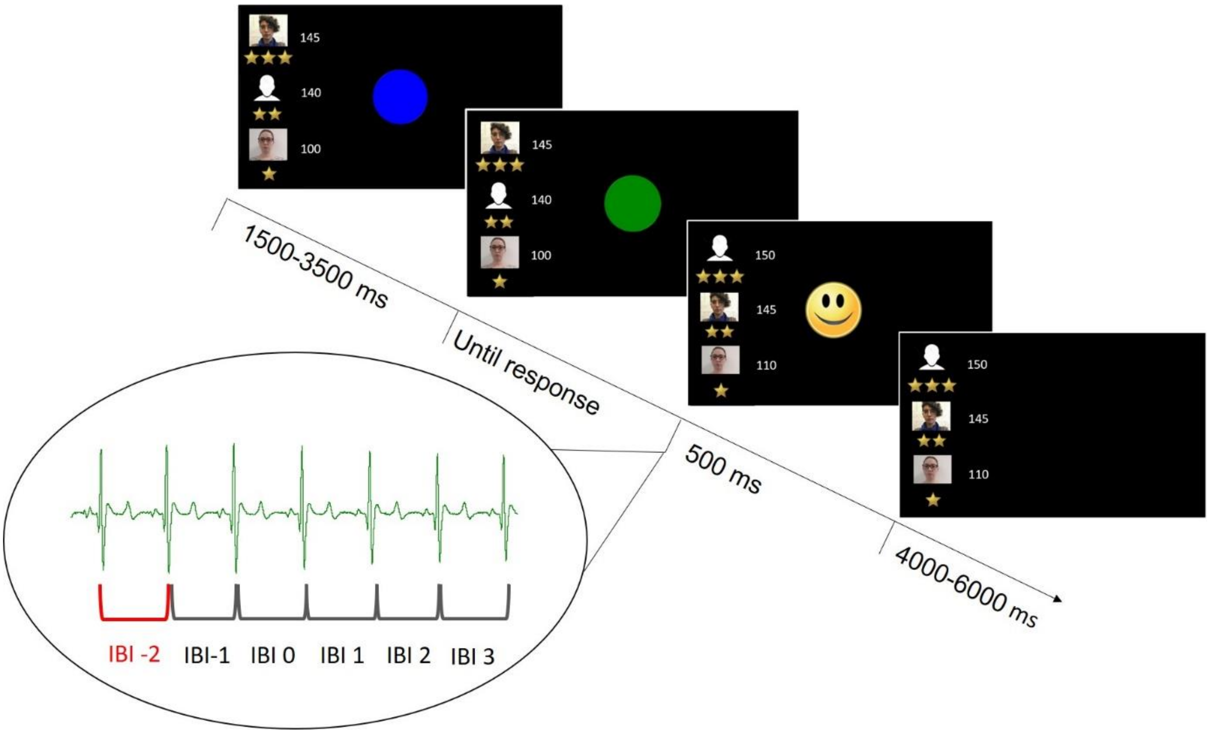

Fig. 1 – Time estimation task and IBI selection. Participants (represented by a photo during the experiment, here depicted as the white figure) kept track of their relative position in the hierarchy throughout the game. During each trial, they received either a positive (i.e. smiley face) or negative (i.e. frown) feedback. Five IBIs (one before the feedback, one around the feedback and three after) were selected and standardized by subtracting each value from a common baseline (IBI-2).

Time Estimation task

The Time Estimation Task and the Subjective Social Status (SSS) questionnaire were administered using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). The task was adapted from Boksem et al. (2011), where it was demonstrated that participants' status (according to their contribution to the collective game) influences their feedback-related EEG activity (MFN). Each trial of the Time Estimation Task started with the presentation of a blue circle that turned green after a random time interval (ranging between 1500-3500 ms).

Participants were required to press the space bar exactly 1 second after the circle had changed colour. Visual feedback was provided at the end of each trial; a smiley face for wins and a sad face for fails. The visual feedback was displayed for 500 ms. To avoid ceiling effects, we adopted a staircase-like procedure. At the start of the task, the ‘win’ threshold for the response time was set at 1 second +/- 550 ms. A response falling within this time was considered a ‘win’ trial and set the threshold for the following trial at 1 second +/- 500 ms. Otherwise, a response falling outside this time was considered a ‘fail’ trial and the threshold was changed to 1 second +/- 600 ms for the following trial. A digital trigger was sent to the physiological recording equipment at the start of the feedback presentation. The inter-trial interval (ITI) was set at 4000-6000 ms. Participants completed 12 blocks of 10 trials each of the Time Estimation Task. Within the game, pictures of all three players (i.e. the participant and two confederates) were presented along with the experimental stimuli. Below each player’s photo her/his individual score was displayed along with a number of stars reflecting performance (3 stars for the best player, 2 for the middle and 1 for the worst), see Fig. 1. The hierarchy and the scores were updated on each trial. For the first 5 blocks, the participant’s scores were manipulated so that she/he would have the highest score (high-status blocks). From block 6 to 7 the participant would switch from the first to the second position in hierarchy (middle-status blocks) and then to the third position from block 8 to 12 (low-status blocks). The order of the high and low status blocks was reversed for half of the participants, so that they started at the bottom of the hierarchy and ended at the top of it. At the end of each block, participants were each asked to report how good they felt they performed on a visual analogic scale (VAS) ranging from 1 to 100.

Physiological Recording

Inter-beat intervals (IBI)

Cardiac activity was recorded with the CED Power1401 and 1902 amplifiers (Cambridge Electronic Design Limited, Cambridge, UK) at 1000 Hz sampling rate and was digitized with Spike2 software (Cambridge Electronic Design Limited, Cambridge, UK). The raw signal was cleaned using the HumRemove Spike2 script to remove interference from the mains (i.e. 50 Hz) and visually inspected for artefacts. Inter-beat intervals (IBIs) were extracted using a customized Matlab (Mathworks, version 2017a) script. Following Crone and colleagues (Crone et al., 2003), we selected two IBIs before the presentation of the feedback slide (IBI-2, IBI-1), the IBI around the feedback slide presentation (IBI 0) and three IBIs following the feedback slide (IBI 1, IBI 2, IBI 3). The values in seconds of IBI-1, IBI 0, IBI 1, IBI 2 and IBI 3 IBIs were standardised to (i.e. subtracted from) the values of IBI-2, see Fig. 1. Thus, our dependent variable (IBI_change) is an index of change in time in the length of each IBI with respect to a common baseline, with positive values indicating a deceleration and negative values an acceleration.

Heart rate variability (HRV)

As our measure of HRV, we computed RMSSD (square root of the mean squared differences of successive normal-to-normal IBIs) during the entire length (approximately 10 minutes) of consecutive high-status and low-status blocks, namely when participants were at the top and at the bottom of the competence-based hierarchy. RMSSD was calculated using HRVTool – an Open-Source Matlab Toolbox for Analyzing Heart Rate Variability (Vollmer, 2019).

Statistical analysis

Data analysis was performed using R (version 3.6.2) statistical software. For statistical analysis, only data from the high and low-status blocks were considered. We excluded the middle-status blocks since the number of trials was smaller in that condition relative to the others and because we were interested in high-low status comparison. Standardised values of IBI_change in seconds were analysed with linear mixed models (LMM) including Status (High, Low), Feedback (Positive, Negative) and IBI (IBI -1, IBI 0, IBI 1, IBI 2 and IBI 3) as fixed factors. The random part of the model included the by-participants random intercepts and slopes of Status and Feedback and the by-participants random intercept for Trial Number (to account for boredom/habituation effects). This model was compared with other models with simpler random or fixed structure using the Akaike Information Criteria (AIC) and the p-value of the Chi-squared test from the *anova* function with the *stats* R package (R Core Team, 2013). AIC and p-information loss values for each model are reported in the Supplementary file "Model Selection".

The statistical significance of fixed effects was determined using Type III ANOVA test with the *mixed* function from *afex* R package (Singmann et al., 2015). The P values were derived using the Satterthwaite's degrees of freedom method. Post-hoc comparisons and simple slope analysis were performed with the *emmeans* R package (Length et al., 2018) via the *emmeans* and *emtrends* functions, respectively, and Tukey correction for multiple comparisons. The effect of status on HRV was calculated with a paired-sample t-test comparing RMSSD in high and low status blocks.

To investigate potential interactions between participants' subjective social status (as measured by the SSS questionnaire), autonomic reactivity to negative and positive feedback according to the game status and HRV, we conducted further exploratory analyses. First, participants were split in two groups according to their SSS score. We set as a cut-off the mean SSS value (5.85) reported by a study on a large sample of 1249 participants (Operario et al., 2004). Participants were included in the lowSSS group if their SSS fell below 5.85 and in the highSSS group if their SSS fell above 5.85. We included in a new mixed-effects model on IBI_change the between-participants factor SSSgroup (highSSS and lowSSS), see Supplementary Materials.

To explore the relationship between SSS and HRV, we ran a correlation analysis between the two variables. Exploratory results are reported for completeness in the Supplementary Materials.

Results

Inter-beat intervals (IBIs)

The full model structure in R notation was:

IBI_change ~ Status * Feedback * IBI + (Status + Feedback | Participant) + (TrialNumber | Participant)

Type III ANOVA revealed significant main effects of FEEDABCK (*F*(1, 23.11)= 6.13, p = .021) and IBI (*F*(4, 10535.11) = 94.64, *p* <.001) and a significant STATUS x FEEDBACK interaction (*F*(1, 10581.50) = 7.31, *p* = .007). Post hoc tests for the main effect of IBI showed that IBI_change values over the five IBIs were significantly different from each other. Specifically, IBI -1 had smaller IBI_change values than IBI 0 (estimate = 0.009, SE = 0.002, z-ratio = -4.411, *p* < .0001), indicating that the heart decelerated following feedback presentation. Values in IBI 0 were larger than in IBI 1 (estimate = 0.007, SE = 0.002, z-ratio = 3.328, *p* = .0078) as well as than in IBI 2 (estimate= 0.025, SE= 0.002, z-ratio = 11.744, *p* < .0001) and IBI 3 (estimate = 0.03697, SE = 0.002, z-ratio = 16.899, *p* < .0001). This suggests that the cardiac deceleration initially occurring in response to the feedback presentation was then followed by an acceleratory pattern that lasted for at least three heart beats (see Fig. 3). Concerning the main effect of FEEDBACK, as shown in Fig. 2, although the heart rate decelerated in response to both positive and negative feedback, a stronger deceleration was observed at the IBI 0 after Negative (M = 0.02, SD = 0.07) compared to Positive (M= 0.01, SD = 0.07) feedback. The same pattern (i.e., larger IBI_change values for Negative than Positive feedback) was observed at IBI 1 (M_{Positive}= 0.008, SD_{Positive} = 0.07, M_{Negative} = 0.01, SD_{Negative} = 0.07), IBI_2 (M_{Positive} = - 0.01, SD_{Positive} = 0.07, M_{Negative} = - 0.005, SD_{Negative} = 0.08) and IBI_3 [M_{Positive} = - 0.02, SD_{Positive} = 0.08, M_{Negative} = - 0.01, SD_{Negative} = 0.09).

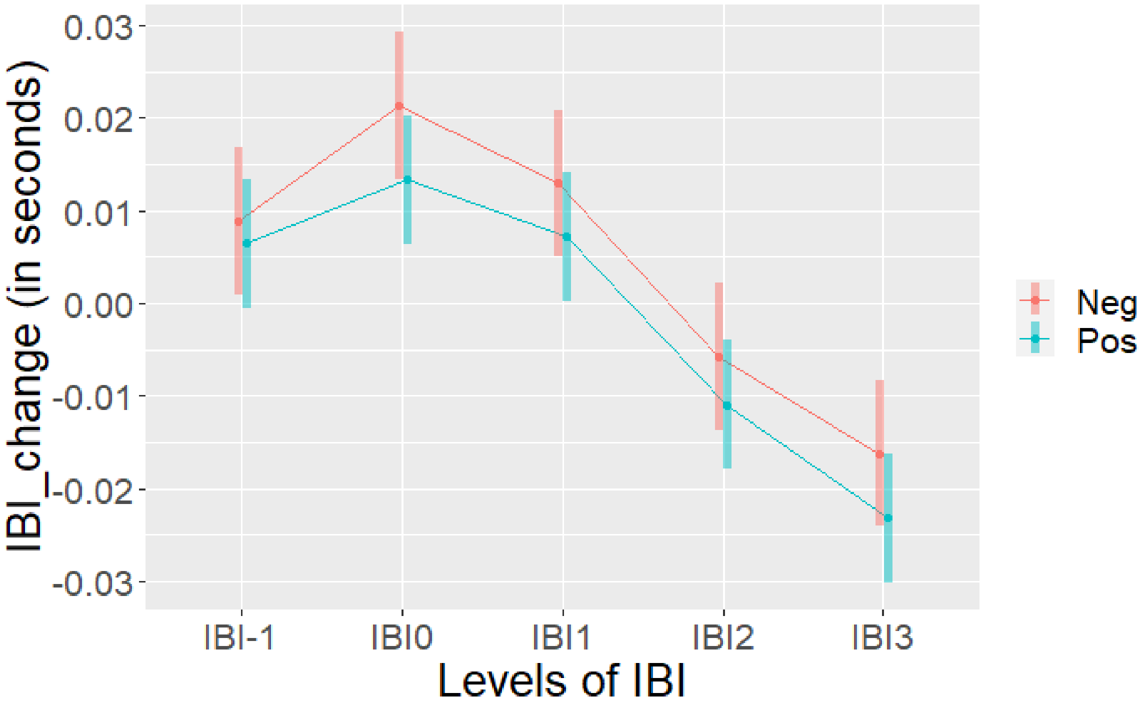

Fig. 2 – IBI length variations (in seconds) from baseline associated with negative and positive feedback in the 5 selected IBIs. Positive values indicate a deceleration and negative values an acceleration with respect to baseline (IBI -2). Neg = negative feedback, Pos = positive feedback

Post-hoc tests on the STATUS x FEEDBACK interaction (see Fig 3) showed that IBI-change values were larger (i.e., there was a stronger cardiac deceleration) following a Negative compared to Positive feedback in the High Status condition (estimate = 0.009, SE = 0.002, z-ratio = 3.489, *p* = 0.002) but not in the Low Status one (estimate = 0.001, SE = 0.002, z-ratio = 0.691, *p* = 0.9007). None of the other comparisons reached significance (all *ps* > .064).

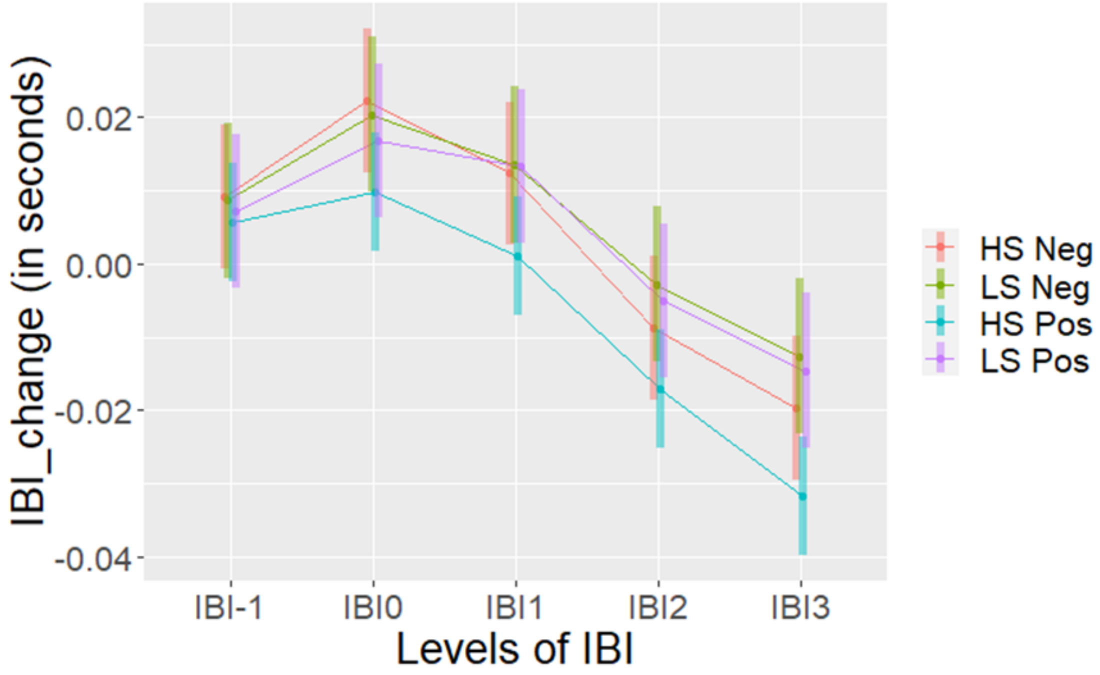

Fig. 3 - IBI length variations (in seconds) from baseline associated with negative and positive feedback and high and low-status in the 5 selected IBIs. Positive values indicate a deceleration and negative values an acceleration with respect to baseline (IBI -2). HS = high-status, LS = low-status, Neg = negative feedback, Pos = positive feedback.

Heart rate variability

The paired sample t-test comparing RMSSD in the high and low-status blocks failed to show a significant difference [$t(23) = -0.76$, $p = 0.45$, $M_{HS\_HRV} = 45.85$, $SD_{HS\_HRV} = 23.32$, $M_{LS\_HRV} = 47$, $SD_{HS\_HRV} = 25.39$), indicating that participants' competence-based social stance did not markedly affect this HRV index of parasympathetic-sympathetic balance .

Discussion

In the present study, we examined whether individuals' competence-based hierarchical stance (i.e., social status) within a cooperative game modulates cardiac reactivity to positive and negative feedback concerning their performance. In line with previous findings (Crone et al., 2003; Hajcak et al., 2003; 2004; van der Veen et al., 2004), we observed that negative feedback elicited a stronger cardiac deceleration than positive feedback. Our observations also add to evidence confirming that the valence performance feedback modulates the cardiac acceleration pattern following initial deceleration (Crone et al., 2003; van der Veen et al., 2004; Kastner et al., 2017). Competence-based social status modulated the strength of cardiac deceleration so that the effect of feedback valence (i.e., higher deceleration for negative than for positive feedback) was only significant in the high-status condition. Visual inspection of the Status x Feedback interaction (see Fig 3) suggests that the maximal cardiac deceleration occurred for the high-status/negative-feedback condition, while the minimal occurred in the high-status/positive feedback. This was statistically confirmed by the significant difference between the two conditions, while no other comparison reached significance.

The fact that cardiac deceleration following negative feedback was maximal in the high-status condition is notably at odds with results reported in Boksem and colleagues' study (Boksem et al., 2012). In the latter, feedback-related medial frontal negativity (MFN) in response to negative feedback was enhanced in the low-status condition. The authors discuss their results in terms of an increased activation of the performance monitoring system induced by the experience of a low-status within a hierarchy, suggesting that low-status individuals are more likely to experience social evaluative threat (Anderson & Berdahl, 2002) and are therefore more engaged in monitoring their performance. Conversely, our results indicate that cardiac deceleration to negative feedback was increased in the high-status condition. While considering that a dissociation was observed between electrocortical (i.e., FRN) and autonomic (i.e., HR deceleration) responses to fair and unfair offers in the Ultimatum Game (Van der Veen & Sahibdin, 2011), indicating that the two measures may index different mechanisms of feedback processing, there are many possible interpretations for our observed results.

Negative feedback as a threat to high status

Errors and negative feedback are perceived as aversive. This is supported by previous studies showing that errors are followed by a defensive startle reflex (Hajcak and Foti, 2008) and that error-related signals are enhanced in certain psychiatric conditions linked to anxiety and negative affect (Hajack et al., 2003; Gehring et al., 2000; Cavanagh & Shackman, 2015). Prolonged cardiac deceleration has been observed in response to negative visual and auditory stimuli (Bradley et al., 2000; Bradley et al., 2001). Moreover, enhanced cardiac deceleration in response to a threatening stimulus was observed when participants were fleeing from it compared to when they were approaching safety in a virtual T-maze, suggesting that HR slowing represents an orienting response rather than a defensive reaction (Rodrigues et al., 2020). Thus, one possible interpretation for our findings is that negative feedback during the high-status condition was experienced as even more aversive than during the low-status condition because it reflected a potential threat to the acquired status. Indeed, being part of unstable volatile hierarchies (where each member's position can be rapidly updated, as in the case of the present study) elicits stronger activity in brain areas linked to social emotion (such as amygdala and medial prefrontal cortex) than being part of a stable hierarchy (Zink et al., 2008). Knight and Mehta (2016) showed that while high-status in a stable hierarchy reduced cortisol responses to social-evaluative threats, the opposite pattern (i.e., an increase in cortisol and testosterone levels) was observed when participants were assigned a high-status position in an unstable hierarchy. Thus, while high status has a protective effect on stress-related responses to social threat (Wager et al., 2009; Gianaros et al., 2007; Gianaros et al., 2012), it also comes with a cost: the need to protect it. Studies on non-human primates (e.g., Gesquiere et al., 2011, see Sapolsky, 2005 for review) indeed show that while higher-ranking individuals display lower levels of stress-related indicators, an exception is found in the alpha male, who exhibits higher levels of stress than low-ranking individuals. In this vein, our results can be interpreted as the effect of a hyper-activation of the performance monitoring system triggered by the threat of losing a high-status position. Thus, when participants were in the high status condition, they became more sensitive to negative feedback and this, in turn, amplified their cardiac response.

Cardiac deceleration as index of prediction error

It should be noted that whether cardiac deceleration after negative feedback reflects the activation of a monitoring system that triggers the implementation of remedial actions (Somsen et al., 2000) or merely the representation of the motivational valence (van der Veen et al., 2000) is still an object of debate. Recent evidence that heart rate deceleration is sensitive to the violation of performance-based expectations (Kastner et al., 2017) supports the monitoring system hypothesis. Although in our task the number of positive and negative feedback cues was equal in both the high and low-status conditions, participants might have expected their performance to be better during the high-status than the low-status blocks, since they were at the top of the hierarchy. Correspondingly, our findings may also be interpreted as an amplified response to the violation of prior expectations. However, if this was the case, we should also have observed an attenuated deceleration for negative feedback in the low-status condition (the one in which the participant is led to believe that he/she is the worst player in the group). Since this is not the case (see Fig. 3), evidence that expectation violation accounts for the effect of status on cardiac deceleration remains equivocal. Nevertheless, some studies report differential effects on neural signals reflecting positive prediction errors (i.e., when the outcome that is better than expected) and negative prediction errors (i.e., when the outcome is worse than expected) (e.g., Holroyd & Coles, 2002). In this vein, it is possible that the high and low-status conditions encompass two distinct predictions that, when violated, give rise to different responses according to outcome valence.

Timing of cardiac response to the feedback

The time window of the feedback response we observed in the present study (i.e., a rapid deceleration at the IBI surrounding the feedback presentation followed by an immediate acceleratory recovery) diverges from what has been reported in previous studies. In fact, orienting HR deceleration to uncued stimuli is typically maximal at the second or third IBI (e.g. Bradley et al., 2012; Rodrigues et al., 2020) and prolonged to even the fourth-fifth IBIs in the case of negative stimuli, while the acceleratory recovery is typically observed around the fifth-sixth IBI for negative stimuli and around the third-fourth IBI for positive stimuli (Bradley et al., 2000; Bradley et al., 2001) Thus, our study suggests that the autonomic response measured here diverges from received understanding of cardiac orienting (see Barry, 1986), and likely reflects the integration of pre- and post-feedback monitoring or mental load (Lacey, 1967) with the representation of fluctuating social status, as expressed on task-locked physiological reactivity: However, we observed the rapid impact of negative versus feedback on HR deceleration, with significant effects occurring within the same interbeat interval (IBI 0). This rapidity indicates a vagus parasympathetic effect (brake) on cardiac rate and is consistent with the earlier observation (Crone et al. 2003) of significant differential feedback effects on HR deceleration occurring on IBI 0 (although persisting into IBI 1 and 2). Nevertheless, we remain cautious in labelling the differential HR response to feedback an orienting response, not least as it occurred within more complex experimental context than that typical of classical attentional orienting tasks. Contrary to previous studies (Crone et al., 2003; van der Veen et al., 2004, Gunter-Moor et al., 2010, Groen et al., 2007), we did not find a significant interaction between Feedback (nor status) and IBI. Specifically, we observed that the heart decelerated in response to both negative and positive feedback, although the magnitude of the deceleration was significantly affected by the experimental conditions. Conversely, other studies (e.g., Crone et al., 2003) reported an acceleration of the HR following the presentation of positive feedback. One noteworthy difference between our task and that of Crone and is that in the latter, positive and negative feedback were represented by ‘neutral’ yellow or blue squares, respectively, while we used stimuli with greater emotional connotation. Whether the visual appearance of feedback cues reliably influences evoked autonomic reactivity deserves further investigation. Another notable difference is that in Crone’s (2003) experiment the feedback was presented 1000 ms after the participant made a response while, in our task, the feedback was elicited immediately on pressing the response bar.

In conclusion, results from the present study support previous findings showing that cardiac deceleration is increased following negative, compared to positive, feedback. Moreover, our results expand on previous research by showing that not only neural (Boksem et al., 2012) but also autonomic responses to negative feedback are modulated by competence-based social status, although, apparently, in different ways. Future research may benefit from the concurrent measurement of EEG and HR to further investigate the observed differences. Although comparable to other published studies (Crone et al. 2003; Van Der Veen & Sahibdin, 2011; Gunter-Moor et al., 2010), a major limitation for the present study is the sample size. Furthermore, our sample was mainly composed of female participants. Thus, our observations, while informative, should be considered exploratory. Our findings will benefit from future studies to provide confirmatory replication in a larger sample balanced for gender and/or meta-analytic appraisal.

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