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Dissociation between medial frontal negativity and cardiac responses in the ultimatum game: Effects of offer size and fairness

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Abstract In the present study, we examined the role of fairness and offer size on brain and cardiac responses in the ultimatum game (UG). Twenty healthy volunteers played the role of responder in a computerized version of the UG in which the fairness and size of the offers were systematically varied. Both fairness and size of the offer influenced the acceptance rates in a predictable way, leading to fewer accepted unfair and low offers. Only unfair high, but not unfair low offers were accompanied by a medial frontal negativity. An unexpected stronger cardiac deceleration to fairer offers was found, which was not affected by the size of the offers. Cardiac and electrocortical measures showed a different relation with performance, and both measures were correlated only modestly. This dissociation between cardiac responses and brain potentials is discussed in terms of a possible differential sensitivity to effects of stimulus probability and violation of the social rules.

Keywords Decision-making · Emotion · Erp

Introduction

The ultimatum game (UG; Güth, Schmittberger, & Schwarze 1982) can be used to study emotion regulation during social interactions. In the UG, two players have to agree on how to divide a sum of money. The first player (the proposer) makes an offer of how to split the money between the two of them. The second player (the responder) decides whether to accept or reject this offer. If the responder accepts the offer, the money will be divided as proposed. If the responder rejects the offer, neither player gets anything. In both cases, the game is over. According to standard economic theory, the rational strategy is for the proposer to offer the lowest possible amount (in order to keep as much money for himself as possible) and for the responder to accept even the smallest amount, since the alternative is getting nothing at all. A large number of studies, however, have found that the majority of proposers and responders act differently. Depending on culture and setting, the basic finding is that most proposers are unexpectedly generous and tend to offer 40%–50% of the stake. The responders accept these offers but reject about half of the unfair offers (i.e., less than 20%–30% of the total amount) (Nowak, Page, & Sigmund, 2000). This more or less irrational behavior shown by the participants suggests that humans are not entirely rational during economic decision making, because responders appear to be sensitive to unfairness and are willing to reject unfair offers so that they can punish proposers for unfair treatment. And realizing this, proposers make generous offers that are less likely to be refused by the responders (Nowak et al., 2000). This behavior can be seen as the result of the complex interaction between emotional (fairness) and cognitive, more rational (financial gain) processes in the human brain while making financial decisions.

Various studies have identified several brain areas involved in the UG. In a first study (Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003), it was found that receiving unfair offers was associated with increased activation in, among other areas, the dorsal part of the anterior cingulate cortex (dACC). This finding was interpreted in terms of a reflection of the conflict between the

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rational and emotional responses to unfair offers. Other research indicates that the ACC is also involved in the affective components of both physical and social pain (Eisenberger & Lieberman, 2004; Eisenberger, Lieberman, & Williams, 2003; Price, 2000; Tolle et al., 1999). The dACC has also been implicated in error processing, uncertainty, conflict, and negative feedback. Although the finding of increased activation in the dACC could not be replicated in a second fMRI study using more or less the same paradigm (Tabibnia, Satpute, & Lieberman, 2008), a recent event-related brain potential (ERP) study seemed to provide more evidence for involvement of the dACC (Boksem & De Cremer, 2010). This study showed that unfair offers in the UG were accompanied by a negative-going wave, peaking about 300 ms after stimulus onset and maximal at right frontal electrode positions. The authors interpreted this negativity as a reflection of negative social outcomes in the UG. Furthermore, they related this wave to a group of negative-going ERP components thought to be generated in the dACC (Dehaene et al., 1994; Gehring & Willoughby, 2002), which are often referred to as *medial frontal negativities* (MFNs; Gehring & Willoughby, 2002). These MFNs have been found in similar paradigms that have also been used in fMRI research and in which it has been found that the dACC was active. An MFN has been found for errors, conflict, unexpected punishment, and negative feedback, and one of the most influential theories in which this group of ERP components has been considered has proposed that, in almost all paradigms, the MFN reflects a reinforcement learning signal that occurs whenever outcomes are worse than expected (Holroyd & Coles, 2002). In this way, the MFN evoked by unfair offers can be seen as an outcome (offer) that is worse than expected (unfair) because the social norm of fairness has been violated. It should be noted, however, that an earlier study reported a similar negative deflection that was strongest for medium fair offers (30% of the stake), as compared with fair (50%) and unfair (10%) offers, but localized this negativity in other brain areas (Polezzi et al., 2008).

The emotional reaction to unfair offers has been further explored by examining the expression of the emotion in terms of bodily responses. In a recent study (Osumi & Ohira, 2009), it was found that unfair offers were accompanied by cardiac deceleration, as compared with fair offers. Moreover, this deceleration was even more pronounced if the stimuli were categorized in terms of rejected and accepted offers. They concluded that cardiac deceleration predicted the rejection of an offer, which is more or less in line with the somatic marker hypothesis, which states that bodily responses can serve as markers for important decisions (Damasio, 1996). It has been suggested that the cardiac response to feedback stimuli, which is possibly related to the response to unfair offers, reflects different aspects of the feedback stimulus than does the MFN (Van der Veen, Mies, van der Molen, & Evers, 2008; Van der Veen, Nieuwenhuis, van der Molen, & Crone, 2004a). It has been hypothesized that the cardiac response is more strongly related to the emotional impact of the feedback stimulus, whereas the MFN more strongly reflects the cognitive, evaluative aspect (Van der Veen, van der Molen, Crone, & Jennings, 2004b). By combining both measures and differentially manipulating cognitive and emotional aspects, more can be learned about the relation between the brain response and the bodily response and the differential impact of cognitive and emotional task aspects on these measures. The fast cardiac deceleration following motivationally significant events has traditionally been interpreted as being part of the orienting response (OR; Graham & Clifton, 1966). Recently, it has been suggested that the physiological processes underlying the OR and the P3 component might strongly overlap and that both might be strongly related (Nieuwenhuis, De Geus, & Aston-Jones, 2011). Interpreted like this, we would expect differential effects of expectancy, which should more strongly affect the OR, cardiac deceleration, and the P3, and outcomes worse than expected, which should more strongly affect the MFN.

In both the studies using ERP measures and the studies using cardiac measures, the size of the offer and the fairness of the offer were confounded; that is, larger offers were automatically fairer. Therefore, it is unclear which role the specific context of an offer plays in both cardiac and brain responses. As was stated before, it is, furthermore, unclear how the cardiac responses and brain responses are related and whether they reflect the same processes. Therefore, we chose to simultaneously examine both cardiac and electrocortical responses to offers in a version of the UG in which relevance and fairness can be studied independently. Fairness was manipulated by varying the proportion of the amount of money offered, and relevance was examined by manipulating the offer size. It was expected that unfair and smaller offers would be experienced as less pleasant and would be rejected more often, as compared with fairer and bigger offers (Tabibnia et al., 2008). We hypothesized that we would find a stronger cardiac deceleration and a larger MFN to unfair offers, as compared with the fair offers (Boksem & De Cremer, 2010; Osumi & Ohira, 2009), and that the more relevant, higher offers would evoke a stronger cardiac and electrocortical response. Finally, it was expected that the cardiac and ERP measures would show only moderate to low correlations, on the basis of earlier studies reporting absent or low correlations in comparable paradigms (Mies, Van der Veen, Tulen, Hengeveld, & van der Molen, 2011; Van der Veen et al., 2004a) and the suggested differential sensitivity to emotional and cognitive aspects of the offer.

Method

Participants

Twenty healthy volunteers (mean age 21.8 years, *SD* = 2.2; 3 males) participated in the study. All volunteers were right-handed, and all had normal or corrected-to-normal vision. Before the start of the experiment, all participants were screened for neurological and psychiatric disorders and were asked to fill out a general health questionnaire. Persons were included if they reported being healthy and did not report substance abuse or any known neurological or psychiatric disorder in the past or present. Research was approved by the local medical ethical committee and was conducted in compliance with the Helsinki Declaration and the regulations regarding good clinical practice in the European Community (GCP) and according to the current national regulations. All participants were financially compensated for their participation in our study. All participants provided oral and written informed consent after the procedure had been fully explained to them.

Stimuli and experimental design

The design of the UG was based on a previous study by Crockett, Clark, Tabibnia, Lieberman, and Robbins (2008), who used this task in a behavioral experiment studying the effects of acute tryptophan depletion. In a first separate session, the participants were instructed about the nature and rules of the UG. To increase the credibility of the UG, the participants were told that they were part of a larger ongoing study in which they would play only the role of the responder. They were told that they would see 120 offers from different proposers on a computer screen. To further increase credibility, the participants were informed that the pictures of the proposers they would see during the task were from persons who had submitted their offers previously and would not be present at the time of the experiment. In reality, there were no real proposers, and the offers were made up by us prior to the experiment. All participants were informed that both themselves and these proposers would be paid according to the choices made by the present participants. Furthermore, they were told that they would have the opportunity to play the role of proposer with persons who would participate in the future. They were asked if they would allow their photograph to be taken and used in future sessions with other participants. If they agreed, their photograph was taken, and they were asked to come up with 10 different offers in the second session. Five participants in our study declined having their photograph taken.

In reality, the 30 different "proposers" that the participants saw during the game were pictures from the Nimstim Face Stimulus set (MacArthur Foundation Research Network).[1] These were the only pictures that were used in our experiment. The photographs of the participants were immediately deleted after their departure. So there were no actual proposers, and participants' offers were used only as a cover story and were not used for real in future trials of our experiment.

In a second session, which was planned a week after the first session, all participants performed the UG as receiver. Participants were instructed again about the nature and rules of the UG and were told once more that they would receive the financial outcomes of 2 trials that would be randomly selected out of the trials in the game. Furthermore, they were instructed again about the consequences of an "accept" or "reject" response and that the offers were real but made by other volunteers who had participated previously. All participants received the same 120 offers, which were presented in a fixed quasirandom order. Offers fell into one of the three *fairness* categories: fair, unfair, or very unfair. Each category was subdivided into a high and low stake size. So there were six categories of offers in our experiment. The 120 trials were divided as follows: There were 20 fair/high trials (40%–50% of €16), 20 unfair/high trials (27%–33% of €25), and 20 very unfair/high trials (18%–22% of €37.50). The same divisions also applied for the low stake size offers. So there were also 20 fair/low trials (40%–50% of €3,35), 20 unfair/low trials (27%–33% of €5), and 20 very unfair/low trials (18%–22% of €7.50). There were 30 different "proposers," so each proposer appeared 4 times during the game. We arranged the pictures of the proposers in such a way that there was an equal balance of gender and race among the faces of the proposers and the pictures were shown in random order. Each trial consisted of the presentation of a picture of the proposer's face, which was shown for 1.5 s, the presentation of the stake, which was shown for 1 s, and the presentation of the offer, which was shown for 3 s (see, e.g., Fig. 1). During the presentation of the offer, the participants had to decide whether to accept or reject the offer by pressing the left or right button on a response device with their right hand. After finishing the game, the participants, who had allowed their pictures to be taken and used in future trials for future participants, were asked to play the role of proposer and to write 10 different proposals on paper.

[1] Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and was supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at tott0006@tc.umn.edu for more information concerning the stimulus set

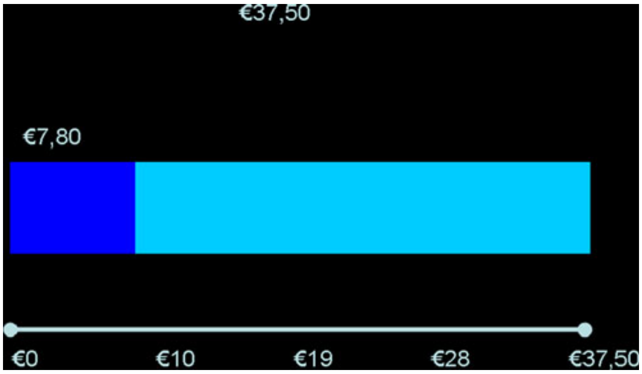

Fig. 1 Example of an offer stimulus (very unfair, high)

Data acquisition

All physiological signals were amplified, sampled, and stored on a portable amplifier (Vitaport System, Temec Instruments B.V., Kerkrade). Electroencephalography (EEG) signals were acquired from the following seven electrode positions: F3, Fz, F4, C3, Cz, C4, and Pz (in relation to A1-A2 of both mastoids), which were positioned according to the international 10–20 system (Sharbrough et al., 1991). Horizontal EOG was recorded from two electrodes placed at the outer canthi of both eyes. Vertical EOG was recorded from electrodes on the infraorbital and supraorbital regions on the left eye. The EEG was sampled at 256 Hz, low-pass filtered at 30 Hz, and high-pass filtered with a time constant of 0.33 s. Electrode impedance was again kept below 8 kOhm. The EEG signal was locked to the onset of the offer, and epochs were extracted between 100 ms preceding and 700 ms following the onset of the offer. The epochs were corrected for vertical EOG artifacts by using a well-established correction method (Gratton, Coles, & Donchin, 1983). Finally, epochs were visually inspected and checked for artifacts, and epochs were excluded from analysis when necessary.

The electrocardiogram (ECG) was recorded from precordial leads and sampled at 512 Hz. R-peaks were detected offline with an accuracy of 2 ms, and the R-peak occurrence times were visually inspected for artifacts and corrected when necessary. The R-peak in the ECG has been widely used to measure time between successive contractions of the heart, and in this way, heart rate and interbeat intervals (IBIs) can be determined. Five IBIs surrounding the offer were selected for further analysis: that is, the preceding IBI (IBI 1), the concurrent IBI (i.e., IBI 0), and three subsequent IBIs (i.e., IBIs 1, 2, and 3).

Statistical analysis

All measures were statistically evaluated using SPSS 16 (SPSS Inc., Chicago, IL). An analysis of variance was performed using a general linear model (GLM) repeated measures design. Percentage of accepted offers was examined using fairness (three levels; fair, unfair, and very unfair) and offer size (two levels; high vs. low) as within-subjects factors. For the MFN, we more or less followed the analysis strategy used in the Boksem and De Cremer (2010). Difference waves were computed between fair and (very) unfair offers for both high and low offers to minimize the effects of overlapping components. Visual inspection of the grand average difference wave forms indicated that the MFN was maximal at Fz around 400 ms after the presentation of the offer. Due to the broad and somewhat skewed distribution of the MFN, an area between 375 and 475 ms after offer onset was chosen as our latency window of interest, and MFN amplitude was computed as the difference between fair and (very) unfair offers in this window. MFN was statistically evaluated with a GLM with electrode position (three levels; Fz, Cz, and Pz), fairness (unfair vs. very unfair), and offer size as within-subjects factor. Cardiac responses were examined using sequential IBI (three levels; IBI0, IBI1, and IBI2), fairness, and offer size as factors. For all analyses, Huynh–Feldt corrections for degrees of freedom were applied when necessary.

Results

The results of 2 participants were excluded due to technical problems (n = 1) and not following instructions leading to rejection of all offers (n = 1).

Behavior

The percentage of accepted offers is shown in Fig. 2 and was tested with a GLM for repeated measures. Main effects of offer size, $F(1, 17) = 13.4$, $p < .005$, $\eta^2 = .440$, and fairness, $F(2, 34) = 93.0$, $p < .0005$, $\eta^2 = .845$, and an interaction between these two factors, $F(2, 30) = 3.8$, $p < .05$, $\eta^2 = .181$,

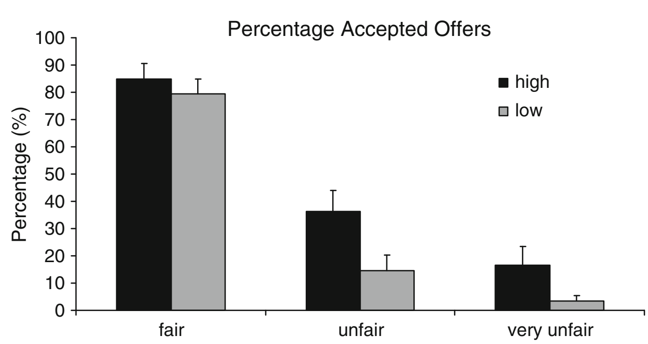

Fig. 2 Percentage of accepted offers for high and low, fair, unfair, and very unfair offers

were found. As was expected, higher offers and fairer offers were accepted more often, and the effect of fairness was larger for high offers. Only for the unfair and very unfair offers was the effect of offer size significant. Reaction time was also statistically evaluated using a GLM. A main effect of offer size was found, $F(1, 17) = 22.1$, $p < .0005$, $\eta^2 = .565$, as well as an interaction between offer size and fairness, $F(2, 30) = 8.8$, $p < .001$, $\eta^2 = .340$. Reactions to low offers were faster, and only for these low offers was a marginally significant effect of fairness found, with faster responses for more unfair offers.

Event-related brain potentials

Grand average ERPs for all stimulus categories and difference waves between fair and (very) unfair offers are shown in Figs. 3 and 4. MFN amplitude, derived from the three central electrodes (Fz, Cz, and Pz), was first analyzed with a repeated measures GLM. Due to too many measurement artifacts on the Pz electrode, 2 additional participants had to be excluded. In this analysis, we found main effects of electrode position, $F(2, 30) = 5.2$, $p < .05$, $\eta^2 = .425$, and offer size, $F(1, 15 = 14.2$, $p < .005$, $\eta^2 = .486$. Follow-up one-sample *t*-tests showed that MFN amplitude significantly differed from zero for both unfair and very unfair high offers on Fz ($N = 18$; unfair, 2.9 μV; very unfair, 4.2 μV, $p < .05$) and Cz ($N = 18$; unfair, 3.1 μV; very unfair, 3.7 μV, $p < .005$), but not for low offers and Pz ($N = 16$). In order to make our electrocortical and cardiac results more comparable (see below), we also tested whether rejected and accepted trials differed with respect to MFN amplitude and evaluated the MFN, defined as the difference between accepted and rejected, with a GLM with electrode as

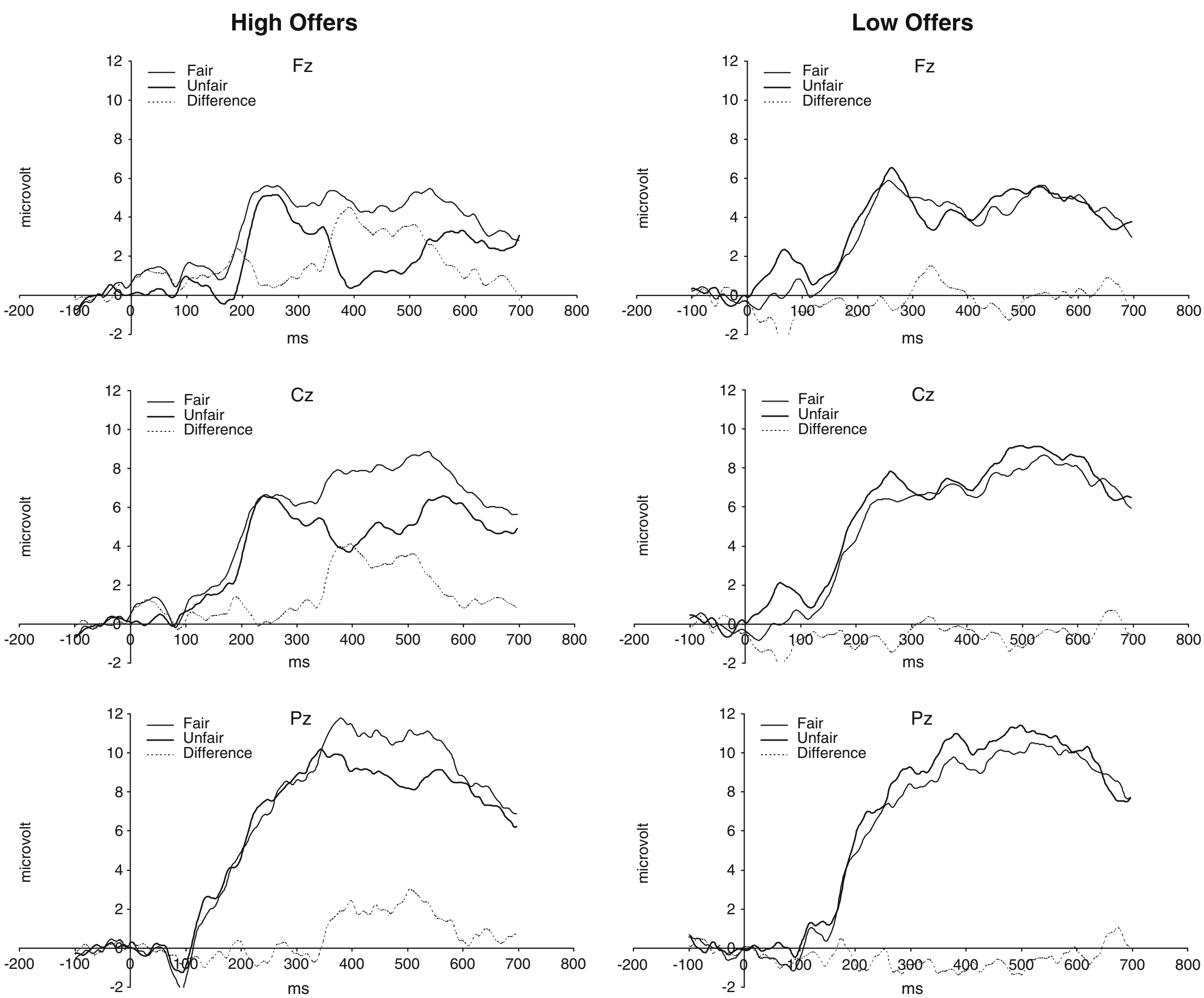

Fig. 3 Grand average ERPs for high (left) and low (right) offers at mid-line electrodes. ERPs elicited by fair and unfair offers are shown, as well as the difference wave between these two

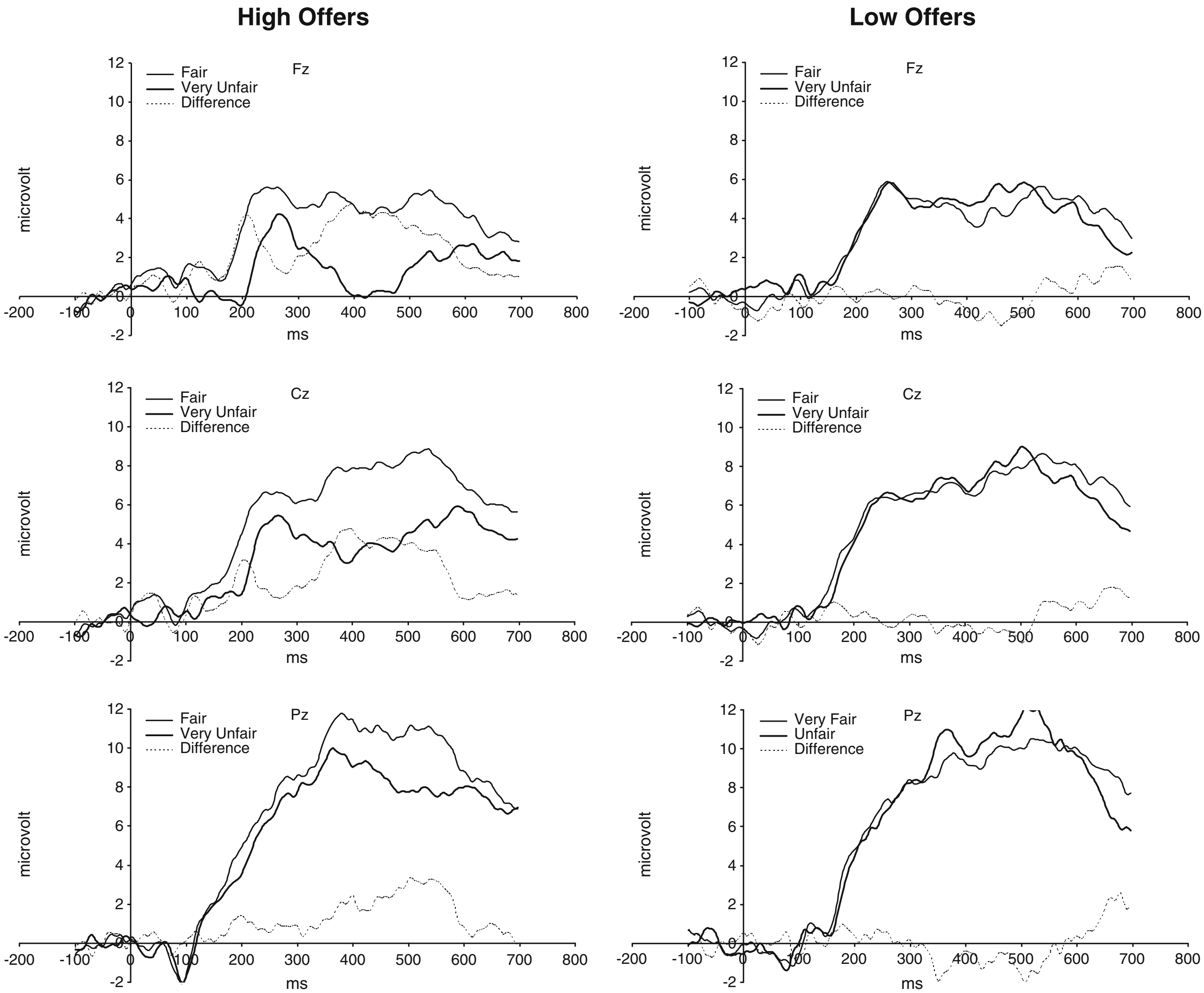

Fig. 4 Grand average ERPs for high (left) and low (right) offers at mid-line electrodes. ERPs elicited by fair and very unfair offers are shown, as well as the difference wave between these two

factor (see Fig. 5). We found no effect of electrode, and also the follow-up one-sample *t*-tests of the MFN amplitude for separate electrodes did not yield significant effects. It should be noted that the effects on Cz (1.6 μV, $p = .056$) and Fz (1.5 μV, $p = .089$) were close to significant. Finally, we explored the possible relation between overt behavior in terms of the average percentage accepted offers and MFN amplitude either computed in terms of fair and (very) unfair offers or computed in terms of rejected or accepted offers. For this analysis, we found a significant correlation only between percentage of accepted offers and the MFN at Fz, computed as the difference between accepted and rejected offers, $R = .59$, $p < .01$. This negative correlation means that a lower percentage of accepted offers were associated with a larger effect size in terms of MFN.

Heart rate

With a GLM for repeated measures, it was found that the cardiac response to the offer showed a main effect of sequential IBI, $F(3, 51) = 8.1$, $p < .01$, $\eta^2 = .324$, and a marginally significant interaction between fairness and sequential IBI, $F(4, 68) = 2.6$, $p = .061$, $\eta^2 = .131$. Follow-up analyses showed that the effect of fairness (three levels, tested with GLM) was only marginally significant at IBI2. Further follow-up analyses showed that for IBI2, only the difference between fair and very unfair offers (paired *t*-test) was significant. As is shown in Fig. 6 (top panel), very unfair offers led to less deceleration, as compared with fair offers. In order to make our results more comparable to the results of the previous study examining cardiac responses in the UG (Osumi & Ohira, 2009), we also tested the

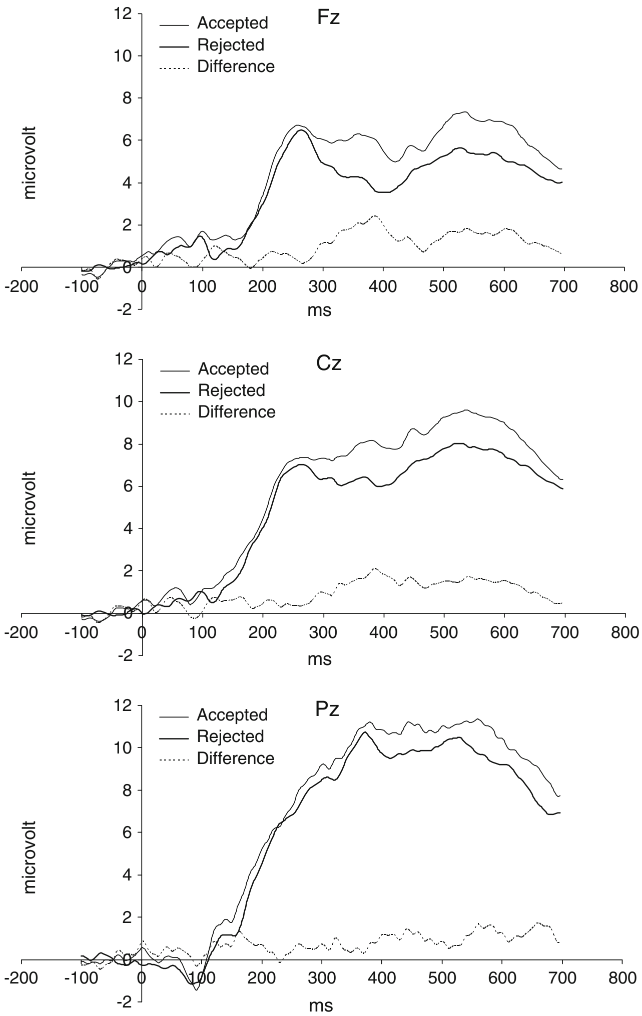

Fig. 5 Grand average ERPs for accepted and rejected offers at mid-line electrodes. Both the separate ERPs and the difference wave are shown

difference between accepted and rejected responses. In a GLM with acceptance (accepted offers vs. rejected offers) and sequential IBI as within-subjects factors, we found a main effect of sequential IBI, $F(2, 34) = 5.3$, $p < .05$, $\eta^2 = .238$, and a marginally significant interaction between acceptance and sequential IBI, $F(3, 51) = 2.8$, $p = .077$, $\eta^2 = .140$. Follow-up analyses showed that only IBI2 showed a marginally significant difference between accepted and rejected offers, caused by less deceleration for rejected offers, as is shown in Fig. 6 (bottom panel). As for the MFN amplitude, we also explored the possible relation between cardiac responses and average percentage of accepted offers. We found a correlation only for the difference between fair and unfair offers at IBI2, and this correlation was negative, $R = .52$, $p < .05$, which means that higher percentages of accepted offers were associated with a smaller effect size in terms of cardiac response.

Association cardiac and brain responses

The association between brain and cardiac responses was explored by computing correlations between the maximal differences for both measures. First, we computed the correlation between MFN, computed as the difference between fair and (very) unfair offers at Fz and Cz, and the equivalent difference score for the cardiac response at IBI2. These analyses did not yield a significant result, although a marginally significant correlation was found between the MFN at Fz for unfair stimuli and the equivalent cardiac response, $R = .40$, $p = .092$. Second, we computed the correlation between the MFN, computed as the difference between accepted and rejected responses at Fz and Cz, and the equivalent cardiac response at IBI2. The correlations between the cardiac response and the MFN at both Cz and Fz were marginally significant ($R = .40$, $p = .097$ for Fz; $R = .41$, $p = .091$ for Cz).

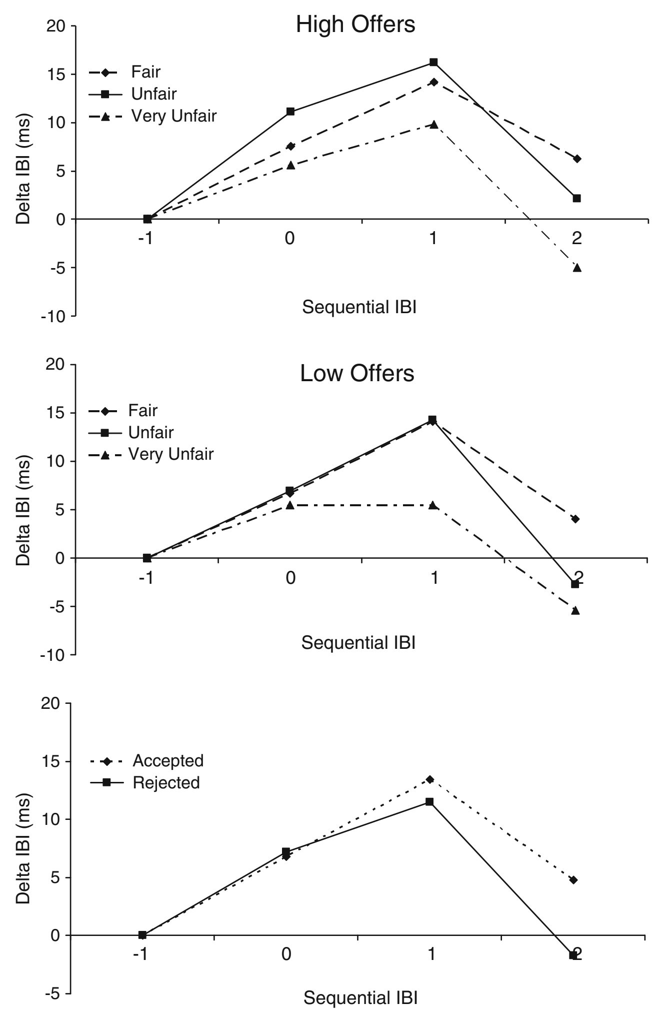

Fig. 6 Cardiac response in terms of delta IBI for high offers (top panel) and low offers (middle panel) and for accepted and rejected offers (bottom panel)

Discussion

The present study examined the effects of fairness and offer size on ERPs and cardiac responses in the UG. As was expected, higher offers and fairer offers were accepted more often. More unfair offers were accompanied by an MFN around 400 ms after stimulus onset, which was maximal at frontal sites. Unexpectedly, very unfair and rejected offers were also accompanied by less cardiac deceleration.

Behavioral results were in line with the earlier studies using a similar version of the UG (Crockett et al., 2008; Tabibnia et al., 2008). As in these studies, both fairness and size of the offer strongly affected the acceptance rate, resulting in fewer accepted offers when the offer was lower or less fair. Somewhat less expected was the interaction between both factors, although this interaction approached significance in one of the previous studies (Crockett et al., 2008). The effect of fairness was stronger for high offers, which can be interpreted in terms of fairness being especially important when the stakes are high (enough).

The finding of MFN to less fair offers was in line with the results of the study of Boksem and De Cremer (2010). As in their study, the effect was maximal at frontal sites, although we could not confirm the very frontal and slightly lateralized effect, due to lower spatial sampling. The maximum in our study seems to peak somewhat later, which is probably caused by a more complex stimulus presentation in our study. In our task, the offer was presented visually as a differently colored part of a bar presenting the stake, combined with a verbal representation of the size of the actual offer and the stake, and participants could reject or accept this offer by pushing a button. In the study of Boksem and De Cremer, the offer was separated into an offer part and a decision part, and ERPs were synchronized to the offer. The offer consisted only of a verbal description of the offer—for example, “Offers you 4 euros,” which is obviously less complex than the offer used in the present study. Interestingly, the offer size was crucial. Only for high offers was this fairness-related MFN found. Size was also manipulated in the Boksem and De Cremer study, but size in their study was completely confounded with fairness, because they used a fixed stake and a variable offer. The effect of offer size might be related to the relative impact of the unfair offer. In the context of higher unfair and very unfair offers, the low unfair and very unfair probably have less emotional impact on the participants, leading to the absence of the MFN for these conditions.

Our ERP results were not in line with the effects in Polezzi et al. (2008), where an adapted version of the UG was also used. A large difference with our study and also the study of Boksem and De Cremer (2010) is that they used a much faster version of the task and did not use different players. Moreover, they repeated the five different offers 40 times and also confounded offer size with fairness. In contrast to both the results of Boksem and De Cremer and our results, they reported the largest negativity for medium offers, which are comparable to our unfair offers, and this negativity did not differ with respect to laterality or anterior/posterior distribution. Apparently, the MFN is strongly dependent on the exact context of the task and the perception of the offers by the players. Our study shows that it makes sense to disentangle size and fairness of the offer but that other factors, such as the pace of the task, the believability of the social context, and other social and emotional factors, most likely play important roles too. It has been suggested that the MFN might reflect social pain, social norm violation, conflict, or outcomes that are worse than expected. In our view, the present results show that the MFN in the UG is strongly context dependent and does not simply reflect the discrepancy between expected outcome and real outcome. This makes an explanation in terms of social norm violation, conflict, or outcomes that are worse than expected less likely, because they all seem to depend strongly on this discrepancy. Moreover, reaction time data seem to rule out an explanation in terms of conflict. If a larger MFN is related to more conflict, it would be expected that these higher conflict trials would be accompanied by longer reaction times. However, reaction times were affected by fairness only for the low offers, and the effects were opposite to what was expected, with faster responses for less fair offers. MFN was found only for high offers, and therefore, an explanation in terms of conflict does not fit the present data. An interpretation in terms of social pain, which can accommodate contextual effects of the size of the experienced unfairness, seems to fit our data best, which is more or less in line with the interpretation of Boksem and de Cremer.

The finding that unfair or rejected offers evoked slightly *less* cardiac slowing was not in line with our hypotheses and previous findings. Osumi and Ohira (2009) reported enhanced cardiac slowing after unfair offers, as compared with fair offers, and this effect was even more pronounced for rejected than for accepted offers. An important difference with the present study is that the actual offer and the decision were separated in the study of Osumi and Ohira. In the present study, the cardiac response to the offer reflects both stimulus evaluation and response processes, whereas in the Osumi and Ohira study, it reflects only evaluation. A possible effect of these additional response processes is that the motor initiation process following the decision might have ended cardiac deceleration and started cardiac acceleration earlier in the present study (Jennings, van der Molen, Somsen, & Terezis, 1990) leading to a shortened decelerative response depending on the actual reaction time. In this way, it could lead to differences between fair and unfair offers only if RT differed between these categories. Although fairness did influence RT, we did not find a main effect of fairness, but only an interaction between fairness and offer size, and the effect of fairness on low offers was only marginally significant. So, this small and differential effect on RT could only partly explain the attenuated deceleration for low unfair offers and could not explain the larger acceleration for high unfair offers. Furthermore, it should be noted that the cardiac deceleration in the Osumi and Ohira study peaked earlier and lasted for a shorter time than did the deceleration in the present study, which makes an explanation in terms of interrupted deceleration even more difficult. Finally, offer size had a bigger and more consistent effect on RT, but offer size did not have any effect on cardiac deceleration.

We would like to argue that the differences between the present findings and the findings of Osumi and Ohira (2009) might be related to the different contexts in which the unfair offers were presented. In the Osumi and Ohira study, one third of the offers were unfair, whereas the other two thirds of the offers were fair or even advantageous for the responder. This means that unfair offers were unexpected not only in the sense of a violation of a social convention, but also in the sense of a less frequent event. In the present study, the fair offers were the less frequent event, and in this way, unfair offers were more expected. This expectancy effect has been shown to play an important role in cardiac responses to stimuli, with more unexpected events leading to more cardiac deceleration (Crone, Bunge, de Klerk, & van der Molen, 2005; Crone et al., 2003). In this way, the expectancy effect could have played a major role in causing differences between fair and unfair offers. This could also explain why the size of the offer did not affect cardiac decelerations. If the cardiac response for a major part reflects expectancy violation, the size of the offer does not play a role, because differently sized offers were presented with the same probability. An interpretation in terms of expectancy is in line with the traditional view that the fast decelerative response following motivationally relevant stimuli is part of the OR (Graham & Clifton, 1966) and the recent suggestion that the processes underling the OR and the P3 are strongly related (Nieuwenhuis et al., 2011). In the present study and in previous studies using the UG (Boksem & De Cremer, 2010; Polezzi et al., 2008), no clear P3 could be measured, and no effects on P3 were reported. In the present study, this might be related to large variation in reaction time, whereas in other studies, the separation of evaluation and decision might also have played a role. Future studies should aim at designing tasks in which both MFN and P3 can be measured at the same time and in which the possible differential effects of simple expectancy violation and outcomes being worse than expected on these different components can be studied simultaneously.

The dissociation between cardiac and ERP results is remarkable and was also found in the different correlation patterns. The MFN amplitude correlated positively with percentage of accepted offers, whereas cardiac deceleration correlated negatively. For the brain response, the correlation was positive and was found when accepted and rejected offers were compared, whereas the correlation with cardiac measures was negative and was strongest when fair and unfair offers were compared. The MFN to accepted and rejected offers more strongly reflects the decisional part of the offer, and therefore, the correlation with performance can be seen as a relation between the decisional aspect of the MFN and the actual decision. The cardiac response to fair and (very) unfair offers, on the other hand, more strongly reflects the evaluative aspect of the offer, and therefore, the correlation with performance can be seen as a relation between the evaluative aspect of the cardiac response and the actual decision. Both probability (*other* than expected) and the effect of the offer being *worse* than expected are thought to affect cardiac deceleration and MFN in a comparable way (Mies et al., 2011; Van der Veen et al., 2008). For instance, in a study by Nieuwenhuis, Yeung, van den Wildenberg, and Ridderinkhof (2003), it was found that the N2 to no-go stimuli in a go–no-go task, which was thought to be related to response inhibition, was strongly dependent on stimulus frequency. In a condition where the go stimulus was the less frequent stimulus, they found a reversal of effects and found an N2 to go stimuli. This shows the importance of probability for the N2, a component that is thought to be closely related to the family of the MFNs. It should be noted, however, that results for the feedback-related negativity are less conclusive (Hajcak, Holroyd, Moser, & Simons, 2005; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003). In a similar way, we have shown in a number of studies (Crone et al., 2005; Crone et al., 2003; Van der Veen et al., 2004a, b, 2008) that cardiac deceleration is enhanced when outcomes are worse than expected. More research is obviously needed to disentangle the conflicting effects of stimulus probability and desirability of the outcome on both cardiac responses and brain activation.

Due to the absence of strong correlations between autonomic and brain responses and the differential sensitivity of these measures to the task manipulations, the present results do not provide evidence for a possible causal relation between these responses. In this way, no support is provided for the somatic marker hypothesis, which states that autonomic changes could serve as a possible input to guide decision making (Damasio, 1996). It should be emphasized, however, that the present study was not designed to test the somatic marker hypothesis.

To summarize, the UG is a useful tool for examining the interaction between emotional and cognitive processes and the integration of these processes within the brain and body. Unfair offers are clearly perceived as undesirable, and this undesirability is reflected in a brain response that is similar to the response to outcomes that are worse than expected and stimuli with conflicting or competing responses. Cardiac responses seem far more sensitive to the basic expectedness of the stimulus, but more research is needed to disentangle the competing influences of probability and outcome.

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