DISSERTATION

Titel der Dissertation

„Do we care about the powerless third? An EEG-study about social interactions in economic decision making“

Verfasserin

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dedicated to Moritz and Emil

“It is when equals have or are assigned unequal shares, or people who are not equal, equal shares, that quarrels and complaints break out”

Aristotle[1]

[1] Nicomachean Ethics 5:III [trans. J.A.K. Thomson; New York: Penguin Books, 1995], 178

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Contents

1 General Introduction

Choice behavior and the nature of sound judgment have occupied several scientific fields for centuries. With the availability of neuroscientific methods, a new research direction emerged with the aim of verifying and expanding existing knowledge by adding a biological perspective. Neuroeconomics is one of these interdisciplinary fields that combines neuroscience with the major disciplines that have dealt so far with the question of how people make decisions or how decisions should be made (for a review see Camerer et al., 2005). With the aim to obtain a more complete model of decision behavior, neuroeconomics draws upon current theories, models, methods, and issues in the field of psychology, economics, and neuroscience. As the name indicates, economics was the driving force in this development. It was a major concern of scientists in this field to find neural correlates of the parameters predictive of choice behavior in the economic domain, not only to validate mathematical models of choice behavior. Though, one might assume that economic models do not need to include neural details to specify more accurate models of decision making, one has to take into account that decision making is not the product of one single observable process. Instead it reflects the interaction of specialized presumable cortical systems. Using brain-imaging techniques helps to specify the interaction of these different determinants. However, in addition to neuroeconomics yet another field has emerged making use of neuroscientific methods. This new field, decision neuroscience, evolved in order to gain a better understanding of decision behavior (Shiv et al., 2005). There are many overlaps between these two fields and terms are often used interchangeably (Smith and Huettel, 2010). Nevertheless, considerable efforts in the field of decision neuroscience are directed to the processes that underlie decision making and judgment.

Although the following work can be incorporated into these two areas, the focus will be on neuroeconomics, since findings in this area have led to the research question elaborated in the present work. Therefore, prior to the presentation of the two main articles published as a result of this thesis, a short introduction in neoclassical economics and *social preferences* will be given, followed by related neuroscientific findings. Since most behavioral economic studies and theories are based on game theoretic paradigms, a description of the games named here can be found in the appendix.

2 Economic Models of Social Preferences

As already mentioned in the beginning, neuroeconomics has its roots or is strongly connected to the field of behavioral economics. Behavioral economics incorporates psychological principles to explain why humans deviate from the rational-agent model as postulated by neoclassic economic and seeks to improve these models of decision behavior using evidence and ideas from neuroscience.

2.1 Neoclassical economics

Neoclassical economics formulates descriptive respectively predictive theories to describe human behavior in the economic system using mathematical techniques. Most of these models are based on psychological concepts and aim at inferring subjective value or preferences. For instance, one well known theorem is the expected utility theory postulated by von Neumann and Morgenstern (1944). The expected utility theory states that individuals choose between uncertain outcomes solely based on the utility value of each outcome multiplied by the probability of each outcome. The resulting utility function describes how individuals will rank each option. Obtained data or revealed preference data are than further used to calibrate the utility model to predict future behavior. Generally, neoclassic models are based on the assumption that human behavior follows a rational principle, e.g. if prices increase, consumption decrease, determined by desire and belief with the aim of maximizing utility. Furthermore, it is assumed that social processes and group phenomena can be explained by the individual rationality respectively the individual behavior as defined above. Furthermore, behavior in groups is expected to represent an equilibrium, which means behavior of each individual does not change as long as the environment does not change (for review see e.g. Brennan and Moehler, 2010).

One core problem of this axiomatic approach is that it hardly ever predicts behavior in natural environments correctly and that there are several phenomena that falsify the beforehand presented axioms.

A well-known experiment showing that the self-interest hypothesis, which assumes that the own material payoff is the sole motivation of all people, cannot account for human behavior, is the so called ultimatum game. In this game a proposer has to split a sum of money between himself and the responder. After the proposer has made his offer, the responder has to decide whether to accept or reject this offer. If the responder accepts the offer the money is distributed accordingly, if the responder rejects the offer both receive nothing. Assuming that both players behave rationally and do not care about the outcome of the other player, the responder would have to accept any positive outcome and the proposer would offer the smallest amount of money to the responder and keep the rest. In fact, most of the offers are about 40% - 50% of the total amount and offers below 20% are rejected with a probability of about 50% (Güth et al., 1982; Camerer, 1995). These results are very robust and have been often replicated; they even do not change with the size of the stake (Hoffman et al., 1996).

This experimental evidence and other controlled experiments using psychological methods have proven the *self-interest hypothesis* per se wrong, since it cannot explain the observed behavior across different experiments. Therefore, it has been adjusted by the assumption that we do have *other-regarding preference* or *social preferences,* respectively. To be precise, humans are assumed to be motivated by self-interests. Yet, concerns for the well-being of others, for fairness and for reciprocity cannot be ignored in social interactions and have to be included as parameters predictive of choice behavior (Fehr and Schmidt, 2006). Important models of economic decision making that allow good predictions concerning these game theoretic paradigms, will be presented in the next section.

2.2 Intention based Reciprocity

Matthew Rabin (1993) formulated a model based on the assumption that people are kind to other kind people, whereas they behave unfair towards those who behave unfair as well. Therefore, people sacrifice their own material payoff to help those who are kind and to punish those being unkind.

The most important fact about his model is that it is in line with the concept of "psychological game theory" developed by Geanakoplos, Pearce and Stacchetti (1989) where payoffs are a function of the players´ beliefs and their action. When player *i* chooses his strategy he must have some beliefs about the strategy the other player will choose. For that reason player´s subjective expected utility depends on the strategy of the player, his beliefs about the other players' strategy, and his beliefs about the other players' beliefs concerning the strategy he will choose. At a first step Rabin mentioned the "kindness function" which measures how kind player *i* is towards player *j.* It is a function of the strategy chosen by player *i* in consequence of the beliefs he has about the strategy player *j* will choose. Kindness is measured by the difference between the actual payoff *j* will get and the equitable payoff in relation to the worst and the best possible outcome. If *i* treats player *j* fair, $f_i(a_i,b_j) = 0$. If it is greater than zero, player i is giving him more than the equitable payoff and if it is less than zero he is giving him less than the equitable payoff. In a second step it is necessary to define player *i*´s beliefs about how kindly *j* is treating him, as a function of the second order beliefs and the first order beliefs concerning the action of player *j*. This utility function ensures that if player *j* treats *i* unfair player *i*´s utility is always smaller than the material utility. On the other hand *i* gets some additional utility from being kind to *j* when *j* is perceived to be kind as well. If the payoffs are high the kindness term becomes less important. Otherwise, if the material payoffs are small social concerns take over.

One major problem of Rabin´s model is that it can only account for two-person games with complete information. Attempts to manage n-person games will be described in the next part.

2.3 Inequity aversion

The model by Fehr and Schmidt (1999) as well as the model by Bolton and Ockenfels (2000) assume that the players' utility not only depends on the players' own material payoff, but may also depend on the payoff of the other players. Before going into detail concerning differences and similarities between these two models, a short description of both models will be given.

Fehr and Schmidt (1999): A theory of Fairness, Competition and Cooperation

Fehr and Schmidt (1999) assume that there are individuals who dislike inequity. They feel inequity if they are worse off or better off in material terms than the other players. And they suffer more if inequity is to their disadvantage compared to situations where they gain an advantage. Therefore, the utility loss from disadvantageous inequality is larger than the loss from advantageous inequality. The utility function reaches its maximum when the payoff of player *i* equals to the payoff of player *j*, at ($x_i = x_j$).

$$U_i(x) = x_i - \alpha_i \frac{1}{n-1} \sum_{j \neq i} \max\{x_j - x_i, 0\} - \beta_i \frac{1}{1-n} \sum_{j \neq i} \max\{x_i - x_j, 0\}$$

Since the loss in utility is larger for disadvantage inequality the weights of the two parts of the utility function have the following thresholds $\beta_i \leq \alpha_i$ and $0 \leq \beta_i < 1$ thus, the subject is loss averse in social comparison. In the case $\beta_i = 0.5$, the subject is indifferent between keeping one dollar and giving it away to his opponent. The smaller β_i becomes the more people like being better off than others. Negative β_i values are ruled out, since these would be associated with a higher utility (more than the actual payoff) when another person is worse off. Nevertheless, the authors do not preclude that there are people who have negative values here. Importantly, in contrast to the model of Bolton and Ockenfels (2000), the player compares his payoff with the payoff of each other player.

Similar to the model of Rabin (1993) this model can account for results in the ultimatum game. Additionally, it is able to explain findings in games with more than two players. One disadvantage of this linear difference aversion model is that results in the dictator game cannot be explained. Here the Fehr and Schmidt model would predict either very fair (s = 0,5) or very unfair (s = 0) offers. Yet, behavioural results show that most offers are in between the two extremes. A model that allows predicting offers in the dictator game will be described in the next part.

Bolton and Ockenfels (2000): Theory of Equity, Reciprocity and Competition

Bolton and Ockenfels (2000) developed the so called ERC model (Equity, Reciprocity, and Competition). This model is based on the idea that people are motivated by the interaction of their own absolute (monetary) payoff from the experiment, as well as by their own relative payoff. Thus, it is assumed that players compare themselves only with the "average" player and do not care about the distribution of payoffs among other players. The aim of each player is to maximize the expected value of the motivation function (as described in the expected utility function):

$$v_i = v_i\ (y_i, \sigma_i),$$

where y_i is the absolute and σ_i the relative payoff of player *I,* defined as

$$\sigma_i = \sigma_i\ (y_i, c, n) = \begin{cases} y_i/c & if\ c > 0 \\ 1/n & if\ c = 0 \end{cases}$$

$$\text{and } C = \sum_{j=1}^{n} y_i \text{ the total pecuniary payoff.}$$

The ERC model allows for good predictions in the dictator and ultimatum game. Additionally, it predicts many of other phenomena observed in games with more than two players (Bolton and Ockenfels, 1997). However, this theory cannot explain, for example, punishment in the Third-Party Punishment Game (Fehr and Fischbacher, 2004), it would predict that players never invest money to punish unfair treatment of another player. In fact, roughly 60% of the players punish the allocator for the violation of cooperation norms: the lower the transfer the higher the punishment. Additionally, 70 - 80% of the players being treated unfair expected that the allocators will be punished for an unfair distribution.

The major difference between these two models of inequity aversion is that they have a different notion about how to integrate the other players in the game. ERC assumes that people only compare themselves to the average player, whereas Fehr and Schmidt (1999) assume that the player compares his/her payoff with each and every other player´s payoff separately. For ERC this implies that there is no difference in utility function when some of the players are rich and others poor compared to all having the same as long as the own payoff is as close as possible to the average payoff. In the model by Fehr and Schmidt people are most happy in the last case, when all receive the same. Although, the model by Charness and Rabin, which will be described next, incorporates inequality aversion too, it is different in the sense that reciprocity, social-welfare and competition are also included.

Charness and Rabin: Social Preferences

Charness and Rabin (2002) developed a linear two person *social preference* model that is quite different to the models described before. Within this model it is possible to capture difference aversion, social welfare, competition, and reciprocity. It therefor incorporates three different parameters, two to capture distributional preferences and one to account for reciprocity. The weights for the three parameters change depending on the other player being ahead or behind and his/her behavior, i.e. whether the other player has misbehaved or not. Given that π_B and π_A are the money payoffs of two players, player A and player B, the utility of B (U_B), whose choice follows a move of player A, is thus given by the sum of the weighted payoffs of player A and B. Whereas, if A is better off s = 1 and r = 0, if B is better off s = 0 and r = 1; q equals to -1 if A has misbehaved and is zero otherwise.

$$U_B(\pi_A, \pi_B) \equiv (\rho * r + \sigma * s + \theta * q) * \pi_A + (1 - \rho * r - \sigma * s - \theta * q) * \pi_B$$

Using this function it is possible to incorporate three different types of distributional preferences by varying the weights σ and ρ, and reciprocity, given by the parameter θ. The three types of distributional preferences are represented as follows:

1. Competitive preferences: if $\sigma \leq \rho \leq 0$; B prefers that his payoff is equal to or higher than that of player A. Insofar it is related to the concept of inequity aversion; since B wants to reduce differences in payoff between himself and player A.
2. Social-welfare preferences: if $1 \geq \rho \geq \sigma > 0$; B prefers to get more for himself and for A; B is more in favor to get more for himself if A is better off.
3. Difference aversion: $\sigma < 0 < \rho < 1$; B prefers equal payoffs and wants to lower A´s payoff if A does better.

Charness and Rabin tested their model regarding empirical results in different two and three -person bargaining games. Decisions in this games where made by either B, or both, A and B. The Dictator Game was used to isolate distributional preferences form reciprocity. By varying the weights according to the ranges given by the different distributional preferences mentioned above, they tried to find out which of these parameters can explain the given data best. They showed that most of the results can be explained by social-welfare preferences and even narrow self-interest. Across all the games investigated, B´s behavior was explained very little by differences aversion and competitive preferences. Concerning A´s predictions about the behavior of B, difference aversion was clearly to the fore.

2.4 Conclusion

The neoclassical approach assumes that people are solely motivated by the material payoff they will get. Lots of empirical studies from various fields using different experimental setups suggest that results cannot be interpreted in terms of the self-interest hypothesis solely. Therefore, some other (intrinsic) motivational factors have to exist that let people behave fair in specific situations. All the models mentioned before provide ways to predict some of the observations made in for example the dictator, ultimatum, and market or prisoner´s dilemma games. Yet, all of them used a different approach.

The model by Rabin (1993) representing a pioneer work in this field is the most different from the other three models. Most remarkable is the fact that intentions of the players are the source of reciprocal behavior. Thus, people receive reward and punishment according to either fair or unfair intentions. Also concerns for equity are incorporated in respect of the intentions of the players. In that sense people have unfair intentions when they perceive to get less money than others. An important aspect of this model is that the subjective utility is always smaller than the actual material utility if the player is treated unfair by the other.

The major problem of Rabin´s model is that it can only be applied to two-person games with complete information. Whereas, the approach used by the other three models also accounts for n-player games.

The differences and similarities of the two difference aversion models by Fehr and Schmidt (1999) and Bolton and Ockenfels (ERC; 2000) have already been outlined above. To sum up, both approaches assume that people are motivated to reduce the difference between their own payoff and the payoff of other players. ERC posits that individuals compare their payoff with the average payoff of all other players, for example in case of three players, one is satisfied as long as he/she gets one third of the total amount. Fehr and Schmidt (1999), on the other side, assume that the players compare their payoff with the payoff of each and every other payoff and thus, one is only satisfied if everyone gets one third of the total amount. Rabin and Charness (2002) compared different distributional preference in regard to results in the ultimatum game and dictator game and their possible variations. In contrast to the models based on the assumption that people are difference averse, they found that people are not mainly motivated by reducing the differences between payoffs. According to them it seems to be more important to increase the payoff for all subjects and especially for those who have a very low payoff. For example, if one player has the possibility to choose between (800,200) and (0,0), everyone will choose the first allocation. This decision is not in line with the difference aversion hypothesis. When subjects are asked to choose between (400,400) or (700,400), with 700 representing the amount the other player will receive, 69% choose the second allocation. These results show that individuals do not care that heavily about the differences in payoff, but do care for the total surplus. To conclude, following Fehr and Schmidt (2006), one major problem concerning the prediction of behavior in games with more than two players is that it is still unclear who the relevant players are that one refers to or in other words whose payoff is taken into account when deciding.

3 Social preferences: From a biological point of view

As outlined above, the main objective of economics is to predict decision behavior of individuals based on the preferences an individual has about consumptions; thus, neuroeconomics tries to answer how these preferences are generated in the brain. Early studies, focused on the processing of gains and losses (Delgado et al., 2000; Bush et al., 2002; Gehring and Willoughby, 2002) as well as on the anticipation and reception of monetary reward (Knutson et al., 2000; Breiter et al., 2001), identified several regions in the brain that are associated with the representation of value and correlate with expressed preferences. This highly interconnected network includes brain regions like the orbitofrontal cortex (OFC), the striatum, the amygdala, and the dopaminergic midbrain (for review see O'Doherty, 2004; Grabenhorst and Rolls, 2011). Compelling evidence supports the notion that the OFC is involved in the representation of reward and the formation of preferences. For instance, activation in the OFC changes for a given food stimulus dependent on the satiety state of the individual. Neurons in the OFC decrease their response from pre- to post-satiety for a given food stimulus, whereas these neurons show no decrease when the food has not been eaten to satiety (Small et al., 2001; Kringelbach et al., 2003). Besides encoding the reward value of a food stimuli (O'Doherty et al., 2001b), the OFC is responsible for representing the reward value of a variety of stimuli, e.g., olfactory (Gottfried et al., 2002; Rolls et al., 2003a), somatosensory (Rolls et al., 2003b), visual (Aharon et al., 2001), auditory (Blood et al., 1999) and monetary stimuli (Elliott et al., 2003). Furthermore, the magnitude of activation changes in relation to the amounts of reward (Elliott et al., 2003) and punishment (O'Doherty et al., 2001a) and plays an critical role in goal directed behavior (Plassmann et al., 2007; Hare et al., 2008). Though it has been shown that ventral striatum is related to preferences concerning different consumer products (Knutson et al., 2007), most studies suggest that this region is central in reward prediction (Schultz et al., 1997) and in coding of stimulus salience even irrespective of reward value (Zink et al., 2003; 2006). The amygdala, which was extensively studied in relation to the processing of aversive events (Adolphs et al., 1995; 1998), plays also a key role in the representation of reward (Bechara et al., 1999). Wherein, the amygdala is supposed to be particularly involved in the learning of stimulus-value associations and in the processing of stimulus intensity (for a review see Baxter and Murray, 2002).

These insights gained from studying the neural correlates of reward processing formed the basis for studies investigating reward processing in the social context drawing on paradigms from behavioral economics. For instance, it has been observed that cooperation (Decety et al., 2004; Tabibnia et al., 2008), altruism (Moll et al., 2006; Izuma et al., 2009), and reciprocity (Rilling et al., 2004; Phan et al., 2010) were associated with the very same regions in the brain. Thus, these social phenomena may have a positive hedonic value per se and may thereby motivate prosocial behavior.

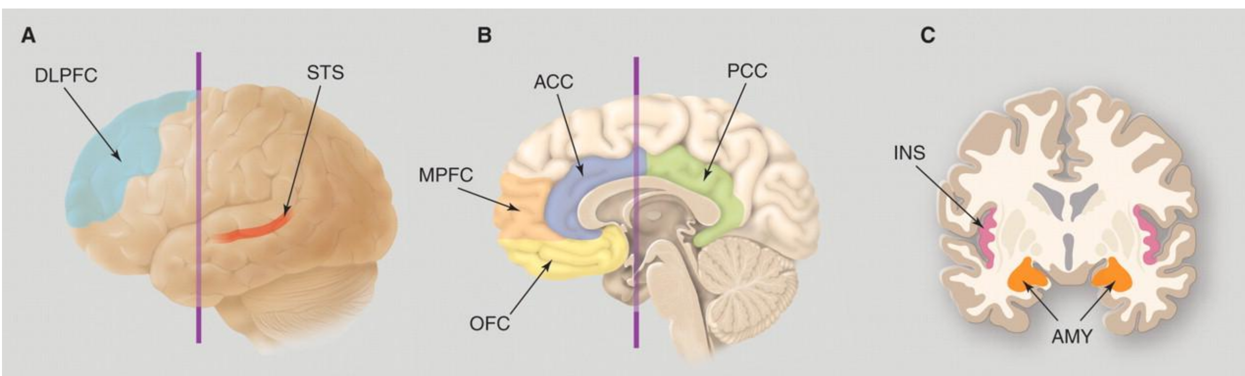

Figure 1| adapted from Sanfey et al. (2007); Core regions implicated in social decision-making.

However, although people do have *social preferences*, there are selfish motives which have a decisive influence on our decisions. Thus, the question arose how these competing motives – self-interest versus other-related preferences – are processed in the brain.

3.1 Neural evidence of inequity aversion

Fliessbach and colleagues (2007) studied the impact of social comparison (Festinger, 1954) on activity in the ventral striatum, as mentioned before, a core region implicated in the representation of the subjective value of primary and secondary incentives. Consistent with the assumption that humans are inequality avers activity in ventral striatum was reduced whenever participants received less than their counterpart. Furthermore, people who are more concerned about social values exhibit enhanced amygdala activation and feel more unpleasant in response to unequal payoffs (Haruno and Frith, 2010).

Since Fliessbach and colleagues (2007) solely studied disadvantageous inequality, Tricomi and colleagues (2010) applied a different paradigm making it possible to study both–advantageous and disadvantageous inequality. Participants who were at the outset better off in material terms showed reduced activity in ventral striatum when money was transferred to themselves compared to conditions, where money was transferred to the disadvantaged counterpart. In a follow-up study by Fliessbach and colleagues (2012) subjects were scanned simultaneously using functional magnetic resonance imaging (fMRI) while they were performing a task where they could earn money following correct responses. When both subjects gave an incorrect response, they received nothing. A correct response of just one participant yielded a reward for those who provided the correct answer, whereas the other received nothing. If both subjects gave the correct answer, both received either the same amount of money, or one received either more than the other or less. Activity in the ventral striatum was reduced when participants received less than their counterpart, but in contrast to the study by Tricomi and colleagues no such decrease could be observed when the other received less. Thus, the subjective value of a reward as represented in the striatum depends on what others receive.

In summary, these studies support the notion that humans compare their payoff with the payoff of relevant others. However, the degree of inequality aversion seems to be related to the reasons for these differences in payoffs.

3.2 Neural correlates of fairness

Recent neuroimaging studies have shown that unfair treatment is related to an increased activation of the anterior insula and the dorsal anterior cingulate cortex (ACC; King-Casas et al., 2008; Takagishi et al., 2009; Guroglu et al., 2010). For instance, unfair proposals in bargaining games are related to increases in insula activation and correlate with the subsequent punishment of the proposer (Sanfey et al., 2003). Interestingly, activity in the left anterior insula is related not only to punishment with respect to unfair treatment of oneself, even when decisions are made for someone else punishment of the unfair counterpart is associated with higher activation in the anterior insula. However, activation in medial prefrontal cortex is solely involved in self-related processing of unfair offers (Corradi-Dell'acqua et al., 2012). Furthermore, Güroğlu and colleagues (2011) found that the relation between activity in the anterior insula and dorsal ACC is highly dependent on the intentions of the proposers. The same holds for subsequent decisions in these games. Using a different approach, the trust game, King-Casas and colleagues (2008) found activation of the anterior insula in response to low offers made by the counterpart and a similar increase in activation in the anterior insula when participants themselves sent back small offers. These findings illustrate that anterior insula and dorsal ACC are highly involved in social interaction and give rise to the emotional reactions in response to unfair treatment; either made by oneself or someone else.

Beside the anterior insula and dorsal ACC there are several other brain regions that play a crucial role in social interactions. For instance, a low-frequent repetitive transcranial magnetic stimulation study (Knoch et al., 2006) showed that diminishing the activation of the right dorsolateral prefrontal cortex (DLPFC), led to a decrease in tendencies to punish unfair behavior, although, offers were viewed as unfair. Furthermore, the rejection rate of offers made by a computer showed no difference. The authors suggest that the DLPFC decreases self-interested impulses and thus enables subjects to implement their fairness goals.

Using pharmacological intervention a recent study found activation in amygdala in relation to processing of inequality (Gospic et al., 2011). Treatment with Benzodiazepine led to a reduction in punishment behavior accompanied by a reduced activation of the amygdala. The control group showed strong activation in the amygdala in accordance with the behavioral response. Activations in the anterior insula and the DLPFC were comparable in these two groups. Thus, Gospic et al. (2011) assume that the negative affect associated with being treated unfair is mainly driven by amygdala responses and this in turn seems to modulate activity in the ACC and the medial prefrontal cortex.

Taken together, activation bilaterally in the anterior insula, the ACC, and the DLPFC are consistently reported following the processing of unfair compared to fair offers. These activations were stronger when receiving unfair offers from a human partner compared to a computer partner. Additionally, unfair offers that had been rejected showed stronger activation in the anterior insula, which was associated with the emotional processing. On the other hand, subjects who accepted low offers showed an increased activation in the DLPFC, commonly associated with executive functions and the manipulation and maintenance of information in working memory (D'Esposito et al., 1995; Prabhakaran et al., 2000). Sanfey and colleagues (2003) proposed that activation in the anterior insula and DLPFC represents the interaction between the emotional goal (reject) and the cognitive rational goal (accept). Since, the ACC is, inter alia, known to be involved when cognitive conflicts do occur (Carter et al., 1999; Botvinick et al., 2001) and is not related to actual behavior in the ultimatum game, the authors assumed that it may reflect a conflict between emotions and cognition. However, electrophysiological studies suggest that ACC is more likely related to violation of expectations and thus, might reflect the violation of social expectations.

3.3 Reward prediction error and social expectations

Recent electrophysiological studies consistently report a negative deflection in the ongoing electroencephalogram (EEG) that is more pronounced following unfair compared to fair offers. Since, it reaches its maximum at about 250 to 300 ms after the offer presentation over fronto-central electrode sites it is interpreted in terms of the medial frontal negativity (MFN). The MFN was first described by Gehring and Willoughby (2002) as a negative-going wave form 265ms after feedback onset. Overall, the MFN is more pronounced, i.e., more negative going, following losses than gains. Dipole source modelling suggested a generator in the ACC. Since, the MFN observed in the study by Gehring and Willoughby was independent from performance feedback given simultaneously to the gain/loss feedback the authors concluded that this component cannot be equated with a previously described component called the feedback-related negativity (FRN; Miltner et al., 1997). The FRN, which is related to negative performance feedback and the corresponding error-related negativity (ERN; Gehring et al., 1993; 1995), which is related to the erroneous responses itself, are both assumed to be generated in the ACC too (Dehaene et al., 1994; Bellebaum and Daum, 2008). Since, the MFN seen after loss feedback bears a resemblance with the FRN that can be observed after negative performance feedback in topography, latency, and underlying neural generator, the question arose whether these two components might reflect the same process. Therefore, Nieuwenhuis and colleagues (2004b) repeated the Gehring and Willoughby (2002) experiment, but changed the salience of the feedback qualities. In line with the assumption that both components represent the same neural process, the EEG component observed distinguished between negative and positive feedback, when performance (correct/incorrect) over utility (gain/loss) was emphasized. Contrary, when utility was more salient than performance the very same component distinguished between gains and losses (see Figure 2).

Since then, several studies had been conducted using various paradigms that broadened our knowledge concerning this early event-related potential (ERP) component associated with the monitoring and evaluation of ongoing events. For instance, negative feedback as well as neutral feedback elicits a MFN that is more pronounced than following positive feedback (Holroyd et al., 2006). Even small gains compared to high gains were found to be associated with MFN amplitudes similar to those observed after losses (Bellebaum et al., 2010). Furthermore, no overt response is required to observe an MFN; even passive viewing in a slot-machine task yields to a MFN more pronounced following losses compared to gains (Donkers et al., 2005).

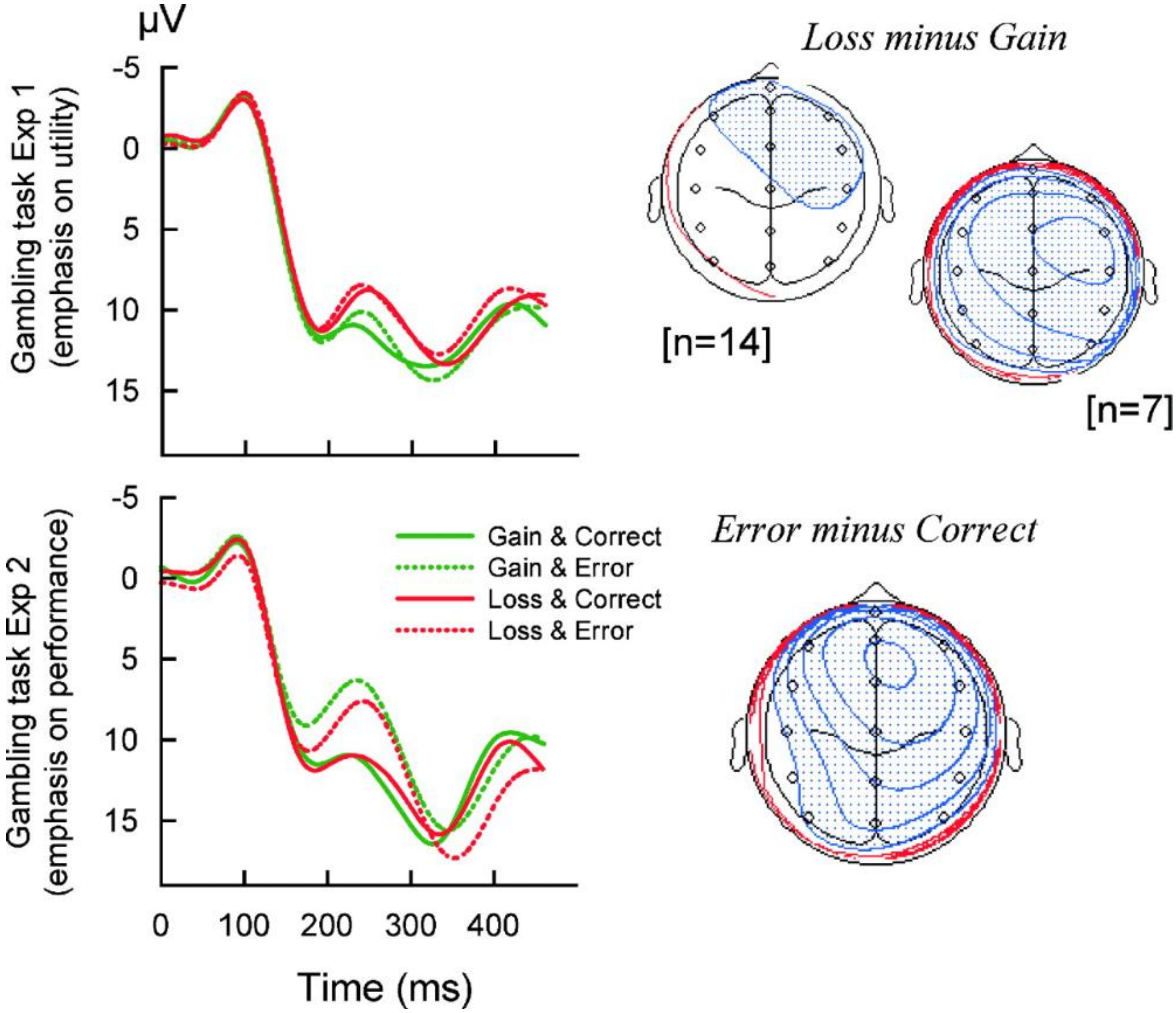

Figure 2| adapted from Nieuwenhuis et al. (2004); *Top:* ERP waveforms at electrode Fcz following feedback emphasising utility. As outlined in the text losses (indicated by a red line) are followed by a more negative going component with peak activity between 200 and 300ms than gains (indicated by a green line). *Bottom:* When performance is emphasised, within the very same time range an enhanced FRN can be observed following feedback indicating an incorrect response (dashed line) compared to feedback indicating a correct response (solid line). *Right Panel:* Scalp topography of MFN difference waves (blue indicates negative values and red indicates positive values).

There have been several attempts to formulate a unifying theory concerning these different mediofrontal ERPs. The most prevailing theory was proposed by Holroyd and Coles in 2002. In 1997 Schultz and colleagues published their work on prediction and reward studying single midbrain dopamine neurons in the monkey brain while their test animals performed a task receiving reward for accurate responses (for a review see Schultz et al., 1997; 1999). Results were intriguing: dopamine neurons responded to reward as well as to novel events right after presentation with phasic activation. After several runs, when the monkey has learned the coherence between cue and reward, dopamine neurons responded already at the cue, whereas, the delivery of rewards itself no longer caused a phasic response. On trials where reward was omitted at the appropriate time, dopamine neurons decreased their firing rate below their basal firing rate (see Figure 3). Schultz and colleagues, concluded that dopamine neurons are sensitive to the “goodness” of ongoing events based on learned predictions about these events. Since, a positive signal is elicited when events exceeds expectations, no change in signal occurs when events are as predicted, and a negative signal can be observed if an event is worse than predicted.

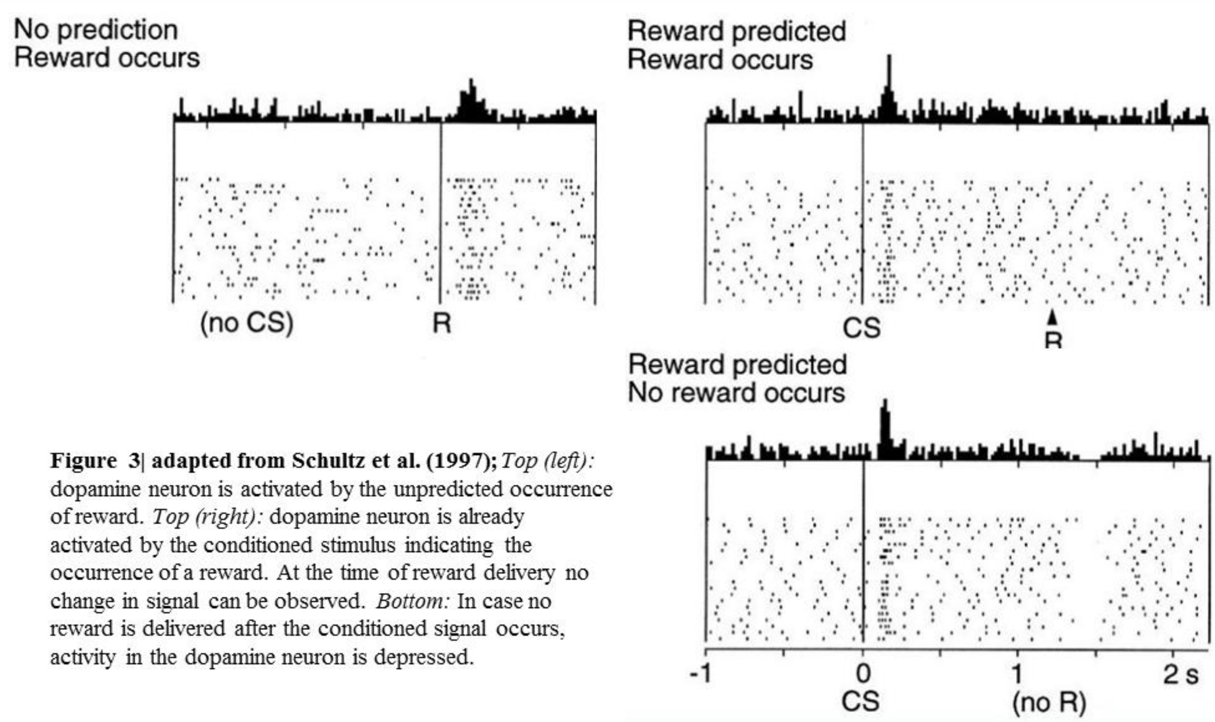

Figure 3| adapted from Schultz et al. (1997); *Top (left):* dopamine neuron is activated by the unpredicted occurrence of reward. *Top (right):* dopamine neuron is already activated by the conditioned stimulus indicating the occurrence of a reward. At the time of reward delivery no change in signal can be observed. *Bottom:* In case no reward is delivered after the conditioned signal occurs, activity in the dopamine neuron is depressed.

Similarities between the characteristics of the MFN, the functions associated with the ACC which is supposed to be the generator of the MFN, and findings regarding the midbrain dopamine system prompted Holroyd and Coles (2002) to postulate a unifying theory. According to this theory the midbrain dopamine system conveys a negative reinforcement learning signal to the ACC, disinhibiting the apical dendrites of motor neurons in ACC and leading to a negative deflection in the ongoing EEG.

Investigations in subsequent years have confirmed the reinforcement theory as proposed by Holroyd and Coles in 2002 to some extent, but also provided new insides. To cut a long story short: The dorsal ACC or anterior medial cingulate cortex (aMCC; as suggested by Vogt et al., 2003 based on cytology) is supposed to evaluate the necessity of a behavioral adaption. Thus, errors, novel events, tasks involving high conflict, and mismatches activate the ACC and exercise the N200 amplitude not necessarily related to the valence of an event, or reward in the narrower sense (Baker and Holroyd, 2011; Wessel et al., 2012). Given that, the MFN distinguishes between events better or worse than expected, similar to the dopaminergic activity outlined before, it is assumed that, though sharing morphological properties, they are distinct from each other. The temporal overlap between N200 and MFN further suggests that the N200 might be suppressed following unpredicted rewards (Baker and Holroyd, 2011). This view is supported by studies investigating these two components using EEG in conjunction with imaging methods. While both activate the ACC, only the MFN, but not the N200, is related to activity in the ventral striatum (Martin et al., 2009; Carlson et al., 2011).

Taken together it is assumed that the MFN distinguishes events on an abstract good-bad dimension (Nieuwenhuis et al., 2004a) or in other words indicates whether a goal has been achieved or not (Hajcak et al., 2006). This is achieved by taking into account prior knowledge or available alternatives to adapt to a changing environment and facilitate future behavior. Whereas, positive and negative reward prediction errors determine the amplitude of the MFN, unpredicted positive events decrease the amplitude and negative events increase the amplitude. As will be described in detail in the following articles, several EEG studies found differences in MFN amplitudes in the context of the ultimatum game. Most of them reported higher – more negative-going–MFN amplitude values after unfair compared to fair offers (e.g., Boksem and De Cremer, 2010; Hewig et al., 2011). In light of the assumptions concerning the appearance of the MFN this might suggest that in the social context rather the expectations regarding other people´s behavior and not merely reward and punishment itself influence the amplitude of the MFN.

4 Research Question – Aim of the Project

The aim of the present project was to elucidate to what extent *social preferences* like inequality aversion, altruism, or spite affect early neuronal processing using EEG and the three-person ultimatum game as a tool. As such, this project is in part a replication of recent neuroscientific studies using the ultimatum game mentioned above. In contrast to previous studies, however, here a "three person ultimatum game" was used to gain additional information about how an unfair offer towards a third person is processed in the brain.

The three-person ultimatum game is a mixture of the regular ultimatum game and the so called dictator game. Compared to the regular two-person ultimatum game it involves a third or dummy player who has to accept any agreement set by the other two players (the responder and the proposer) and thus, it provides a good possibility to study social motives that occur in strategic interaction (e.g. reciprocity, fairness, altruism, etc.). Though, Güth and van Damme (1998, p.230) report that, "there is no single rejection that can clearly be attributed to a low share for the dummy", it still remains unclear whether the proposer and the responder just do not express other-regarding behavior in the presence of competition to achieve their own goals, or if they actually do not care about the dummy´s share. Evidence from the Third-Party Punishment game and the Dictator game, as well as the fact that the fair distribution is the most often offered and accepted one in the three-person ultimatum game, seem to show that players are concerned about the share for the powerless third. Thus, the two remaining questions are still: *Who are the players we refer to and for what reason do we care about them*?

These questions were addressed systematically in two studies. In study 1, a standard anonymous setting was used, in study II; both recipients were recorded simultaneously and in the same room. Both studies focused on the MFN as an index for early evaluation processes in economic decision making. Assuming that people do not care about the dummy player, as predicted by behavioral economics, it was expected that the amplitude of the MFN is not affected by unfair offers towards the powerless third in study I. Accordingly, the MFN should only distinguish between fair and unfair offers towards the responder. Proposing that humans are inequity avers unbalanced offers should be associated with more pronounced MFN amplitudes than symmetrical offers.

The ability to predict others action or to share others emotions and feelings are two major determinants of social interaction. There are several functional neuroimaging studies (Carr et al., 2003; Jackson et al., 2005) showing that observing an emotional state of another person activates the same brain areas which are associated with one´s own emotional state, the so called empathic response. Additionally, these studies suggest that this empathic response is automatic and does not require conscious processing. Recent studies found that the MFN was also elicited while observing errors or losses made by another person (van Schie et al., 2004; Fukushima and Hiraki, 2006). Fukushima and Hiraki (2009) concluded in their study that the MFN elicited by observing others receiving a loss "reflects empathic states towards external agents". In line with empathy research, differences in the MFN amplitude related to offers assigned to the third, passive player had been expected in study II. Furthermore, since the brain activity of the dummy player (yoked control) was recorded simultaneously it was possible to examine the difference between making a choice and having no choice or in other words between having power and having no power, respectively. By this means one might be able to specify the characteristics of the MFN more accurately which are consistently reported in experiments concerning economic decision making.

5 Article I

Do we care about the powerless third?

An ERP study of the three-person ultimatum game

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Running head: Social preferences and the MFN

Keywords: MFN, ultimatum game, social preferences, altruism, egoism, inequality aversion

Abstract

Recent years have provided increasing insights into the factors affecting economic decision making. Little is known about how these factors influence decisions that also bear consequences for other people. We examined whether decisions that also affected a third, passive player modulate the behavioral and neural responses to monetary offers in a modified version of the three-person ultimatum game. We aimed to elucidate to what extent social preferences affect early neuronal processing when subjects were evaluating offers that were fair or unfair to themselves, to the third player, or to both. As an event-related potential index for early evaluation processes in economic decision making, we recorded the medial frontal negativity (MFN) component in response to such offers. Unfair offers were rejected more often than equitable ones, in particular when negatively affecting the subject. While the MFN amplitude was higher following unfair as compared to fair offers to the subject, MFN amplitude was not modulated by the shares assigned to the third, passive player. Furthermore, rejection rates and MFN amplitudes following fair offers were positively correlated, as subjects showing lower MFN amplitudes following fair offers tended to reject unfair offers more often – but only if those offers negatively affected their own payoff. Altogether, the rejection behavior suggests that humans mainly care about a powerless third when they are confronted with inequality as well. The correlation between rejection rates and the MFN amplitude supports the notion that this ERP component is also modulated by positive events and highlights how our expectations concerning other humans' behavior guide our own decisions. However, social preferences like inequality aversion and concern for the well-being of others are not reflected in this early neuronal response, but seem to result from later, deliberate and higher-order cognitive processes.

1. Introduction

Most economic models assume that people are solely motivated by their own material payoff, i.e. they always choose what is best for them. In recent years, this view, the so called self-interest hypotheses, has been questioned. A well-known experiment which shows that this hypothesis does not fully account for human behavior in economic decision making is the so called ultimatum game (Güth et al., 1982). In this two-person game a proposer has to split a certain amount of money between a responder and himself followed by the decision of the responder whether to accept or reject it. If the offer is accepted the money is allotted accordingly - however, if the responder rejects the offer both players receive nothing. Assuming that both players behave rationally and thus do not care about the outcome of the other, the responder would have to accept any positive outcome and the proposer should offer the smallest amount of money. In reality, most of the offers accepted by the responder are about 40%-50% of the total amount while offers below 20% are rejected with a probability of about 50% (Güth et al., 1982; Camerer, 1995).

Observations like these which indicate that people are self-interested but also inequality averse led to a reformulation of models of economic decision making, and the addition of 'other-regarding' preferences to these models. More specifically, models of *social preferences* assume that people compare their own material payoff either with the payoff of each other player (Fehr and Schmidt, 1999) or with the average payoff across all players involved (Bolton and Ockenfels, 2000). People feel inequity if they are worse off or better off than their reference players, leading to a reduction of utility. This reduction is larger for disadvantageous inequality, i.e., being worse off than others in material terms, than for advantageous inequality, i.e., being better off (Fehr & Schmidt, 1999).

Recent event-related potential (ERP) studies document that the distinction between equitable and disadvantageous inequitable offers is already reflected by differences in an ERP component occurring 270 ms after the onset of an offer in the ultimatum game (Polezzi et al., 2008). Characterized by a negative deflection and being more pronounced with regard to inequitable as compared to equitable offers, this component was interpreted in terms of the medial frontal negativity (MFN; Gehring and Willoughby, 2002). These authors were one of the first who observed such a negative deflection in the ERP after monetary losses compared to gains. Dipole source modeling and results from studies using fMRI suggest the MFN signal to be generated in the anterior cingulate cortex (ACC; Gehring and Willoughby, 2002; Martin et al., 2009). Later studies supported this finding and proposed the MFN signal to be related to the reinforcement learning system (Holroyd and Coles, 2002). The reinforcement theory states that the midbrain dopaminergic system codes the subjective value of a certain outcome or object as a function of expectancy. In that sense predicted rewards cause a phasic activation of dopaminergic neurons whereas the omission of a reward leads to a depression. As predicted rewards do not increase the firing rate, it is assumed that the mesencephalic dopaminergic system creates a reward prediction error signal which is conveyed to cortical regions (e.g. the ACC) to allow for the adaption of the behavior (Schultz, 1999; 2010).

In line with this assumption the MFN is usually observed in tasks reflecting monetary losses after the onset of negative feedback (Gehring and Willoughby, 2002), or after feedback indicating an incorrect response (Miltner et al., 1997; Holroyd and Coles, 2002). Furthermore, the amplitude of the MFN is related to subjective values like social norms (Boksem and De Cremer, 2010), i.e. being more pronounced following unfair offers compared to fair offers when subjects are highly concerned by social norms. These findings among others led to the suggestion that the MFN is apparent whenever favorable or unfavorable events are evaluated along an abstract 'good-bad' dimension (Nieuwenhuis et al., 2004a).

Along these lines one might speculate that the MFN indicates the loss of utility when perceiving disadvantageous inequality. Proposing that humans are inequality averse, unbalanced offers unfair to one of the participants should be associated with more pronounced MFN amplitudes than symmetrical offers. This view is supported by behavioral studies showing that people prefer an equal split (Güth et al., 2007) and recent neuroimaging studies reporting ACC activity during the processing of unfair offers (Sanfey et al., 2003; Guroglu et al., 2011). Haruno and Frith (2010) (using a different experimental paradigm) also found increased activity in the ACC in relation to trials where participants received less than their counterparts. Activation was independent of individual differences in social value orientation.

The standard ultimatum game represents a useful behavioral paradigm to study social aspects of decision making as it is simple and has been studied extensively within various disciplines and using different methods (for a review see Rilling and Sanfey, 2011). Nevertheless, this simplicity comes with some major limitations. For instance, it presupposes that players have equal needs for the payoff as it is usually played in anonymous context. In contrast, in a natural environment people mostly know with whom they interact or have at least some information about their counterpart. Another major disadvantage of the standard ultimatum game is the fact that players decide only for themselves, and decisions are not influenced by the presence of other people or groups. However, in real life we hardly make decisions independently of others as others usually observe or are even able to affect our decisions by their mere presence. The present study therefore attempted to overcome this limitation by adding a third player to the standard ultimatum game setup.

As already mentioned, an MFN can be observed whenever subjects feel unfairly treated in the standard ultimatum game. Yet, the question remains how subjects evaluate offers when the proposer behaves unfairly towards someone else and when the decisions made affect this third person as well. In particular, we are interested in how the MFN amplitude is related to advantageous inequality as compared to disadvantageous inequality as well as to equity. In the present ERP study this question will be systematically addressed by introducing a third player to the original ultimatum game. In this version of the ultimatum game, originally developed by Güth and van Damme (1998), a given sum of money is split up between three players: the proposer, the responder, and a dummy-player, reflecting the powerless third. If accepted by the subjects in the role of the responder, the money will be allocated according to the split offered by the proposer; otherwise, no player receives any money. The powerless third is in a yoke-situation and has no decision role in the game. This way, it is possible to study the relation between advantageous inequality (receiving more than the third player) and disadvantageous inequality (receiving less than the third player). Furthermore, by having such a fixed reference agent (the third dummy-player) in contrast to the consistently changing proposers (Sanfey et al., 2003; Polezzi et al., 2008; Boksem and De Cremer, 2010) it is possible to focus on the impact of social motives that occur in strategic social interactions.

2. Materials and Methods

2.1. Participants

Eighteen undergraduate students (6 male; mean age = 23.2 ± 2.7 years) from the University of Vienna participated in the experiment. Two of these subjects had to be excluded from further analysis since post-experimental debriefing revealed that they had not believed in the existence of a third player.

All subjects were naive to the experiment, had normal or adequately corrected vision, and were healthy and right-handed, as assessed by the Edinburgh Handedness Inventory (EHI Oldfield, 1971). Scores for the EHI were above 70 in all subjects. Subjects were paid for their participation the amount of money they earned in four randomly chosen trials, resulting in earnings between 15 and 20 Euros on average. Written informed consent from each participant was obtained prior to the experiment. The study was conducted in accordance with the *Declaration of Helsinki* (1973, revised in 1983) and local guidelines and regulations of the University of Vienna and the Faculty of Psychology.

2.2. Stimulus Material

In order to design the experimental setting realistic offers were collected pre-experimentally following the strategy method introduced by Selten (1965). To this end, we created six possible allocations with a total sum of 15 Euro as well as another six with a total of 12 Euros. Students from different Universities in Vienna were asked to choose one offer from each group resulting in two different offers for each student. After they had chosen the offers a photograph was taken. These photographs together with the two offers formed the stimulus material used for the role of the proposers.

Offers significant for the present study resulted from 81 subjects (40 males) and were either fair (1/3 of the total amount) to all three players, unfair to the responder and the third player (both received less than 15%), or unfair to only one player (receiving less than 15%), whereas one of the others received at least one third of the whole amount. In total each of these four different categories consisted of 27 offers. The remaining 54 offers were neither really unfair (less than 15%) nor fair (1/3 of the total amount). In all these conditions the proposers allocated at least 1/3 of the total amount to themselves. In total 162 offers were presented in six blocks with containing 27 offers each.

2.3. Paradigm and Procedure

Participants played as responders in a modified version of the three-person ultimatum game (Güth and Van Damme, 1998). To ensure that participants believed in the presence of a dummy player, i.e. a third player, subjects were informed as part of the cover story that a second subject of the same gender as the subject him/herself participated in the experiment in a different EEG lab within the same building. In order to increase the feasibility of this setup, subjects were introduced to a second experimenter who supposedly was in charge of preparing the third player for EEG recordings and for running the experiment in the other lab.

All subjects received written instructions about the experimental task and were informed that they themselves, as well as the other players, would receive the amount of money from four randomly chosen trials. To save money only the four most successful proposers would receive compensation. Furthermore, subjects were shown the questionnaires filled out by the proposers to emphasize that the proposals were made by real persons. To avoid possible effects on the decisions to be made due to the physical appearance of the proposers, photographs were not presented prior to each offer (c.f. Solnick and Schweitzer, 1999), but - following a suggestion by Knoch and colleagues (2006) - prior to each of the six blocks.

Hence, each block started with the presentation of photographs of the 27 proposers of the upcoming trials, followed by 27 offers which subjects had to accept or reject (Figure 1). The presentation of these offers, written in German (light gray background, black font color), consisted of three lines: the first line always contained the amount the proposer wanted to keep (e.g. “John gets 4€”), the second indicated the amount the responder, i.e. the participant, would receive (e.g. “You get 4€”), and the third line indicated the amount the third player would get (e.g. “Player 2 gets 4€”). After 4000 ms two squares appeared below the offer, each of which either contained the word “accept” or “reject”. These two alternatives changed the position randomly among the trials. Subjects were instructed to press the corresponding button of a response pad (PST Serial Response Box by Psychology Software Tools, Inc.) with their right hand to indicate the chosen alternative. Immediately after the response, a feedback of the actual allocation (format similar to the offers) was given for 2000 ms. A variable interval of a mean duration of 2500 ms +/- 200 ms presenting a black fixation cross on a light gray screen separated the trials (offers). At the end of each block subjects were informed about the amount of money they had gained so far. To further ensure that participants believed in the presence of the other participant, i.e., the third player, 12 randomly chosen trials were followed by questions concerning the current offer (e.g.: 'Was the proposer male or female?'). Subjects were told that these questions have to be answered by the third player to maintain his or her attention to the task. As there was no real dummy-player, answers in reality were given by the experimenter who was in a different room. Initiated at the subjects' own pace, the next block of trials started, again with the introduction of the subsequent proposers.

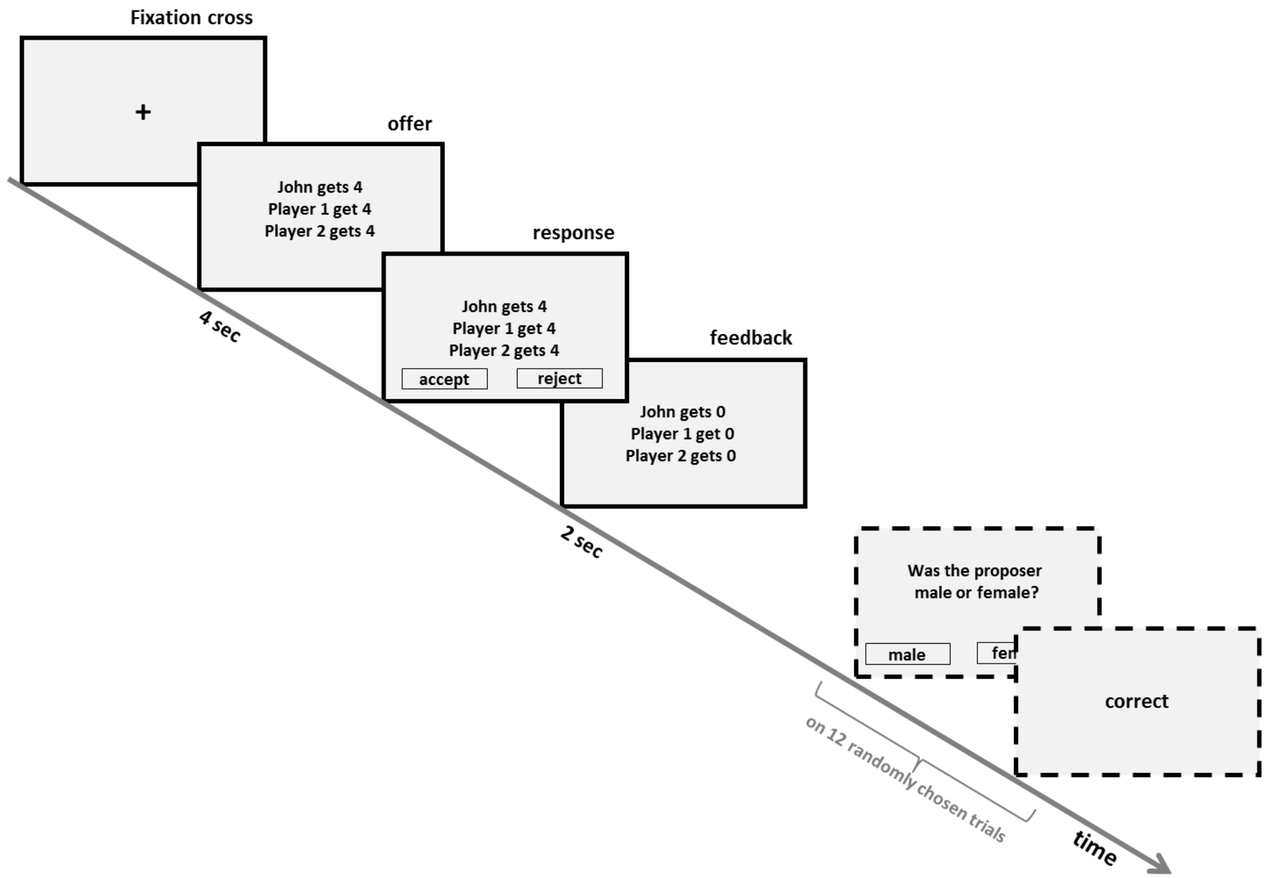

Figure 1| Single-trial setting. Trials started with a fixation cross with a variable time interval, followed by the presentation of the offer. After the duration of 4 sec two boxes appeared at the bottom of the screen indicating that participants can respond. Upon pressing the button, the feedback was presented. On 12 randomly chosen trials the feedback was followed by questions to be answered by the third player.

Stimulus presentation was controlled by a Pentium IV 3.00 GHz computer and E-prime software (E-prime 2.0, Psychology Software Tools, Inc., Pittsburgh, Pennsylvania). The whole experiment lasted for approximately 50 minutes including the short breaks between the blocks. After the experimental session subjects were debriefed, i.e. they were informed about the purpose of the experiment and the fact that no real third player had been present.

2.4. Electrophysiological recordings

Participants were seated comfortably in a sound-attenuated and dimly lit room in front of a 19-inch cathode ray tube monitor. EEG data from each subject were recorded via 61 Ag/AgCl equidistantly located scalp electrodes embedded in an elastic cap (EASYCAP GmbH, Herrsching, Germany; montage M10), referenced to non-cephalic balanced sterno-vertebral electrodes (Stephenson and Gibbs, 1951). For eye movement artifact correction vertical and horizontal electro-oculograms (VEOG, HEOG) were recorded bipolar from above and below the left eye (VEOG) and from right and left outer canthi (HEOG). The subjects' skin was slightly scratched with a sterile needle at all recording sites in order to minimize skin potential artifacts and to ascertain homogeneous electrode impedances below 2 kΩ. Signals were amplified using a DC-amplifier with high baseline stability and an input impedance of 100 GΩ (Ing. Kurt Zickler GmbH, Pfaffstätten, Austria). Signals were digitized with a 1 kHz sampling rate and recorded within a frequency range from DC to 250 Hz.

2.5. Data processing and analysis

Reaction times (RT) were transformed using a logarithmic function (Knutson et al., 2007). RTs were then analyzed by means of a repeated-measures ANOVA with the two within-subjects factors *self-related fairness* (levels: fair, unfair) and *other-related fairness* (levels: fair, unfair); the first being the assignment to the responder and the second to the dummy player. For the comparison of rejection rates, a Friedman test was used.

Eye movement and blink artifacts were first eliminated using a linear regression approach on the basis of parameters obtained in pre-experimental calibration trials (Bauer and Lauber, 1979). Blink coefficients were identified using a template matching procedure. Blink correction was then performed by subtracting vertical and horizontal EOG signals weighted this way from each EEG channel. Subsequently, epochs of 800 ms following the presentation onset of the offer were extracted and baseline-corrected by subtracting the mean amplitude in the interval 200 ms before presentation onset. Data were then down-sampled to 250 smp/s and low pass filtered (6dB/octave slope) at 30 Hz cutoff. Before averaging the data were detrended, i.e. linear trends in the EEG signals were removed using the function "detrend" provided by EEGLAB 6.03b (Delorme and Makeig, 2004). To further improve data quality, e.g. correcting for residual artifacts occurring repeatedly, we followed the approach as outlined in Delorme and colleagues (2007): Trials containing strong non-stereotype artifacts like movement or muscle-artifacts were rejected from further analysis based on visual inspection followed by an independent component analysis (ICA) using the extended infomax algorithm (Bell and Sejnowski, 1995; Lee et al., 1999) as implemented in the EEGLAB toolbox 6.03b (Delorme and Makeig, 2004). Individual independent components were screened for time courses and maps reflecting typical artifacts and then removed by back-projecting only the remaining, non-artifact components to the voltage time series.

Based on visual inspection of the grand-averaged waveforms and scalp distributions of difference waves (Figure 2 and Figure 3) the MFN was quantified as the average baseline-corrected amplitude value in the time range between 240 and 340 ms after stimulus (offer) onset at electrode FCz (Boksem and De Cremer, 2010; Wu et al., 2011). To reduce confounding effects of other ERP components on the amplitude of the MFN we created difference waves by subtracting ERPs elicited by offers with an equal share for all three players from the ERPs elicited by each of the three inequitable offers (unfair share for the subject, the dummy, or both). Additionally we created two difference waves by subtracting MFNs during *Other* fair from *Other* unfair for the two levels of fairness for the subject (*Self* Fair, *Self* Unfair). MFN amplitudes of difference waves were quantified as the average voltage in the 280 to 360 ms time interval at FCz, against the pre-stimulus baseline.

MFN amplitude values at the selected location were submitted to separate 2x2 repeated measurement ANOVAs with the factors *Self* (levels: fair and unfair offers to the responder) and *Other* (levels: fair and unfair offers to the dummy player). These analyses were aimed to describe whether an observed effect can be interpreted in terms of the offer made to the responder (factor *Self*), or to the dummy player (factor *Other*; Boksem et al., 2011). All factors were defined as within-subject factors. The degrees of freedom for repeated measures ANOVAs were Greenhouse-Geisser corrected whenever appropriate. To test whether difference waves are significantly different from zero a one-sample t-test was applied to the average voltage between 280 to 360 ms at FCz. In addition, to scrutinize potential differences in processing the outcome for the powerless third, controlled for the two outcomes for the responding subject, we conducted a paired sample t-test on MFN difference waves. For all analyses the significance threshold was set to $p \leq 0.05$. Finally, to assess the relation between early neuronal processes and actual behavior, MFN amplitudes for each condition as well as the associated difference waves (unfair minus fair) at channel FCz were analyzed in relation to the rejection rates of unequal offers using Pearson correlation coefficients (using directed, one-tailed significance levels; based on the results of Hewig et al., 2011).

3 Results

3.1. Behavioral Results

Analysis of the reaction times (see Table 1) revealed a significant main effect for the factor Self ($F(1,15)=9.591$ $p=.031$ $eta^2=.275$) and a significant S*elf* x O*ther* interaction ($F(1,15)=5.682$ $p=.007$, partial $\eta^2=.390$). In case both – responder and dummy – received an equally high share the shortest mean reaction times (1076.85 ms, SD = 227.62) were observed, while offers unfair to the responder but fair to the dummy showed the longest mean reaction time (1230.31 ms, SD=220.62). There was a statistically significant difference in rejection rates depending on the type of offer, $\chi^2(3)=22.552$, $p<.001$. Post-hoc analyses with Wilcoxon Signed-Rank Tests were conducted with a Bonferroni correction applied, resulting in an individual significance level of $P = .008$. There was no significant difference in rejection rates when comparing offers with an unfair share for the responder (unfair/fair vs. unfair/unfair; $Z= -1.398$, $p=.162$). Despite an overall reduction in rejection rates for offers with a comparatively low share for the dummy (fair/unfair), rejection rates did not significantly differ from offers with a low share for both players (unfair/unfair; $Z=-2.120$, $p=.034$) or offers with a low share for the responder (unfair/fair, Z=-2.552, p=.011). However, when both players received a fair share offers were accepted significantly more often than all the other possible offers (all p<.001).

Table 1| Behavioral results from the three-person Ultimatum Game. Reaction times (in ms) with standard deviations in brackets and relative frequencies of rejections (in %) are given.

	$fair^R$ / $fair^D$	$fair^R$ / $unfair^D$	$unfair^R$ / $fair^D$	$unfair^R$ / $unfair^D$
Mean RT	1076.32	1221.96	1230.31	1150.16
(SD)	(227.62)	(251.42)	(220.62)	(231.59)
Rejection Rate	3.00%	39.35%	64.96%	70.37%

3.2. ERP data

Analysis of the MFN amplitude revealed a significant main effect for *Self*, (F(1, 15) = 5.589 p=.032, partial η^2=.271) whereas, the factor *Other* did not reach significance (F(1, 15) = 1.033, p >.10, partial η^2=.064). There were no significant interaction effects (F(1,15)=1.253, p>.10, partial η^2=.077). The largest, more negative going, MFN amplitude was found for offers where only the responder received a low share (mean +/- SD, 1.79 µV +/- 3.64), and offers assigning a low share to only the dummy were accompanied by the least pronounced MFN amplitude (3.56 µV +/- 2.28; see Figure 2). Thus, the MFN only distinguishes between fair and unfair offers for the responder, being larger for unfair offers, irrespective of the share for the dummy.

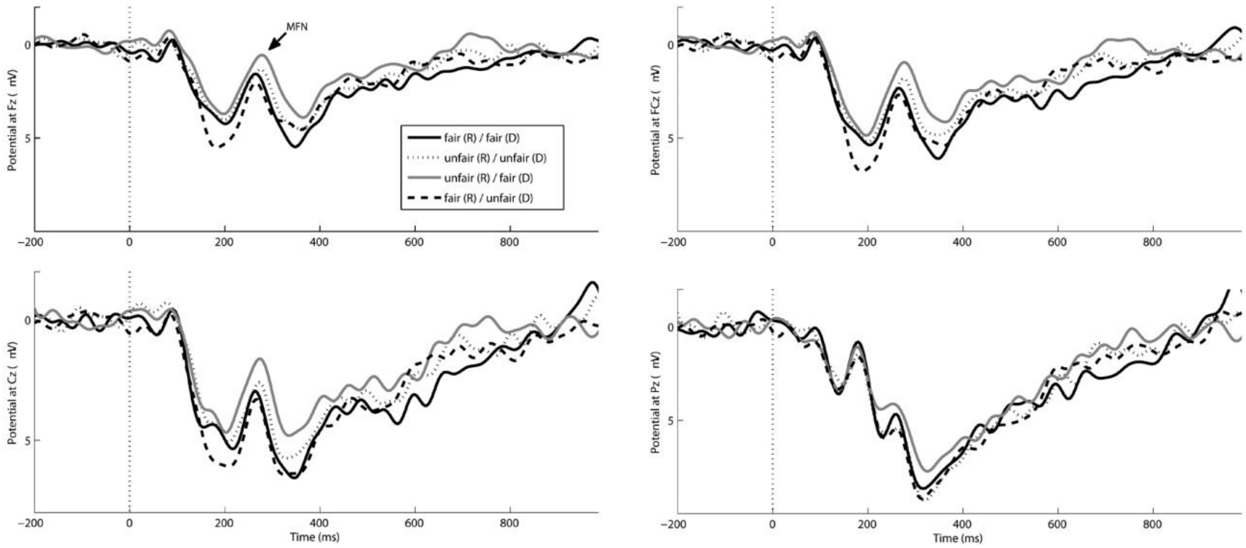

Figure 2| Grand average ERP waveforms at Fz, Fcz, Cz and Pz for the offers: fair/fair (solid line), fair/unfair (dashed line), unfair/fair (gray line), or unfair/unfair (dotted line). Negative is plotted up, Zeros on the timeline indicate the onset of the offer; format: responder/dummy.

Analysis of difference waves confirmed this finding. Again, the amplitude of the difference wave associated with offers that comprise a low share for the responder and a high share for the other players (unfair/fair minus fair/fair) was most pronounced and significantly different from zero (mean=-1.643, t(15)=-2.491, p=.025, d=.881). Otherwise, subtracting ERPs elicited by equal offers (fair/fair) from ERPs elicited by offers with a low share for the dummy (fair/unfair) did not yield a difference wave significantly different from zero (t(15)=.199, p=.845, d=.069). In addition, comparing unfair offers assigned to the dummy when responders themselves received a fair share as compared to an unfair share did not yield a significant difference either (t(15)=1.119, p=.281, d_z=.028). The amplitudes of the difference waves reached their maximum 310 ms following offer onset, with a scalp distribution peaking over the fronto-central area (Figure 3). The same applied for P3 neither main effects nor interactions reached the level of significance (all p >.093).

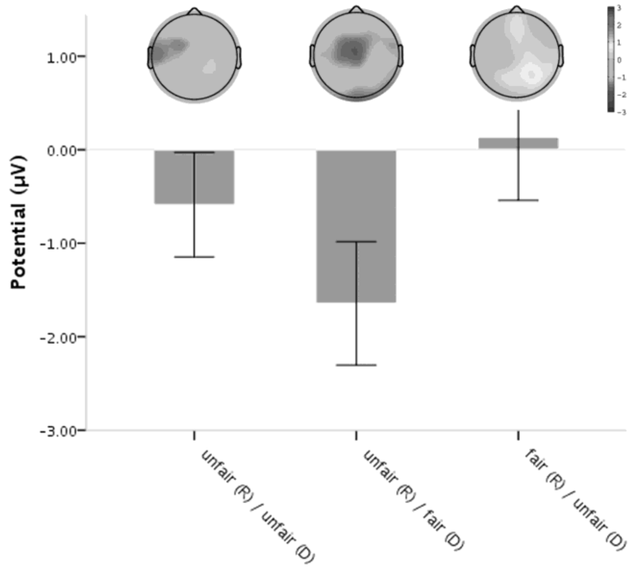

Figure 3| Scalp potential topography of the average voltage differences between equal offers (fair/fair) and the three unequal offers (fair/unfair, unfair/fair and unfair/unfair) for the time point of the MFN (240 - 340 ms following offer onset). The bar chart depicts the respective mean MFN amplitude values. Error bars indicate 1 SE.

To investigate the relationship between electrophysiological data and behavioral choices we conducted correlation analyses. Previous research on the standard ultimatum game found that MFN amplitudes following fair offers were related to rejection rates of offers with unequal splits (Hewig et al., 2011). Even though this statistical relationship could not be explained by their data and had not been measured or reported in previous studies, similar results were obtained in the present study: MFN amplitudes associated with equal offers were related to rejection rates of offers with an unequal split (see Table 2). Notably, this was only the case when responders themselves received a low share: Rejections rates of offers with low shares for both players, the responder and the dummy-player, were positively related to the MFN amplitude associated with equally fair offers ($r=.46$, $p=.037$). Likewise, responders who frequently rejected offers with a low share for themselves exhibited smaller MFN amplitudes following equal offers ($r=.60$, $p=.007$). No correlations ($p>.475$) were observed for the other correlation analyses (see Table 2 for all correlations).

Table 2| Correlations between mean MFN amplitudes for equal (fair/fair) offers and rejection rates of the different offers *p<.01, **p<.05

	$fair^R$ / $fair^D$	$fair^R$ / $unfair^D$	$unfair^R$ / $fair^D$	$unfair^R$ / $unfair^D$
MFN at FCz	-,071	,017	.598**	.458**

4 Discussion

The aim of this study was to investigate how the behavioral and neural responses of a responder in an ultimatum game are affected by a third, passive player. Since the MFN has been associated with early evaluation processes in economic decision making, the analysis focused on this ERP component. Usually the MFN is more negative going when people experience an undesirable outcome or event compared to a more acceptable one. We assumed that involving a third player might affect the way people evaluate their payoffs, and in turn modulate the MFN amplitudes. To this end, we recorded EEG from participants playing in the role of the responders in a modified version of the three-person ultimatum game. Overall, the results indicate that people dissociate between high and low offers assigned to them. In particular, the amplitude differences about 300ms after the presentation of the offer can be mainly explained by the share for oneself, while the non-significant main effect for other-related fairness suggests that the subjects' neural responses were not indexing the fairness of offers to the powerless third. In addition, no effect was found when comparing difference waves between fair and unfair offers assigned to the powerless third. Furthermore, though there seems to be a relation between MFN amplitude and behavior in the ultimatum game (Hewig et al., 2011), this effect was only observed with offers that negatively affected the responder's payoff.

Previous ERP studies on the two-person ultimatum game have shown that offers with a low share for the responder were associated with more pronounced MFN amplitudes as compared to offers with equal ones (Boksem and De Cremer, 2010; Hewig et al., 2011; Wu et al., 2011).

The MFN is believed to reflect a subjective motivational judgment indicating whether an event or outcome is better or worse than expected (Gehring and Willoughby, 2002; Nieuwenhuis et al., 2004a). In line with this assumption people who are more concerned about fairness norms exhibit more pronounced MFN amplitudes following norm violations in the ultimatum game (Boksem and De Cremer, 2010). Furthermore, several authors have shown that an MFN can be observed when gambling task outcomes refer to someone else (van Schie et al., 2004; Fukushima and Hiraki, 2006). Even when the task performance of others does not affect the subjects themselves, particularly those with high trait empathy have higher MFN amplitudes when the other person makes a mistake and loses money (Fukushima and Hiraki, 2009). Therefore, we assumed that the MFN would be as well modulated by an unfair share towards the third player. According to a recent neuroimaging study advantageous inequity as compared to disadvantageous inequity is less rewarding as indicated by reduced activity in brain areas that are associated with reward processing. Subjects who were better off in material terms than their counterparts showed less activity in ventral striatum and ventromedial prefrontal cortex when they received money that augmented the difference in payoff (Tricomi et al., 2010). Following the concept of inequality aversion, we expected unequal offers always to be associated with higher MFN amplitudes than equal ones. This assumption was not confirmed by the data. A recent study using the two-person ultimatum game found that MFN amplitude differences following fair and unfair offers were not modulated by observing the allocation outcome of other unrelated responders – proposer dyads (Wu et al., 2011). Involving a third player we found similar results as Wu and colleagues, suggesting that neither an external reference point nor a fixed reference agent clearly modulate this early ERP component. Furthermore, in a social comparison task prosocial subjects responded with higher amygdala activity and felt more unpleasant in response to unequal payoffs. Individualist showed the opposite pattern, i.e., an increase in reward difference was associated with decreased activity in the amygdala (Haruno and Frith, 2010). The ACC, the dorsolateral prefrontal cortex and the anterior insula, i.e., brain areas that have been associated with the processing of unfair offers in the ultimatum game (Sanfey et al., 2003), were found to show higher activity when subjects received less than their counterpart. Interestingly those regions were similarly activated in prosocial subjects and individualist. Since it is supposed that the MFN is generated in the ACC according to Gehring and Willoughby (2002), our results broaden these findings due to the higher temporal resolution of the EEG and suggest that the initial response is mainly self-related. Nevertheless, it is important to remember that the three players in our experiment remained anonymous to each other, which is the standard procedure in these kind of paradigms (Camerer, 1995; Güth et al., 2007). This is in contrast to studies that found evidence for a component that might be interpreted as an other-related MFN where pairs were either seated in the same room or knew each other already prior to the experiment (Fukushima and Hiraki, 2006; 2009). Thus, it might be possible that decreasing the degree of psychological or physical distance between players might have resulted in different behavioral and neuronal responses.

However, concerning the behavioral responses we found consistency with previous behavioral studies. Participants preferred equal shares, whereas offers with a low share for the responder were rejected most frequently (Güth et al., 2007). Furthermore, in line with previous ERP studies (Boksem and De Cremer, 2010; Hewig et al., 2011) no relation between the amplitude of the MFN difference wave and rejection rates were found. Nevertheless, MFN amplitude following equitable offers was highly related to rejection rates of offers with low shares for the responder. This finding has already been reported in previous studies on the two-person ultimatum game (e.g. Hewig et al., 2011). Several studies on the MFN are based on the assumption that alterations of the amplitudes are solely related to the processing of negative events or events that are worse than expected (Gehring and Willoughby, 2002; Nieuwenhuis et al., 2004a). According to Holroyd and Coles (2002; 2008), though, unexpected negative events would have an enhancing effect, unexpected positive events would have an attenuating effect on the MFN amplitude. Pedroni and colleagues (2011) argue that there are actually two processes that occur at the time a MFN can be observed, an evaluation on a good-bad dimension, as proposed in previous studies, and the evaluation of the (positive) reward value. In light of the assumption that positive and particularly unexpected positive events lead to a change in MFN amplitude, Hewig and colleagues (2011) propose two possible explanations for the relation between rejections rates and MFN amplitudes following equal offers. Either more reward sensitive participants reject unfair offers because they are disappointed, or those who expect others to be selfish are more likely to reject unfair offers, due to their negative view of others. More precisely, if offers with a high share for oneself are related to stronger reward-related responses, these offers are also accompanied by a reduction in MFN amplitude. In this regard participants with lower MFN amplitudes following equal offers are more disappointed when offered a relatively small amount and hereupon reject these proposals. On the other hand if participants believe that proposers are rather selfish by keeping most of the money for themselves, they may expect receiving mainly unequal offers. This negative view of others might lead to higher rejection rates and smaller MFN amplitudes in relation to equal "better than expected" proposals. Our findings provide some new insights on this relation between neural and behavioral response. In the study by Hewig and colleagues (2011) offers with an equal amount for both players represented the highest possible reward for the responder. In the present study there are two possible conditions with high shares for the responder. Equal offers as well as advantageous unequal offers denote a high share for the responder. Assuming that reward sensitivity predicts decision behavior, both offers with high shares for the responder should be related to rejection rates or at least should be related to each other. Yet, such a relation could not be established in the present study. Only equal offers were related to decision behavior. This evidence suggests that in the context of social interaction our expectations concerning the behavior of others might already guide our own behavior. Similarly, in contradiction to the hypotheses that negative emotions following unfair offers might facilitate memory for cheaters (Mealey et al., 1996; Vanneste et al., 2007; Barclay, 2008), a recent study on the standard two person ultimatum game found that the proposers' behavior per se does not enhance memory. Conversely, when offers did not meet the expectations of the responders, they remembered the proposers' face more efficiently (Chang and Sanfey, 2009).

Importantly, the so-called power coalition – the third player receives far less than the other two players – was rejected quite frequently. Rejections of those offers were not at all related to MFN amplitudes. Similarly a recent study measuring skin conductance responses (SCR) revealed that an inequitable offer in the standard two person game is followed by an increase in SCR. However, when people are playing the two-person ultimatum game on behalf of another person, they do not show this increase in SCR following an unfair offer. Yet, these offers were rejected as often as when playing for themselves. Therefore, affective responses were solely related to self-relatedness, while behavioral responses were not (Civai et al., 2010). This suggests that economic decisions are not necessarily always related to the emotional response – in particular when there is enough time for a controlled, deliberative process. Yet, when these deliberative processes are inhibited by time pressure, decisions as in the ultimatum game are only guided by affective processes as indicated by an increase in rejection rate (Sutter et al., 2003; Cappelletti et al., 2008). In the present study participants had unlimited time to decide whether to accept or reject an offer, which might also explain the discrepancy between the early neuronal and the subsequent behavioral response especially with regard to offers that affect the third, passive player. Nevertheless, note that the neuroimaging study on inequality aversion by Haruno and Frith (2010) suggests that the amygdala activity in response to unequal reward pairs reflects a rapid intuitive response. This assumption is based on the finding that cognitive load had no effect on inequality aversion. Evaluation of reward differences and reaction time did not differ in a high cognitive load compared to a low-load condition. This is in line with behavioral studies on the ultimatum game that found no difference in rejection rates under cognitive load, whereas, responders reject unfair offers more often under time pressure (Sutter et al., 2003; Cappelletti et al., 2008). Of course, it would have been interesting to elucidate later parts of the decision making process, but this is beyond the scope of the present work. Nevertheless, the relation between the different parts of the decision making process is of central importance to gain a more accurate and exhaustive understanding of (economic) decision making.

Taken together, the results of the present study show that inequality aversion cannot explain variability in the early neuronal evaluation process. On an early neuronal level, humans dislike disadvantageous inequality and seem to favor advantageous inequality. Although the decision behavior observed in this study suggests that humans care about the powerless third, there is no evidence for an early affective response suggesting that subjects do not care about what the other person receives. Thus, we propose that the first automatic response to inequality is mainly self-related, whereas, concerns for the well-being of others are part of higher cognitive, deliberative or intuitive processes following the first automatic response.

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Concept and design: JA, FF. Execution: JA, FF, and DMP. Data analyses: JA, FF, and DMP. Manuscript: JA, DMP, HB, CL, FF. HB supervised the project.

References

Barclay, P. (2008). Enhanced recognition of defectors depends on their rarity. *Cognition* 107**,** 817-828.

Bauer, H., and Lauber, W. (1979). Operant conditioning of brain steady potential shifts in man. *Applied Psychophysiology and Biofeedback* 4**,** 145-154.

Bell, A.J., and Sejnowski, T.J. (1995). An Information-Maximization Approach to Blind Separation and Blind Deconvolution. *Neural Computation* 7**,** 1129-1159.

Boksem, M.A., and De Cremer, D. (2010). Fairness concerns predict medial frontal negativity amplitude in ultimatum bargaining. *Social neuroscience* 5**,** 118-128.

Boksem, M.A., Kostermans, E., and De Cremer, D. (2011). Failing where others have succeeded: Medial Frontal Negativity tracks failure in a social context. *Psychophysiology* 48**,** 973-979.

Bolton, G., E., and Ockenfels, A. (2000). ERC: A Theory of Equity, Reciprocity, and Competition. *American Economic Review* 90**,** 166-193.

Camerer, C.T., Richard, H. (1995). Anomalies: Ultimatums, Dictators and Manners. *The Journal of Economic Perspectives* 9**,** 209-219.

Cappelletti, D., Güth, W., and Ploner, M. (2008). Being of two minds: an ultimatum experiment investigating affective processess. *Jena Economic Research Papers* 2008-048.

Chang, L.J., and Sanfey, A.G. (2009). Unforgettable ultimatums? Expectation violations promote enhanced social memory following economic bargaining. *Frontiers in behavioral neuroscience* 3**,** 36.

Civai, C., Corradi-Dell'acqua, C., Gamer, M., and Rumiati, R.I. (2010). Are irrational reactions to unfairness truly emotionally-driven? Dissociated behavioural and emotional responses in the Ultimatum Game task. *Cognition* 114**,** 89-95.

Delorme, A., and Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods* 134, 9-21.

Fehr, E., and Schmidt, K.M. (1999). A Theory of Fairness, Competition, and Cooperation. *The Quarterly Journal of Economics* 114, 817-868.

Fukushima, H., and Hiraki, K. (2006). Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity. *Soc Cogn Affect Neurosci* 1, 149-157.

Fukushima, H., and Hiraki, K. (2009). Whose loss is it? Human electrophysiological correlates of non-self reward processing. *Social neuroscience* 4, 261-275.

Gehring, W.J., and Willoughby, A.R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* 295, 2279-2282.

Guroglu, B., Van Den Bos, W., Van Dijk, E., Rombouts, S.A., and Crone, E.A. (2011). Dissociable brain networks involved in development of fairness considerations: understanding intentionality behind unfairness. *Neuroimage* 57, 634-641.

Güth, W., Schmidt, C., and Sutter, M. (2007). Bargaining outside the lab - a newspaper experiment of a three-person ultimatum game. *Economic Journal* 117, 449-469.

Güth, W., Schmittberger, R., and Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior & Organization* 3, 367-388.

Güth, W., and Van Damme, E. (1998). Information, Strategic Behavior, and Fairness in Ultimatum Bargaining: An Experimental Study. *Journal of Mathematical Psychology* 42, 227-247.

Haruno, M., and Frith, C.D. (2010). Activity in the amygdala elicited by unfair divisions predicts social value orientation. *Nat Neurosci* 13, 160-161.

Hewig, J., Kretschmer, N., Trippe, R.H., Hecht, H., Coles, M.G., Holroyd, C.B., and Miltner, W.H. (2011). Why humans deviate from rational choice. *Psychophysiology* 48, 507-514.

Holroyd, C.B., and Coles, M.G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychol Rev* 109**,** 679-709.

Holroyd, C.B., and Coles, M.G. (2008). Dorsal anterior cingulate cortex integrates reinforcement history to guide voluntary behavior. *Cortex; a journal devoted to the study of the nervous system and behavior* 44**,** 548-559.

Knoch, D., Pascual-Leone, A., Meyer, K., Treyer, V., and Fehr, E. (2006). Diminishing reciprocal fairness by disrupting the right prefrontal cortex. *Science* 314**,** 829-832.

Knutson, B., Rick, S., Wimmer, G.E., Prelec, D., and Loewenstein, G. (2007). Neural predictors of purchases. *Neuron* 53**,** 147-156.

Lee, T.-W., Girolami, M., and Sejnowski, T.J. (1999). Independent Component Analysis Using an Extended Infomax Algorithm for Mixed Subgaussian and Supergaussian Sources. *Neural Computation* 11**,** 417-441.

Martin, L.E., Potts, G.F., Burton, P.C., and Montague, P.R. (2009). Electrophysiological and hemodynamic responses to reward prediction violation. *Neuroreport* 20**,** 1140-1143.

Mealey, L., Daood, C., and Krage, M. (1996). Enhanced memory for faces of cheaters. *Ethology and Sociobiology* 17**,** 119-128.

Miltner, W.H.R., Braun, C.H., and Coles, M.G.H. (1997). Event-Related Brain Potentials Following Incorrect Feedback in a Time-Estimation Task: Evidence for a “Generic” Neural System for Error Detection. *Journal of cognitive neuroscience* 9**,** 788-798.

Nieuwenhuis, S., Holroyd, C.B., Mol, N., and Coles, M.G. (2004). Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. *Neurosci Biobehav Rev* 28**,** 441-448.

Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9**,** 97-113.

Pedroni, A., Langer, N., Koenig, T., Allemand, M., and Jäncke, L. (2011). Electroencephalographic Topography Measures of Experienced Utility. *The Journal of Neuroscience* 31**,** 10474-10480.

Polezzi, D., Daum, I., Rubaltelli, E., Lotto, L., Civai, C., Sartori, G., and Rumiati, R. (2008). Mentalizing in economic decision-making. *Behav Brain Res* 190**,** 218-223.

Rilling, J.K., and Sanfey, A.G. (2011). The neuroscience of social decision-making. *Annu Rev Psychol* 62**,** 23-48.

Sanfey, A.G., Rilling, J.K., Aronson, J.A., Nystrom, L.E., and Cohen, J.D. (2003). The neural basis of economic decision-making in the Ultimatum Game. *Science* 300**,** 1755-1758.

Schultz, W. (1999). The Reward Signal of Midbrain Dopamine Neurons. *Physiology* 14**,** 249-255.

Schultz, W. (2010). Dopamine signals for reward value and risk: basic and recent data. *Behavioral and Brain Functions* 6**,** 24.

Selten, R. (1965). Die Strategiemethode zur Erforschung des eingeschränkt rationalen Verhaltens im Rahmen eines Oligopolexperimentes. Seminar für Mathemat. Wirtschaftsforschung u. Ökonometrie.

Solnick, S.J., and Schweitzer, M.E. (1999). The Influence of Physical Attractiveness and Gender on Ultimatum Game Decisions. *Organizational behavior and human decision processes* 79**,** 199-215.

Stephenson, W.A., and Gibbs, F.A. (1951). A balanced non-cephalic reference electrode. *Electroencephalography and clinical neurophysiology* 3**,** 237-240.

Sutter, M., Kocher, M., and Strauß, S. (2003). Bargaining under time pressure in an experimental ultimatum game. *Economics Letters* 81**,** 341-347.

Tricomi, E., Rangel, A., Camerer, C.F., and O/'Doherty, J.P. (2010). Neural evidence for inequality-averse social preferences. *Nature* 463**,** 1089-1091.

Van Schie, H.T., Mars, R.B., Coles, M.G., and Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nat Neurosci* 7**,** 549-554.

Vanneste, S., Verplaetse, J., Van Hiel, A., and Braeckman, J. (2007). Attention bias toward noncooperative people. A dot probe classification study in cheating detection. *Evolution and Human Behavior* 28**,** 272-276.

Wu, Y., Zhou, Y., Van Dijk, E., Leliveld, M.C., and Zhou, X. (2011). Social Comparison Affects Brain Responses to Fairness in Asset Division: An ERP Study with the Ultimatum Game. *Front Hum Neurosci* 5**,** 131.

6 Article II

Agency matters!

Social preferences in the three-person ultimatum game

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Running head: Agency, social preferences and the MFN

Keywords: altruism, spite, social preferences, MFN, ultimatum game

Abstract

In the present study ERPs were recorded simultaneously while two participants were playing the three-person ultimatum game. Both participants received different offers from changing proposers about how to split up a certain amount of money between the three players. One of the participants had no say; whereas the other was able to harm the payoff of all other players. The aim of the study was to investigate how the outcomes of the respective other are evaluated by participants who were treated fairly or unfairly themselves and to what extent agency influences concerns for fairness. Analyses were focused on the medial frontal negativity (MFN) as an early index for subjective value assignment. Recipients with veto-power exhibited enhanced, more negative-going, MFN amplitudes following proposals that comprised a low share for both recipients, suggesting that responders favored offers with a fair amount to at least one of the two players. Though, the powerless players cared about the amount assigned to the responder, MFN amplitudes were larger following fair compared to unfair offers assigned to the responder. Similarly, concerns for fairness which determined the amplitude of the MFN, suggested that the powerless players exhibited negative and conversely the responders, positive social preferences.

1 Introduction

Comparative processes are essential to assess the emotional meaning assigned to a given situation. Whether we perceive something as pleasant or unpleasant depends on the alternatives and their accessibility (Ben-Ze'ev, 2000). For example, a rewarding stimulus might get devalued in situations associated with feelings of anger or envy. Thus, the nature of emotions elicited by the reception, omission, or termination of reward or punishment depends on what we expect and on what others receive in comparison to one selves (Festinger, 1954; Rolls, 2005). This circumstance becomes apparent when looking at recent findings in the field of neuroeconomics investigating how people evaluate specific situations associated with reward or punishment in relation to significant others using simple experimental games.

One, beside several others (for review see Rilling and Sanfey, 2011) commonly used experimental game to study reward related decision processes and the underlying neural correlates in a social context, is the Ultimatum Game (UG; Güth et al., 1982). In its original version a proposer is endowed with a sum of money he has to share with a responder. He/she can send any positive amount to the responder, who in turn has the possibility to reject or accept the proposed division of money. If the proposed distribution is accepted by the responder, money will be allocated accordingly. Otherwise, if rejected by the responder, both receive nothing. The proposer can make only one proposal, all players are anonymous to each other, and the game ends after the responder has made his/her decision. Of course, the aim of each player in this bargaining game is to maximize money. Nevertheless, most responders are willing to abandon their division if it is smaller than 20% of the total amount and proposers offer about 40% to 50% of the total amount (Güth et al., 1982; Thaler, 1988; Güth and Van Damme, 1998). Though, behavior in this game seems to be rather irrational, results are very robust and do not markedly change with the size of the stake (Slonim and Roth, 1998; Cameron, 1999; Munier and Costin, 2002). Even demographic variables, intellectual abilities, and socio-economic status do not modulate behavior in this game (Güth et al., 2007; Nguyen et al., 2011).

There are several regions in the brain that are implicated in the representation of the subjective value of reward and punishment (for reviews see, Schultz, 2006; Grabenhorst and Rolls, 2011).

One of these, the anterior cingulate cortex (ACC), and in particular its dorsal part, might be of particular importance in the comparative processes discussed above. In comparison with other areas associated with the representation of reward, the ACC integrates various aspects of a decision, e.g., probability, payoff, and effort (Kennerley et al., 2009; 2011). Furthermore, the ACC not only evaluates values of alternatives during choice, but also the consequences of choices made. However, this region is not necessarily related to actual decision behavior (Seo and Lee, 2007; Luk and Wallis, 2009). For this, the ACC receives input from different neuronal sources associated with certain qualities of reward and has strong connections to motor areas (e.g. Vogt et al., 1992). All of these are requirements needed to synthesize these various aspects of a given situations and to adapt preferences in light of the current goal and the effort that has to be taken.

Hence, it is not surprising that activation in the dorsal part of the ACC (dACC) is consistently reported in neuroimaging studies investigating decision processes in the UG (Sanfey et al., 2003; Gospic et al., 2011; Kirk et al., 2011); irrespective of participant's age (Guroglu et al., 2011). Electrophysiological studies provide further evidence for the involvement of the dACC in the context of the UG. The medial frontal negativity (MFN), an event related potential which is supposed to be generated in the dACC (Gehring and Willoughby, 2002; Luu et al., 2003; Wessel et al., 2012), can be observed after the receipt of negative compared to positive feedback (Miltner et al., 1997; Luu et al., 2003; Nieuwenhuis et al., 2004b), after events that deviate from what we expect (Potts et al., 2006; Hajcak et al., 2007; Pfabigan et al., 2011), and in response to losses compared to gains (Gehring and Willoughby, 2002), irrespective of whether an action or choice preceded (Donkers et al., 2005; Martin et al., 2009). Furthermore, a similar negative deflection can be reported when we observe someone else receiving negative feedback or losing money (Fukushima and Hiraki, 2009). Generally, it is assumed that the MFN discriminates events on an abstract good-bad dimension (Nieuwenhuis et al., 2004a; Hajcak et al., 2006) or whether a goal has been achieved or not (Holroyd et al., 2006). Given that the MFN can be observed already 250ms after the onset of an event it is used as an index for early evaluation processes in economic decision making. Having in mind that for some individuals the subjective value assigned to a certain reward highly depends on what others receive, the MFN should as well be modulated by social preferences like inequality aversion, altruism, or reciprocity. This has been confirmed in parts by studies investigating the UG. Since, fair offers elicited more positive MFN amplitudes than unfair offers and thus, are preferred in view of the assumptions on the MFN (e.g. Boksem and De Cremer, 2010; Hewig et al., 2011). Though results show that differences in MFN amplitude are related to concerns for fairness and rejection rate (Boksem and De Cremer, 2010; Hewig et al., 2011), it is unclear to what extent MFN amplitude differences between fair and unfair offers are affected by the proposer himself as a reference agent, or does the MFN just differentiate between high and low amounts of money? A recent electrophysiological study investigated the influence of social comparison on behavior in the UG and MFN amplitudes by adding a social reference point, i.e., average proposals in other proposer-responder dyads were also presented to the responders (Wu et al., 2011); yet, no influence on the MFN amplitude could be reported. In a previous study we added a human agent as a reference point by employing a three-person UG (Alexopoulos et al., 2012). This third player, a dummy-player so to speak, had no bearing in the game itself. Money had to be split up between all three players, and the responder, who's EEG was recorded during the game, had to accept or reject the allocation as otherwise customary in the standard UG. Results, as indicated by the MFN amplitudes, showed that responders only differentiated between fair and unfair offers towards themselves disregarding the share assigned to the dummy-player. Nevertheless, disadvantageously unequal, unfair offers assigned to the responder were followed by the most pronounced MFN amplitude. From there suggested that the third person had an impact on the responders´ MFNs, and that he/she acts as the relevant reference agent responders care about. Though, several studies suggested that empathic concerns are reflected in the MFN, the MFN observed in the responders seemed to be associated with negative social preferences. Nevertheless, it must be considered that participants were usually acquainted with each other whereas, dummy-players were unacquainted and in fact there presence was simulated in our study. Therefore, one could assume that the actual presence of the dummy-player could have changed the direction of social preferences.

In the current study we therefore aimed to clarify whether pre-play communication and the actual presence of the third player changes the pattern of MFN amplitudes. To this end, we recorded EEG simultaneously from both recipients – the responder and the dummy-player – while they were playing the three-person UG using the same setting as reported in Alexopoulos et al. (2012). Since, several studies have shown that pre-play communication facilitates cooperation in social dilemma or bargaining games, respectively (for a survey see Crawford, 1998), we expected a similar effect on the early neural processes. More precisely, we expect a more negative MFN difference wave for unfair compared to fair offers assigned to the third player and an interaction of unfairness towards oneself with unfairness towards the other for unsubtracted, non-difference, ERP amplitudes. Additionally, given that the dummy-players had no impact on the game, i.e., they could not punish unfair treatment, they acted as a yoked control group to clarify the impact of agency.

In addition to the ERP data individual concerns for fairness were collected, as previous studies reported that fairness concerns are related to MFN amplitude differences (Boksem and De Cremer, 2010). To this end we applied a justice sensitivity scale (Schmitt et al., 2004; Schmitt et al., 2010), which measures the degree to which individuals are concerned about injustice towards oneself and others.

2 Materials and Methods

2.1 Participants

Thirty-six undergraduate students (16 males; mean age = 23.3 ± 2.69 years) from the University of Vienna participated in the experiment. All subjects were healthy, right handed and naïve to the paradigm applied. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were paid between 15 and 20 Euros on average; actual earnings depended on their performance in the game.

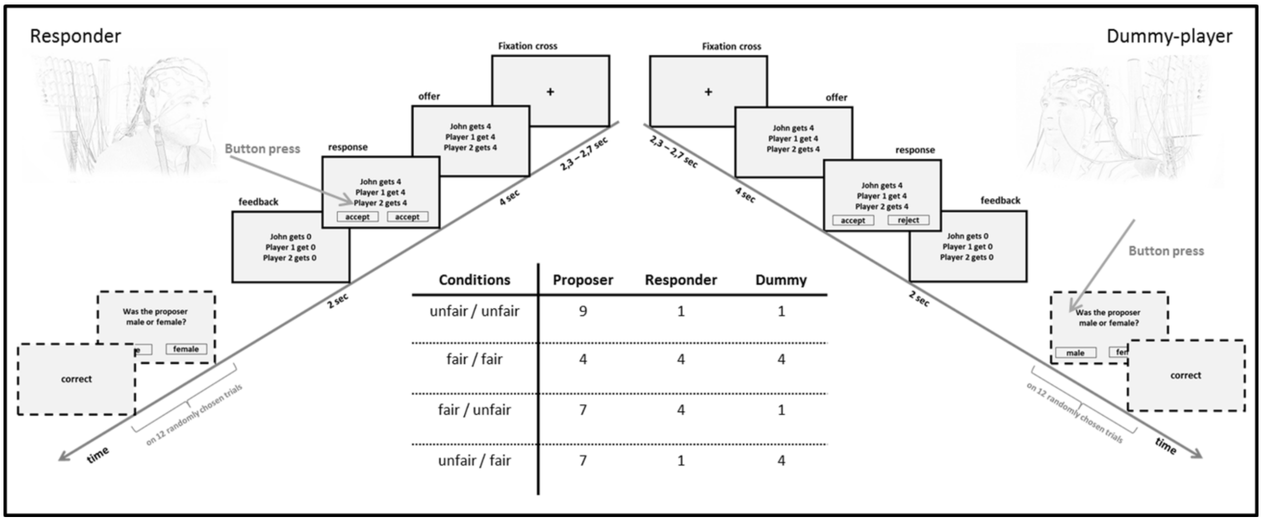
The study was conducted in accordance with the *Declaration of Helsinki* (1973, revised in 1983) and local guidelines and regulations of the University of Vienna and the Faculty of Psychology. Written informed consent was obtained prior to the experiment.

2.2 Justice Sensitivity

Individual differences in the perception of justice were measured using the Justice Sensitivity Inventory (Schmitt et al., 2004; 2010). This 40 item questionnaire encompasses justice sensitivity from four different perspectives: the victim, the observer, the perpetrator and the beneficiary. Each of the four subscales is covered by 10 questions that participants have to answer on a six-point Likert scale ranging from 0 to 5. Correlations between socially desirable and undesirable traits (Schmitt et al., 2004) as well as results from social bargaining games suggest that observer and beneficiary sensitivity reflect the degree to which a person is concerned about injustice towards others (Fetchenhauer and Huang, 2004). High scores on the domain victim sensitivity reflect concerns for justice towards oneself and are related to rather selfish behavior (Gollwitzer et al., 2009).

2.3 Stimulus Material

Altogether 324 proposals representing different divisions of the amount of 12, 15 or 18 Euros between the three players were presented. Half of these proposals were generated by the computer; the other half was provided by human proposers collected pre-experimentally (for details see Alexopoulos et al., 2012). In each of the two condition (computer/human proposer) subjects received 27 fair offers (1/3 of the total amount for each player), 27 offers twice with an unfair share for one player only (receiving less than 15 %, whereas the other one received 1/3), and further 27 offers with an unfair share for both receivers. In addition, 54 offers were presented that did not meet any of the previous criteria and were therefore excluded from further analysis. In all condition the proposers allocated at least 1/3 of the total amount to themselves (see Fig.1 for examples of the different categories).



Conditions	Proposer	Responder	Dummy
unfair / unfair	9	1	1
fair / fair	4	4	4
fair / unfair	7	4	1
unfair / fair	7	1	4

Figure 1| Schematic representation of the three-person UG. Structure of a single trial (for detailed description see text) and the four conditions each with an exemplary allocation.

In accordance with our previous study (Alexopoulos et al., 2012) the presentation of these proposals, written in German (light gray background, black font color), consisted of three lines: the first line contained the amount the proposer (e.g. “John gets 4€”) or the computer (e.g. “The computer gets 4€”) wanted to keep, the second indicated the amount the responder, i.e., the participant, would receive (e.g. “Player 1 gets 4€”), and the third line indicated the amount the third player would get (e.g. “Player 2 gets 4€”). Offers were presented in six blocks with rest periods of varying duration in between. During these breaks both players were presented with the photographs of the proposers of the subsequent trials. Stimulus presentation was controlled by a Pentium IV 3.00 GHz computer using E-prime software (E-prime 2.0, Psychology Software Tools, Inc., Sharpsburg, Maryland).

2.4 Paradigm and Procedure

Participants were invited in gender-matched pairs. Upon arrival we ensured that these pairs were not acquainted with one another in any way. Then they were informed about the further procedure, received written instructions concerning the nature of three-person UG and were prepared for EEG recordings. In order to increase the feasibility of this setup and to emphasize that half of the proposals were made by human agents, both were shown the completed questionnaires of the proposers and were informed that they themselves, as well as the other players, would receive the amount of money they earned on four randomly chosen trials in their respective roles in this game. The roles (i.e., dummy-player or responder) were randomly assigned.

Throughout the experiment, the two sat opposite each other without visible contact in a sound-attenuated and dimly lit room. Both participants were seated in front of a 19-inch cathode ray tube monitor and were about 1.2 m apart from each other.

Each block of trials started with the introduction of the proposers, followed by 54 offers which had to be accepted or rejected by the subjects in the role of the responder (Fig. 1). Trials were pseudo-randomized, hence each block contained the same number of human and computer offers. Offers were presented for 4000ms followed by two squares apparent below the offer, each either containing the word “accept” or “reject”. These two alternatives changed their position randomly among the trials. Responders were instructed to press the corresponding button of a response pad (PST Serial Response Box by Psychology Software Tools, Inc.) with their right hand to indicate the chosen alternative. Subsequently feedback was given for the duration of 2000ms. The format of the feedback was similar to the offer and indicated the actual allocation. Trials were separated by a variable inter-trial interval with a duration of 2300ms to 2700ms during which a black fixation cross was presented. At the end of each block participants were informed about the amount of money they had gained so far followed by the introduction of the subsequent proposers. To maintain the attention of the other participant, i.e., the third player, twelve randomly chosen trials were followed by questions concerning the current offer (e.g.: 'Was the proposer male or female?'). Below these questions two squares appeared, each of which either contained the word "yes" or "no" and subjects in the role of the third player had to press the corresponding button to answer. For every correct answer both subjects received 0.50 Euros additional to the outcome of four randomly chosen trials.

2.5 Electrophysiological recordings

EEG data from both subjects were recorded via 61 Ag/AgCl equidistantly located scalp electrodes embedded in an elastic cap (EASYCAP GmbH, Herrsching, Germany; montage M10), referenced to non-cephalic balanced sterno-vertebral electrodes (Stephenson and Gibbs, 1951). For eye movement artifact correction vertical and horizontal electro-oculograms (VEOG, HEOG) were recorded bipolarily from above and below the left eye (VEOG), and from right and left outer canthi (HEOG). The subjects' skin was slightly scratched with a sterile needle at all recording sites in order to minimize skin potential artifacts and to ascertain homogeneous electrode impedances below 2 kΩ. Simultaneously recorded signals were amplified using two separate DC-amplifiers with high baseline stability and an input impedance of 100 GΩ (Ing. Kurt Zickler GmbH, Pfaffstätten, Austria). Signals were digitized with a 1 kHz sampling rate and recorded within a frequency range from DC to 250 Hz. Synchronization of data collection was achieved using an external signal generator synchronizing the two DC-amplifiers.

2.6 Data preprocessing

Eye movement and blink artifacts were first eliminated using a linear regression approach on the basis of parameters obtained in pre-experimental calibration trials (Bauer and Lauber, 1979). Epochs of 1000ms, 800ms following stimulus (offer) onset and 200ms preceding the onset, were extracted for the conditions fair/fair, unfair/unfair, fair/unfair, and unfair/fair (see Fig.1). For further data processing EEGLAB 6.03b was used (Delorme and Makeig, 2004). The 800ms epochs were aligned to the 200ms baseline preceding the presentation of the offer. Subsequently, data were down-sampled to 250 smp/s, low pass filtered (6dB/octave slope) at

30 Hz cutoff, and linear trends were removed. To further improve data quality, e.g. correcting for artifacts occurring repeatedly, we followed the approach suggested by Delorme and colleagues (2007) which we already used and described in details in Alexopoulos et al. (2012).

2.7 Data analysis

Based on visual inspection of grand-averaged waveforms, scalp potential topography of difference waves, and in accordance with previous literature, the MFN was quantified as the average baseline corrected mean amplitude value in the time range between 220 and 280ms after stimulus onset at electrode Fcz, Cz, and Pz (Alexopoulos et al., 2012; Boksem et al., 2012). Though, statistical analyses revealed similar results for all electrodes; reported results are based on Cz since this electrode gave the highest effect sizes. To reduce confounding effects of other ERP components on the amplitude of the MFN and to scrutinize potential differences in processing of the outcome for the other recipient, we created difference waves. These difference waves were constructed by subtracting ERPs following fair offers from unfair offers towards the respective other, while the level of fairness towards oneself was kept constant. This way we obtained two difference waves for each player: (1) *Self* fair, *Other* unfair minus fair, and (2) *Self* unfair, *Other* unfair minus fair. Subsequently we extracted the mean amplitude value between 220 and 280ms after stimulus onset at electrode Cz.

Amplitude values of the MFN for the condition *human* and *computer* were submitted to 2x2 repeated measures ANOVAs with the factors *Self* (levels: fair and unfair share for oneself) and *Other* (levels: fair and unfair share for the other player) separately for both groups of subjects (responder and third player). All factors were defined as within-subject factors. To test whether difference waves are statistical different from zero a one-sample t-test was applied. To assess the relation between early neuronal processes and individual differences in justice sensitivity, MFN amplitudes, respectively the associated difference waves (unfair minus fair) at channel Cz were correlated with justice sensitivity scores (using Pearson correlation and two-tailed significance levels). Due to the low variability in acceptance rates we refrained from correlation analyzes of MFN amplitudes and decision behavior. For all analyses the significance threshold was set to $p \leq 0.05$. All statistical analyses were carried out with IBM SPSS Statistics 19 software (IBM Corp., Armonk, NY, USA).

3 Results

3.1 Performance

On average responders accepted 53 % (SD = 43.15) of the offers made by the computer, compared to 52 % (SD = 43.35) of offers made by human proposers. There was a statistically significant difference in acceptance rates depending on which type of offer was received, $\chi2(3) = 34.193$, $P = .000$. Post-hoc analysis with Wilcoxon Signed-Rank Tests was conducted with Bonferroni correction applied, resulting in a significance level set at $p<0.008$. Median (Interquartile range) acceptance rates for fair/fair, unfair/unfair, unfair/fair and fair/unfair offers were 96% (96-100); 0% (0-7), 33% (0-75) and 52% (24-97). Rejection rates were significantly higher for inequitable offers compared to equitable offers (for all comparisons $p<.001$). Offers with an unfair share for both players were rejected significantly more often than those which represented an unfair share to the dummy-player only.

3.2 ERP data

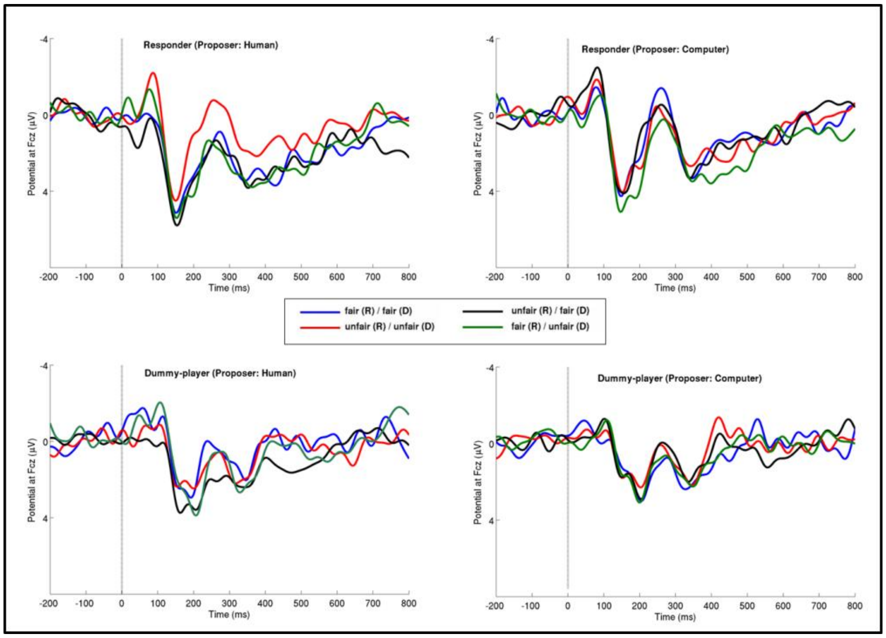


Figure 2| Grand average ERP waveforms for each recipient and proposer at Cz for the offers: fair/fair (blue line), unfair/unfair (red line), unfair/fair (black line), or fair/unfair (green line); format: responder/dummy-player. Negative is plotted up; Zeros on the timeline indicate the onset of the offer.

3.2.1 Responders

For the responders, mean MFN amplitudes in the time window 220 to 280ms after a proposal given by a human agent revealed no significant main effect for the factor *Self,* ($F(1, 15) = 1.056$, $p=.320$, partial $\eta^2=.066$) and the factor *Other* ($F(1, 15) = 1.644$, $p=.219$, partial $\eta^2=.099$). However, the interaction *(Self x Other)* was statistically significant ($F(1, 15) = 21.159$, $p=.000$, partial $\eta^2=.585$). Grand-average waveforms depicted in Figure 2 clearly show an increased MFN following offers with a low share for both recipients (unfair/unfair). Further analyses revealed that MFN amplitudes following this kind of offers were statistically significant compared to all other possible offers (for all $p < 0.04$). Likewise, only in cases when the responder received an unfair share the amplitudes of difference waves (unfair/unfair minus unfair/fair) were significantly different from zero (mean= -2.372µV, $t(15)=-4.592$, $p=.000$) (see Fig. 3). In case the responder received a fair share, however, no effect for high and low offers assigned to the dummy-player could be found (mean= 1.078µV, $t(15)=-1.490$, $p=.157$). The correlation analyzes of MFN difference waves and individual differences in justice sensitivity revealed a statistical relationship given by perpetrator sensitivity being negatively related to MFN amplitudes following proposals comprising unfair amounts towards the dummy-player ($r= -.574$, $p=.025$). Thus, responders who are concerned about injustice towards others exhibit larger, more negative going, MFN amplitudes following advantageous inequality (see Fig. 3).

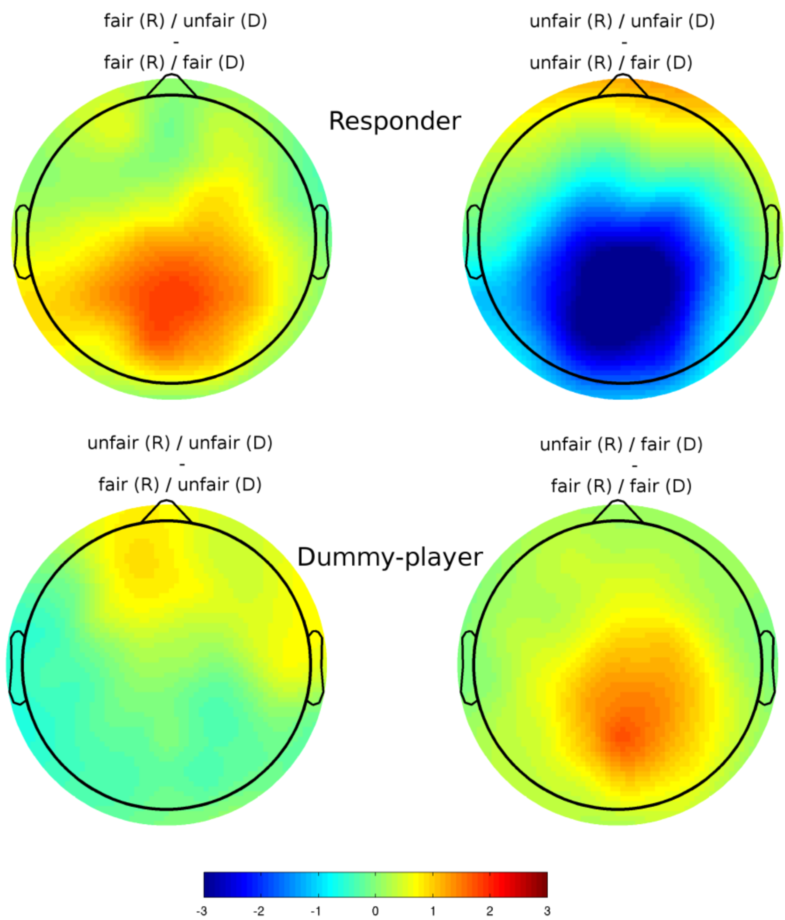


Figure 3| Scalp potential topography of the average voltage differences between fair and unfair offers for the other and the two levels of fairness towards oneself for the time point of the MFN (220 - 280ms following offer onset).

3.2.2 Dummy-player

Analysis of the mean MFN amplitudes for the dummy-players revealed a significant interaction effect for *Self* x *Other*, ($F(1, 15) = 8.891$, $p=.009$, partial $\eta^2=.372$) whereas, the factor *Self* ($F(1, 15) = .006$, $p =.938$, partial $\eta^2=.000$) and factor *Other* ($F(1, 15) = 4.008$, $p =.064$, partial $\eta^2=.211$) again did not reach significance. Grand-averaged waveforms (see Figure 2) of the dummy-players indicate that compared to all other possible offers, those offers with a low share for only the responders (unfair/fair) are associated with a diminished negative going component. Consequently, only in case the dummy-player received a fair share, statistically significant differences between unfair and fair offers towards the responder could be observed (mean= 2.245, $t(15)=4.324$, $p=.001$). In case the dummy-player received an unfair amount, no difference in MFN amplitudes associated with unfair compared to fair offer towards the responder could be observed (mean= -.286µV, $t(15)=-.378$, $p=.710$). Scalp distribution further evince that differences were largest over the central area and deviate in positive direction (see Fig. 3). The relation between justice sensitivity and MFN amplitudes was analyzed similar to the responders' data. Victim sensitivity was positively related to MFN amplitudes following offers with an unfair share for the responder, regardless of whether the dummy-player received a fair share ($r= .691$, $p=.003$) or an unfair share ($r=.554$, $p=.026$; see Fig. 4). Accordingly, dummy-players who were more concerned about injustice towards themselves exhibited larger positive going MFN amplitudes following unfair offers for the responder.

None of the statistical analyses applied to the ERP data associated with proposals made by the computer reached significance – neither for the responders ($p>.124$) nor for the dummy players ($p>.391$). Furthermore, we found no differences between the responders and the dummy-players with regard to justice sensitivity ($p>.296$ for all four scales).

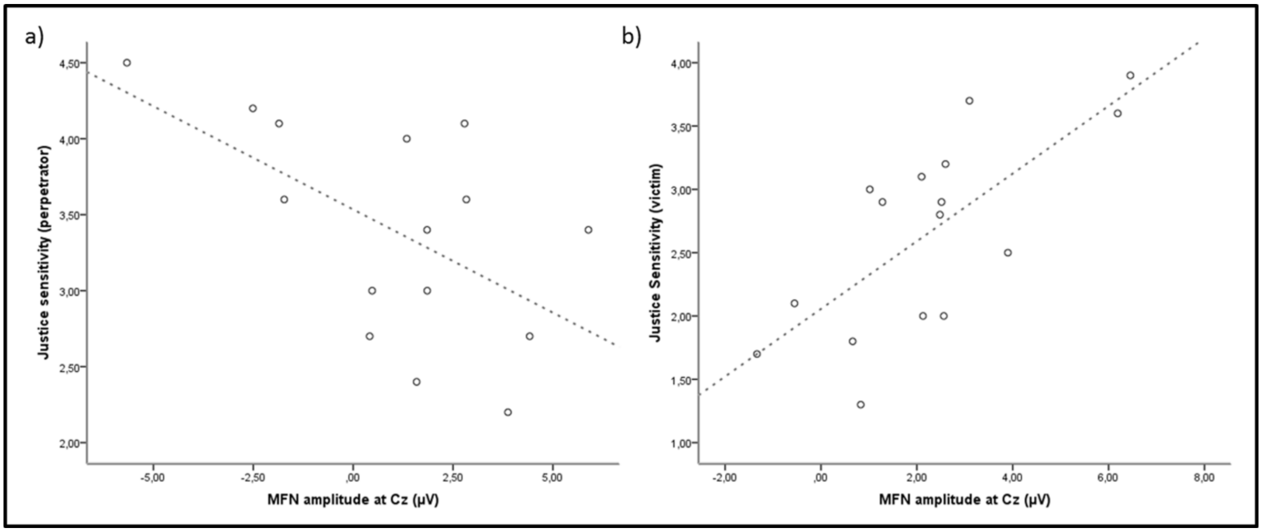


Figure 4| Correlation between Justice Sensitivity scores and the difference in MFN amplitude between fair and unfair offers towards the respective other each with fair shares for oneself a) MFN differences wave for fair and unfair offers towards the dummy-player and perpetrator sensitivity of the responders b) MFN differences wave for fair and unfair offers towards the responder and victim sensitivity of the dummy-player

4 Discussion

In contrast to previous studies in the current study two participants were recorded simultaneously while playing the three-person UG. Both participants played the part of the receivers with those in the role of the dummy-player having no say. The responders, on the other side, had veto power and thus, were able to harm the payoff of all other players. These differences in power became apparent already about 250ms after the onset of the different offers. For both participants a difference in MFN amplitude depending on the share assigned to the respective other can be reported. In line with previous literature MFN amplitudes elicited by unfair offers were more negative going than those elicited by fair offers, but this only applied for the responders. The dummy-players showed to some extend the opposite pattern; unfair offers compared to fair offers towards the responder were followed by positive-going amplitudes within the time range of the MFN.

The amplitude of the MFN is associated with the subjective value assigned to a certain situation (Holroyd and Coles, 2008; Rigoni et al., 2010); whereas, value is derived by comparative processes. Thus, expectations or prior experience and available options change the absolute value of a given reward and the associated MFN amplitude. Several studies have shown that social processes are also reflected in the amplitude of the MFN (for review see Thoma and Bellebaum, 2012). For instance, a recent attempt to investigate MFN amplitude changes in the context of the three-person UG found that responders did not differentiate between fair and unfair offers assigned to the dummy-player (Alexopoulos et al., 2012). Nevertheless, offers that clearly favored the dummy-player opposed to the subjects themselves were followed by the most pronounced MFN amplitudes. In contrast, offers that were equally unfair for both – the dummy-player and the responder – did not reveal distinct MFN amplitudes. Being speculative, anger towards the proposer and envy towards the dummy-player may have led to the increase in amplitude. In contrast to the present study these two recipients were anonymous to each other. We assume that the change in experimental setup has led to the observed differences in the ERP patterns of the responders. In the present study offers with an equally low share for the two recipients elicited the most pronounced, negative going, amplitude at the time a MFN is usually observed. This suggests that offers comprising a fair share for at least one of the two recipients are evaluated nearly as satisfying as offers with an equally high share for all three players. Furthermore, responders clearly differentiated between high and low offers assigned to the dummy-player, with low offers leading to a more negative going MFN, at least when they themselves received an unfair share as well.

It is well known that pre-play communication enforces cooperation in social dilemma games or bargaining games, respectively (for a survey see Crawford, 1998 or; Greiner et al., 2005 investigating pre-play communication in the three-person UG). In line with this finding there are at least two explanations for the changes in MFN amplitudes: Strategic issues, since the reputation of the responder is at risk, or changes in utility, since group identity enhances "we" feelings among group members, commonly summarized as emphatic concerns (Greiner et al., 2010). Recent efforts in the field of social neuroscience provide evidence that empathy is modulated by perceived group membership (Hein et al., 2010) and that empathy-related processes are expressed in the appearance of the MFN. Receiving negative feedback is associated with an increase in MFN amplitude, observing someone else receiving negative feedback similarly elicits a MFN whereas, the magnitude depends on the perceived similarity with the other (Carp et al., 2009), the closeness (Kang et al., 2010), self-reported levels of empathy (Fukushima and Hiraki, 2009), and the degree to which participants include others in their self-concept (Kang, 2010 (Kang et al., 2010). Since the MFN is supposed to be generated in the ACC, the fact that the ACC is a key structure implicated in the empathic response to physical and social pain of others (Singer et al., 2004; Masten et al., 2011), further suggests that empathic concerns over strategic issues have influenced the appearance of the MFN. This view is further supported by the relation between justice sensitivity and MFN amplitudes found in the present study.

Even though MFN amplitudes did not differentiate between high and low offers assigned to the dummy-player in cases were responders received a high share, the mean amplitude of MFN difference waves varied with the degree to which subjects reported to be concerned about injustice towards others. Boksem and DeCremer (2010) already reported that MFN amplitudes following unfair offers in the standard UG varied with self-reported concerns for fairness and honesty.

In the present study the degree to which responders included the share for the dummy-player when they themselves received a fair share in the evaluation process, similarly varied with their concerns for fairness. Responders scoring high on perpetrator sensitivity exhibited larger MFN amplitudes following advantageously unequal offers. Perpetrator sensitivity is highly related to socially desirable traits as well as to cooperative behavior in social dilemma games (Schmitt et al., 2004; Gollwitzer et al., 2005). Since perpetrator sensitivity focuses on situations where people actively take advantage of another party, it is assumed to be linked to feelings of guilt (Thomas et al., 2010). Hence, discomfort caused by actively contributing to injustice might be reflected in higher, more negative-going, MFN amplitudes in response to unfair offers towards the dummy-player. In other words, feelings of guilt might reduce the value of the relatively high share assigned to the responder in light of a low, unfair share towards the dummy-players.

However, also MFN amplitudes of the participants playing in the role of the dummy-players were related to justice sensitivity though, a somewhat different picture is emerging. First of all the dummies´ MFN amplitudes, though differing with respect to the outcome of the responder, were more pronounced for fair than unfair offers towards the responder. This is in contrast of what one would expect considering the data of the responders. Nevertheless, Marco-Pallares and colleagues (2010) showed that in a competitive setting observing someone else receiving a gain led to higher, more negative-going MFN amplitudes, whereas in neutral conditions MFN amplitudes were higher following losses as compared to gains of the performer. Second, offers with low shares for the responder and high shares for the dummy-player elicited a MFN difference wave significantly different from zero, but again with positive polarity. Furthermore, the higher the scores of the dummy-players were on the victim sensitivity scale, the more positive amplitudes following low offers for the responders could be observed. Victim sensitivity covers situations associated with injustice towards oneself and is related to socially undesirable traits like vengeance, jealousy and distrust. In bargaining games victim sensitive individuals tend to be less cooperative, i.e., they offer less in the UG or dictator game. The dummy-players are at a disadvantage from the outset, because they have no influence on the proposed allocation. This might have led to the finding that advantageous, unequal offers are more favorable than any other possible offer and even more so in subjects who are generally more concerned about fairness towards themselves. Furthermore, dummy-players might have anticipated receiving lower offers than the responders, therefore high offers for the dummy-player were an unexpected reward leading to a reduction in MFN amplitude.

To conclude, the change in setting clearly affected the way responders processed offers towards the powerless third. Contrary to our previous study where the responders reacted mere selfish, the presence of the dummy-player seemed to enforce “we” feelings and empathic concerns. This was shown by differences in the maximum negative MFN amplitudes. Likewise the responders in the anonymous setting, the powerless players exhibited negative social preferences. While there are parallels between those two, there are also substantial differences: Responders in the anonymous setting preferred all possible offers over those that assigned a low share to themselves and a high share towards the other. Therefore, we assumed that envy might play a crucial role. In contrast, the powerless players preferred offers with low shares towards the responder and high shares towards themselves, which might be more closely related to spite.

In the present study we have shown that the influence of agency and physical distance on social preferences can already be observed at an early neural level. Nevertheless, participants were unfamiliar to each other prior to the experiment and we did not control for sympathy, future research has to show how the level of familiarity or sympathy will further enforce this “we” feelings.

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Concept and design: JA, FF. Execution: JA, FF, and DMP. Data analyses: JA, DMP, and FF. Manuscript: JA, DMP, HB, and FF. HB supervised the project.

References

Alexopoulos, J., Pfabigan, D. M., Lamm, C., Bauer, H., & Fischmeister, F. P. (2012). Do we care about the powerless third? An ERP study of the three-person ultimatum game. Frontiers in Human Neuroscience, 6, 59.

Bauer, H., & Lauber, W. (1979). Operant conditioning of brain steady potential shifts in man. Applied Psychophysiology and Biofeedback, 4, 145-154.

Ben-Ze'ev, A. (2000). The Subtlety of Emotions: The MIT Press.

Boksem, M. A., & De Cremer, D. (2010). Fairness concerns predict medial frontal negativity amplitude in ultimatum bargaining. Social neuroscience, 5, 118-128.

Boksem, M. A., Kostermans, E., Milivojevic, B., & De Cremer, D. (2012). Social status determines how we monitor and evaluate our performance. Social Cognitive and Affective Neuroscience, 7, 304-313.

Cameron, L. A. (1999). Raising the Stakes in the Ultimatum Game: Experimental Evidence from Indonesia. Economic Inquiry, 37, 47-59.

Carp, J., Halenar, M. J., Quandt, L. C., Sklar, A., & Compton, R. J. (2009). Perceived similarity and neural mirroring: evidence from vicarious error processing. Social neuroscience, 4, 85-96.

Crawford, V. (1998). A Survey of Experiments on Communication via Cheap Talk. Journal of Economic Theory, 78, 286-298.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. Journal of neuroscience methods, 134, 9-21.

Donkers, F. C., Nieuwenhuis, S., & van Boxtel, G. J. (2005). Mediofrontal negativities in the absence of responding. Brain research. Cognitive brain research, 25, 777-787.

Festinger, L. (1954). A theory of social comparison processes. HUman Relations, 7, 117-140.

Fetchenhauer, D., & Huang, X. (2004). Justice sensitivity and distributive decisions in experimental games. Personality and Individual Differences, 36, 1015-1029.

Fukushima, H., & Hiraki, K. (2009). Whose loss is it? Human electrophysiological correlates of non-self reward processing. Social neuroscience, 4, 261-275.

Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. Science, 295, 2279-2282.

Gollwitzer, M., Rothmund, T., Pfeiffer, A., & Ensenbach, C. (2009). Why and when justice sensitivity leads to pro- and antisocial behavior. Journal of Research in Personality, 43, 999-1005.

Gollwitzer, M., Schmitt, M., Schalke, R., Maes, J., & Baer, A. (2005). Asymmetrical Effects of Justice Sensitivity Perspectives on Prosocial and Antisocial Behavior. Social Justice Research, 18, 183-201.

Gospic, K., Mohlin, E., Fransson, P., Petrovic, P., Johannesson, M., & Ingvar, M. (2011). Limbic justice--amygdala involvement in immediate rejection in the Ultimatum Game. PLoS biology, 9, e1001054.

Grabenhorst, F., & Rolls, E. T. (2011). Value, pleasure and choice in the ventral prefrontal cortex. Trends in cognitive sciences, 15, 56-67.

Greiner, B., Güth, W., & Zultan, R. (2005). Let the Dummy Talk! - Unilateral Communication and Discrimination in Three-Person Dictator Experiments. Cologne: Department of Economics.

Greiner, B., Güth, W., & Zultan, R. (2010). Social Communication and Discrimination: A Video Experiment: Max-Planck-Institute of Economics.

Guroglu, B., van den Bos, W., van Dijk, E., Rombouts, S. A., & Crone, E. A. (2011). Dissociable brain networks involved in development of fairness considerations: understanding intentionality behind unfairness. Neuroimage, 57, 634-641.

Güth, W., Schmidt, C., & Sutter, M. (2007). Bargaining outside the lab - a newspaper experiment of a three-person ultimatum game. Economic Journal, 117, 449-469.

Güth, W., Schmittberger, R., & Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. Journal of Economic Behavior & Organization, 3, 367-388.

Güth, W., & Van Damme, E. (1998). Information, Strategic Behavior, and Fairness in Ultimatum Bargaining: An Experimental Study. Journal of Mathematical Psychology, 42, 227-247.

Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. Biological psychology, 71, 148-154.

Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2007). It's worse than you thought: the feedback negativity and violations of reward prediction in gambling tasks. Psychophysiology, 44, 905-912.

Hein, G., Silani, G., Preuschoff, K., Batson, C. D., & Singer, T. (2010). Neural responses to ingroup and outgroup members' suffering predict individual differences in costly helping. Neuron, 68, 149-160.

Hewig, J., Kretschmer, N., Trippe, R. H., Hecht, H., Coles, M. G., Holroyd, C. B., & Miltner, W. H. (2011). Why humans deviate from rational choice. Psychophysiology, 48, 507-514.

Holroyd, C. B., & Coles, M. G. (2008). Dorsal anterior cingulate cortex integrates reinforcement history to guide voluntary behavior. Cortex; a journal devoted to the study of the nervous system and behavior, 44, 548-559.

Holroyd, C. B., Hajcak, G., & Larsen, J. T. (2006). The good, the bad and the neutral: electrophysiological responses to feedback stimuli. Brain research, 1105, 93-101.

Kang, S. K., Hirsh, J. B., & Chasteen, A. L. (2010). Your mistakes are mine: Self-other overlap predicts neural response to observed errors. Journal of Experimental Social Psychology, 46, 229-232.

Kennerley, S. W., Behrens, T. E. J., & Wallis, J. D. (2011). Double dissociation of value computations in orbitofrontal and anterior cingulate neurons. Nature Neuroscience, 14, 1581-1589.

Kennerley, S. W., Dahmubed, A. F., Lara, A. H., & Wallis, J. D. (2009). Neurons in the frontal lobe encode the value of multiple decision variables. Journal of cognitive neuroscience, 21, 1162-1178.

Kirk, U., Downar, J., & Montague, P. R. (2011). Interoception drives increased rational decision-making in meditators playing the Ultimatum Game. Frontiers in Neuroscience, 5.

Luk, C. H., & Wallis, J. D. (2009). Dynamic encoding of responses and outcomes by neurons in medial prefrontal cortex. The Journal of neuroscience : the official journal of the Society for Neuroscience, 29, 7526-7539.

Luu, P., Tucker, D. M., Derryberry, D., Reed, M., & Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. Psychological Science, 14, 47-53.

Marco-Pallares, J., Kramer, U. M., Strehl, S., Schroder, A., & Munte, T. F. (2010). When decisions of others matter to me: an electrophysiological analysis. BMC Neuroscience, 11, 86.

Martin, L. E., Potts, G. F., Burton, P. C., & Montague, P. R. (2009). Electrophysiological and hemodynamic responses to reward prediction violation. Neuroreport, 20, 1140-1143.

Masten, C. L., Morelli, S. A., & Eisenberger, N. I. (2011). An fMRI investigation of empathy for 'social pain' and subsequent prosocial behavior. Neuroimage, 55, 381-388.

Miltner, W. H. R., Braun, C. H., & Coles, M. G. H. (1997). Event-Related Brain Potentials Following Incorrect Feedback in a Time-Estimation Task: Evidence for a “Generic” Neural System for Error Detection. Journal of cognitive neuroscience, 9, 788-798.

Munier, B., & Costin, Z. (2002). High Stakes and Acceptance Behavior in Ultimatum Bargaining: A Contribution from an International Experiment. Theory and Decision, 53, 187-207.

Nguyen, C. M., Koenigs, M., Yamada, T. H., Teo, S. H., Cavanaugh, J. E., Tranel, D., & Denburg, N. L. (2011). Trustworthiness and negative affect predict economic decision making. Journal of Cognitive Psychology, 23, 748-759.

Nieuwenhuis, S., Holroyd, C. B., Mol, N., & Coles, M. G. (2004). Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. Neurosci Biobehav Rev, 28, 441-448.

Nieuwenhuis, S., Yeung, N., Holroyd, C. B., Schurger, A., & Cohen, J. D. (2004). Sensitivity of Electrophysiological Activity from Medial Frontal Cortex to Utilitarian and Performance Feedback. Cerebral cortex, 14, 741-747.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia, 9, 97-113.

Pfabigan, D. M., Alexopoulos, J., Bauer, H., & Sailer, U. (2011). Manipulation of feedback expectancy and valence induces negative and positive reward prediction error signals manifest in event-related brain potentials. Psychophysiology, 48, 656-664.

Potts, G. F., Martin, L. E., Burton, P., & Montague, P. R. (2006). When things are better or worse than expected: the medial frontal cortex and the allocation of processing resources. Journal of cognitive neuroscience, 18, 1112-1119.

Rigoni, D., Polezzi, D., Rumiati, R., Guarino, R., & Sartori, G. (2010). When people matter more than money: an ERPs study. Brain Res Bull, 81, 445-452.

Rilling, J. K., & Sanfey, A. G. (2011). The neuroscience of social decision-making. Annual Review Psychology, 62, 23-48.

Rolls, E. T. (2005). Emotion Explained: Oxford University Press.

Sanfey, A. G., Rilling, J. K., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2003). The neural basis of economic decision-making in the Ultimatum Game. Science, 300, 1755-1758.

Schmitt, M., Baumert, A., Gollwitzer, M., & Maes, J. (2010). The Justice Sensitivity Inventory: Factorial Validity, Location in the Personality Facet Space, Demographic Pattern, and Normative Data. Social Justice Research, 23, 211-238.

Schmitt, M., Gollwitzer, M., & Arbach, D. (2004). Justice sensitivity : assessment and location in the personality space. Saarbrücken: Universitäts- und Landesbibliothek.

Schultz, W. (2006). Behavioral theories and the neurophysiology of reward. Annual Review Psychology, 57, 87-115.

Seo, H., & Lee, D. (2007). Temporal filtering of reward signals in the dorsal anterior cingulate cortex during a mixed-strategy game. The Journal of neuroscience : the official journal of the Society for Neuroscience, 27, 8366-8377.

Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. Science, 303, 1157-1162.

Slonim, R., & Roth, A. E. (1998). Learning in High Stakes Ultimatum Games: An Experiment in the Slovak Republic. Econometrica, 66, 569-596.

Stephenson, W. A., & Gibbs, F. A. (1951). A balanced non-cephalic reference electrode. Electroencephalography and clinical neurophysiology, 3, 237-240.

Thaler, R. H. (1988). Anomalies: The Ultimatum Game. Journal of Economic Perspectives, 2, 195-206.

Thoma, P., & Bellebaum, C. (2012). Your error?s got me feeling - How empathy relates to the electrophysiological correlates of performance monitoring. Frontiers in Human Neuroscience, 6.

Thomas, N., Baumert, A., & Schmitt, M. (2010). Justice Sensitivity as a Risk and Protective Factor in Social Conflicts. In E. Kals & J. Maes (Eds.), Justice and Conflicts. Theoretical and Empirical Contributions (pp. 107-120): Springer-Verlag Berlin Heidelberg.

Vogt, B. A., Finch, D. M., & Olson, C. R. (1992). Functional Heterogeneity in Cingulate Cortex: The Anterior Executive and Posterior Evaluative Regions. Cerebral cortex, 2, 435-443.

Wessel, J. R., Danielmeier, C., Morton, J. B., & Ullsperger, M. (2012). Surprise and error: common neuronal architecture for the processing of errors and novelty. The Journal of neuroscience : the official journal of the Society for Neuroscience, 32, 7528-7537.

Wu, Y., Zhou, Y., van Dijk, E., Leliveld, M. C., & Zhou, X. (2011). Social Comparison Affects Brain Responses to Fairness in Asset Division: An ERP Study with the Ultimatum Game. Front Hum Neurosci, 5, 131.

7 Conclusion and Outlook

There is comprehensive evidence that humans do not necessarily act in a rational, profit maximizing way in strategic social interactions. For instance, they give up money, or even invest money to punish others without a recognizable benefit for themselves. This observation has led to the awareness that humans do not solely care about their own material payoff, but also about the payoff others receive. Nevertheless, since most studies focused on two-person strategy games, it is unclear whose payoff people care about. Within the scope of this work, it was shown that people do care about the powerless third; however, whether they exhibit positive or negative *social preferences* depends on physical proximity. As indicated by the amplitude of the MFN, in a complete anonymous condition responders did not differentiate between fair and unfair offers towards the powerless third. Whereas, unfair offers compared to fair offers towards themselves were followed by more pronounced MFN amplitudes. When players were seated in the same room and EEG was recorded simultaneously, an interaction between treatment of oneself and the respective other was found for both participants (players). Whereas, responders preferred all offers were at least one of the two received a fair amount, dummy-players favored offers where they received more than the responder.

In the present project only the two extremes, complete anonymity and sitting in the same room with previous communication, had been investigated. Nevertheless, it is unclear at what time the direction of *social preferences* changes. In regard to the economic models discussed in chapter 2, results related to early neural processing clearly favor the model of Fehr and Schmidt (1999) over the ERC model proposed by Bolton and Ockenfels (2000). This is supported by the observation that at least at an early stage of evaluation responders cared about the payoff of each and every other player and not just about whether they received 1/3 of the total amount. However, and this holds for both models, inequity aversion may only play a subordinate role during early neural processing. Since neither results of the responders nor the dummy-players could evidence that humans devalue a reward if it has been unevenly distributed: for instance, the dummy-players even favored an advantageous, unequal offer.

In paper II we discussed the results of both studies and came to the conclusion that physical distance and agency, respectively power, changed the direction of *social preferences*. Nevertheless, there is one important issue that has not been addressed yet. By now, several neuroimaging studies have shown that closeness and similarity between players changed the degree of empathic concerns. In the present project or particularly in the second study we did not control for these variables. However, especially those factors could have a significant influence on the direction of *social preferences* and should be investigated in future studies.

Besides the social relationship between participating players, personality also plays a crucial role in social interactions. Though several studies have shown that demographic variables, intellectual abilities, and socio-economic status do not modulate behavior in this game (Güth et al., 2007; Nguyen et al., 2011), there is strong variability in behavior related to state affect, personality characteristics and attachment behavior. For instance individuals with higher levels of cognitive control are less likely to reject unfair offers (De Neys et al., 2011). Similarly, anxiously attached individuals (Almakias and Weiss, 2012) and suffering responders increase their acceptance rate (Mancini et al., 2011). On the other hand, individuals with high levels of self-esteem are supposed to demand more and hence, reject low offers more frequently (Dunn et al., 2010). Impulsiveness and anger are further factors leading to higher rejection rates in the ultimatum game (Pillutla and Murnighan, 1996; Crockett et al., 2010). Anger and contempt are supposed to underlie irrational decision making whereas higher levels of trust and the belief in good intentions of others lead to more rational behavior (Nguyen et al., 2011). Scheres and Sanfey (2006) used the Behavioral Activation System (BAS) to look for individual differences in the ultimatum game. The BAS consists of three scales: (1) Reward responsiveness, measuring positive responses to the occurrence of reward, (2) drive, measuring the persistent pursuit of a desired goal and (3) fun seeking. They found that higher scores in the drive scale corresponded to higher offers in the ultimatum game, lower offers in the dictator game, and a larger discrepancy between the offers in the two games. Additionally, high scores in the reward responsiveness scale corresponded to lower offers in the dictator game and a larger discrepancy between the two games. For the fun seeking scale they found no significant correlation. The authors assume that individuals with high scores in the reward responsiveness scale and the drive scale use a certain strategy in these games. They first seek to maximize the likelihood of reward and in the next step seek to maximize the size of the reward.

Though, or perhaps because, results are very diverging, personality could as well determine whether a person exhibits positive or negative *social preferences* and should be assessed in future studies.

Complete list of references

Adolphs, R., Tranel, D., and Damasio, A.R. (1998). The human amygdala in social judgment. *Nature* 393**,** 470-474.

Adolphs, R., Tranel, D., Damasio, H., and Damasio, A. (1995). Fear and the human amygdala. *The Journal of Neuroscience* 15**,** 5879-5891.

Aharon, I., Etcoff, N., Ariely, D., Chabris, C.F., O'connor, E., and Breiter, H.C. (2001). Beautiful faces have variable reward value: fMRI and behavioral evidence. *Neuron* 32**,** 537-551.

Alexopoulos, J., Pfabigan, D.M., Lamm, C., Bauer, H., and Fischmeister, F.P. (2012). Do we care about the powerless third? An ERP study of the three-person ultimatum game. *Frontiers in human neuroscience* 6**,** 59.

Almakias, S., and Weiss, A. (2012). Ultimatum Game behavior in light of attachment theory. *Journal of Economic Psychology* 33**,** 515-526.

Baker, T.E., and Holroyd, C.B. (2011). Dissociated roles of the anterior cingulate cortex in reward and conflict processing as revealed by the feedback error-related negativity and N200. *Biological psychology* 87**,** 25-34.

Barclay, P. (2008). Enhanced recognition of defectors depends on their rarity. *Cognition* 107**,** 817-828.

Bauer, H., and Lauber, W. (1979). Operant conditioning of brain steady potential shifts in man. *Applied Psychophysiology and Biofeedback* 4**,** 145-154.

Baxter, M.G., and Murray, E.A. (2002). The amygdala and reward. *Nat Rev Neurosci* 3**,** 563-573.

Bechara, A., Damasio, H., Damasio, A.R., and Lee, G.P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 19**,** 5473-5481.

Bell, A.J., and Sejnowski, T.J. (1995). An Information-Maximization Approach to Blind Separation and Blind Deconvolution. *Neural Computation* 7**,** 1129-1159.

Bellebaum, C., and Daum, I. (2008). Learning-related changes in reward expectancy are reflected in the feedback-related negativity. *European Journal of Neuroscience* 27**,** 1823-1835.

Bellebaum, C., Polezzi, D., and Daum, I. (2010). It is less than you expected: the feedback-related negativity reflects violations of reward magnitude expectations. *Neuropsychologia* 48**,** 3343-3350.

Ben-Ze'ev, A. (2000). *The Subtlety of Emotions.* The MIT Press.

Blood, A.J., Zatorre, R.J., Bermudez, P., and Evans, A.C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nat Neurosci* 2**,** 382-387.

Boksem, M.A., and De Cremer, D. (2010). Fairness concerns predict medial frontal negativity amplitude in ultimatum bargaining. *Social neuroscience* 5**,** 118-128.

Boksem, M.A., Kostermans, E., and De Cremer, D. (2011). Failing where others have succeeded: Medial Frontal Negativity tracks failure in a social context. *Psychophysiology* 48**,** 973-979.

Boksem, M.A., Kostermans, E., Milivojevic, B., and De Cremer, D. (2012). Social status determines how we monitor and evaluate our performance. *Social Cognitive and Affective Neuroscience* 7**,** 304-313.

Bolton, G., E., and Ockenfels, A. (1997). "A Theory of Equity, Reciprocity, and Competition ", in: *Levine's Working Paper Archive.*).

Bolton, G., E., and Ockenfels, A. (2000). ERC: A Theory of Equity, Reciprocity, and Competition. *American Economic Review* 90**,** 166-193.

Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S., and Cohen, J.D. (2001). Conflict monitoring and cognitive control. *Psychological Review* 108**,** 624-652.

Breiter, H.C., Aharon, I., Kahneman, D., Dale, A., and Shizgal, P. (2001). Functional Imaging of Neural Responses to Expectancy and Experience of Monetary Gains and Losses. *Neuron* 30**,** 619-639.

Brennan, G., and Moehler, M. (2010). "Neoclassical Economics," in *Encyclopedia of Political Theory,* ed. M. Bevir. SAGE Publications), 946-951.

Bush, G., Vogt, B.A., Holmes, J., Dale, A.M., Greve, D., Jenike, M.A., and Rosen, B.R. (2002). Dorsal anterior cingulate cortex: a role in reward-based decision making. *Proc Natl Acad Sci U S A* 99**,** 523-528.

Camerer, C.F., Loewenstein, G., and Prelec, D. (2005). Neuroeconomics: How Neuroscience can inform economics. *Journal of Economic Literature* XLIII**,** 9-64.

Camerer, C.T., Richard, H. (1995). Anomalies: Ultimatums, Dictators and Manners. *The Journal of Economic Perspectives* 9**,** 209-219.

Cameron, L.A. (1999). Raising the Stakes in the Ultimatum Game: Experimental Evidence from Indonesia. *Economic Inquiry* 37**,** 47-59.

Cappelletti, D., Güth, W., and Ploner, M. (2008). Being of two minds: an ultimatum experiment investigating affective processess. *Jena Economic Research Papers* 2008-048.

Carlson, J.M., Foti, D., Mujica-Parodi, L.R., Harmon-Jones, E., and Hajcak, G. (2011). Ventral striatal and medial prefrontal BOLD activation is correlated with reward-related electrocortical activity: a combined ERP and fMRI study. *Neuroimage* 57**,** 1608-1616.

Carp, J., Halenar, M.J., Quandt, L.C., Sklar, A., and Compton, R.J. (2009). Perceived similarity and neural mirroring: evidence from vicarious error processing. *Social neuroscience* 4**,** 85-96.

Carr, L., Iacoboni, M., Dubeau, M.C., Mazziotta, J.C., and Lenzi, G.L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proc Natl Acad Sci U S A* 100**,** 5497-5502.

Carter, C.S., Botvinick, M.M., and Cohen, J.D. (1999). The contribution of the anterior cingulate cortex to executive processes in cognition. *Review Neuroscience* 10**,** 49-57.

Chang, L.J., and Sanfey, A.G. (2009). Unforgettable ultimatums? Expectation violations promote enhanced social memory following economic bargaining. *Frontiers in behavioral neuroscience* 3**,** 36.

Charness, G., and Rabin, M. (2002). Understanding Social Preferences With Simple Tests. *The Quarterly Journal of Economics, MIT Press* 117**,** 817-869.

Civai, C., Corradi-Dell'acqua, C., Gamer, M., and Rumiati, R.I. (2010). Are irrational reactions to unfairness truly emotionally-driven? Dissociated behavioural and emotional responses in the Ultimatum Game task. *Cognition* 114**,** 89-95.

Corradi-Dell'acqua, C., Civai, C., Rumiati, R.I., and Fink, G.R. (2012). Disentangling self- and fairness-related neural mechanisms involved in the ultimatum game: an fMRI study. *Soc Cogn Affect Neurosci*.

Crawford, V. (1998). A Survey of Experiments on Communication via Cheap Talk. *Journal of Economic Theory* 78**,** 286-298.

Crockett, M.J., Clark, L., Lieberman, M.D., Tabibnia, G., and Robbins, T.W. (2010). Impulsive choice and altruistic punishment are correlated and increase in tandem with serotonin depletion. *Emotion* 10**,** 855-862.

D'esposito, M., Detre, J.A., Alsop, D.C., Shin, R.K., Atlas, S., and Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature* 378**,** 279-281.

De Neys, W., Novitskiy, N., Geeraerts, L., Ramautar, J., and Wagemans, J. (2011). Cognitive control and individual differences in economic ultimatum decision-making. *PLoS One* 6**,** e27107.

Decety, J., Jackson, P.L., Sommerville, J.A., Chaminade, T., and Meltzoff, A.N. (2004). The neural bases of cooperation and competition: an fMRI investigation. *Neuroimage* 23**,** 744-751.

Dehaene, S., Posner, M.I., and Tucker, D.M. (1994). Localization of a Neural System for Error Detection and Compensation. *Psychological Science* 5**,** 303-305.

Delgado, M.R., Nystrom, L.E., Fissell, C., Noll, D.C., and Fiez, J.A. (2000). Tracking the hemodynamic responses to reward and punishment in the striatum. *Journal of neurophysiology* 84**,** 3072-3077.

Delorme, A., and Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods* 134**,** 9-21.

Donkers, F.C., Nieuwenhuis, S., and Van Boxtel, G.J. (2005). Mediofrontal negativities in the absence of responding. *Brain research. Cognitive brain research* 25**,** 777-787.

Dunn, B.D., Makarova, D., Evans, D., and Clark, L. (2010). "I'm worth more than that": trait positivity predicts increased rejection of unfair financial offers. *PLoS One* 5**,** e15095.

Elliott, R., Newman, J.L., Longe, O.A., and Deakin, J.F. (2003). Differential response patterns in the striatum and orbitofrontal cortex to financial reward in humans: a parametric functional magnetic resonance imaging study. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 23**,** 303-307.

Fehr, E., and Fischbacher, U. (2004). "Third Party Punishment and Social Norms", in: *Zurich IEER Working Paper.* (Zürich).

Fehr, E., and Schmidt, C. (2006). "The Economics of Fairness, Reciprocity and Altruism - Experimental Evidence and New Theories," in *Handbook on the Economics of Giving, Reciprocity and Altruism*. Elsevier), 615-691.

Fehr, E., and Schmidt, K.M. (1999). A Theory of Fairness, Competition, and Cooperation. *The Quarterly Journal of Economics* 114**,** 817-868.

Festinger, L. (1954). A theory of social comparison processes. *Human Relations* 7**,** 117-140.

Fetchenhauer, D., and Huang, X. (2004). Justice sensitivity and distributive decisions in experimental games. *Personality and Individual Differences* 36**,** 1015-1029.

Fliessbach, K., Phillipps, C.B., Trautner, P., Schnabel, M., Elger, C.E., Falk, A., and Weber, B. (2012). Neural responses to advantageous and disadvantageous inequity. *Front Hum Neurosci* 6**,** 165.

Fliessbach, K., Weber, B., Trautner, P., Dohmen, T., Sunde, U., Elger, C.E., and Falk, A. (2007). Social comparison affects reward-related brain activity in the human ventral striatum. *Science* 318**,** 1305-1308.

Fukushima, H., and Hiraki, K. (2006). Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity. *Soc Cogn Affect Neurosci* 1**,** 149-157.

Fukushima, H., and Hiraki, K. (2009). Whose loss is it? Human electrophysiological correlates of non-self reward processing. *Social neuroscience* 4**,** 261-275.

Geanakopolos, J., Pearce, D., and Stacchetti, E. (1989). Psychological Games and Sequential Rationality. *Games and Economic Behavior* 1**,** 60-79.

Gehring, W.J., Coles, M.G., Meyer, D.E., and Donchin, E. (1995). A brain potential manifestation of error-related processing. *Electroencephalogr Clin Neurophysiol Suppl* 44**,** 261-272.

Gehring, W.J., Goss, B., Coles, M.G.H., Meyer, D.E., and Donchin, E. (1993). A Neural System for Error Detection and Compensation. *Psychological Science* 4**,** 385-390.

Gehring, W.J., and Willoughby, A.R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* 295**,** 2279-2282.

Gollwitzer, M., Rothmund, T., Pfeiffer, A., and Ensenbach, C. (2009). Why and when justice sensitivity leads to pro- and antisocial behavior. *Journal of Research in Personality* 43**,** 999-1005.

Gollwitzer, M., Schmitt, M., Schalke, R., Maes, J., and Baer, A. (2005). Asymmetrical Effects of Justice Sensitivity Perspectives on Prosocial and Antisocial Behavior. *Social Justice Research* 18**,** 183-201.

Gospic, K., Mohlin, E., Fransson, P., Petrovic, P., Johannesson, M., and Ingvar, M. (2011). Limbic justice--amygdala involvement in immediate rejection in the Ultimatum Game. *PLoS biology* 9**,** e1001054.

Gottfried, J.A., Deichmann, R., Winston, J.S., and Dolan, R.J. (2002). Functional heterogeneity in human olfactory cortex: an event-related functional magnetic resonance imaging study. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 22**,** 10819-10828.

Grabenhorst, F., and Rolls, E.T. (2011). Value, pleasure and choice in the ventral prefrontal cortex. *Trends in cognitive sciences* 15**,** 56-67.

Greiner, B., Güth, W., and Zultan, R. (2005). "Let the Dummy Talk! - Unilateral Communication and Discrimination in Three-Person Dictator Experiments", in: *Working Paper Series in Economics.* (Cologne: Department of Economics).

Greiner, B., Güth, W., and Zultan, R. (2010). "Social Communication and Discrimination: A Video Experiment", in: *Jena Economic Research Papers.* Max-Planck-Institute of Economics).

Guroglu, B., Van Den Bos, W., Rombouts, S.A., and Crone, E.A. (2010). Unfair? It depends: neural correlates of fairness in social context. *Soc Cogn Affect Neurosci* 5**,** 414-423.

Guroglu, B., Van Den Bos, W., Van Dijk, E., Rombouts, S.A., and Crone, E.A. (2011). Dissociable brain networks involved in development of fairness considerations: understanding intentionality behind unfairness. *Neuroimage* 57**,** 634-641.

Güth, W., Schmidt, C., and Sutter, M. (2007). Bargaining outside the lab - a newspaper experiment of a three-person ultimatum game. *Economic Journal* 117**,** 449-469.

Güth, W., Schmittberger, R., and Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior & Organization* 3**,** 367-388.

Güth, W., and Van Damme, E. (1998). Information, Strategic Behavior, and Fairness in Ultimatum Bargaining: An Experimental Study. *Journal of Mathematical Psychology* 42**,** 227-247.

Hajcak, G., Moser, J.S., Holroyd, C.B., and Simons, R.F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biological psychology* 71**,** 148-154.

Hajcak, G., Moser, J.S., Holroyd, C.B., and Simons, R.F. (2007). It's worse than you thought: the feedback negativity and violations of reward prediction in gambling tasks. *Psychophysiology* 44**,** 905-912.

Hare, T.A., O'doherty, J., Camerer, C.F., Schultz, W., and Rangel, A. (2008). Dissociating the role of the orbitofrontal cortex and the striatum in the computation of goal values and prediction errors. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 28**,** 5623-5630.

Haruno, M., and Frith, C.D. (2010). Activity in the amygdala elicited by unfair divisions predicts social value orientation. *Nature Neuroscience* 13**,** 160-161.

Hein, G., Silani, G., Preuschoff, K., Batson, C.D., and Singer, T. (2010). Neural responses to ingroup and outgroup members' suffering predict individual differences in costly helping. *Neuron* 68**,** 149-160.

Hewig, J., Kretschmer, N., Trippe, R.H., Hecht, H., Coles, M.G., Holroyd, C.B., and Miltner, W.H. (2011). Why humans deviate from rational choice. *Psychophysiology* 48**,** 507-514.

Hoffman, E., Mccabe, K.A., and Smith, V.L. (1996). On Expectations and the Monetary Stakes in Ultimatum Games. *International Journal of Game Theory* 25**,** 289-301.

Holroyd, C.B., and Coles, M.G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychological Review* 109**,** 679-709.

Holroyd, C.B., and Coles, M.G. (2008). Dorsal anterior cingulate cortex integrates reinforcement history to guide voluntary behavior. *Cortex; a journal devoted to the study of the nervous system and behavior* 44**,** 548-559.

Holroyd, C.B., Hajcak, G., and Larsen, J.T. (2006). The good, the bad and the neutral: electrophysiological responses to feedback stimuli. *Brain research* 1105**,** 93-101.

Izuma, K., Saito, D.N., and Sadato, N. (2009). Processing of the Incentive for Social Approval in the Ventral Striatum during Charitable Donation. *Journal of cognitive neuroscience* 22**,** 621-631.

Jackson, P.L., Meltzoff, A.N., and Decety, J. (2005). How do we perceive the pain of others? A window into the neural processes involved in empathy. *Neuroimage* 24**,** 771-779.

Kang, S.K., Hirsh, J.B., and Chasteen, A.L. (2010). Your mistakes are mine: Self-other overlap predicts neural response to observed errors. *Journal of Experimental Social Psychology* 46**,** 229-232.

Kennerley, S.W., Behrens, T.E.J., and Wallis, J.D. (2011). Double dissociation of value computations in orbitofrontal and anterior cingulate neurons. *Nature Neuroscience* 14**,** 1581-1589.

Kennerley, S.W., Dahmubed, A.F., Lara, A.H., and Wallis, J.D. (2009). Neurons in the frontal lobe encode the value of multiple decision variables. *Journal of cognitive neuroscience* 21**,** 1162-1178.

King-Casas, B., Sharp, C., Lomax-Bream, L., Lohrenz, T., Fonagy, P., and Montague, P.R. (2008). The rupture and repair of cooperation in borderline personality disorder. *Science* 321**,** 806-810.

Kirk, U., Downar, J., and Montague, P.R. (2011). Interoception drives increased rational decision-making in meditators playing the Ultimatum Game. *Frontiers in Neuroscience* 5.

Knoch, D., Pascual-Leone, A., Meyer, K., Treyer, V., and Fehr, E. (2006). Diminishing reciprocal fairness by disrupting the right prefrontal cortex. *Science* 314**,** 829-832.

Knutson, B., Rick, S., Wimmer, G.E., Prelec, D., and Loewenstein, G. (2007). Neural predictors of purchases. *Neuron* 53**,** 147-156.

Knutson, B., Westdorp, A., Kaiser, E., and Hommer, D. (2000). FMRI visualization of brain activity during a monetary incentive delay task. *Neuroimage* 12**,** 20-27.

Kringelbach, M.L., O'doherty, J., Rolls, E.T., and Andrews, C. (2003). Activation of the human orbitofrontal cortex to a liquid food stimulus is correlated with its subjective pleasantness. *Cerebral cortex* 13**,** 1064-1071.

Lee, T.-W., Girolami, M., and Sejnowski, T.J. (1999). Independent Component Analysis Using an Extended Infomax Algorithm for Mixed Subgaussian and Supergaussian Sources. *Neural Computation* 11**,** 417-441.

Luk, C.H., and Wallis, J.D. (2009). Dynamic encoding of responses and outcomes by neurons in medial prefrontal cortex. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 29**,** 7526-7539.

Luu, P., Tucker, D.M., Derryberry, D., Reed, M., and Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. *Psychological Science* 14**,** 47-53.

Mancini, A., Betti, V., Panasiti, M.S., Pavone, E.F., and Aglioti, S.M. (2011). Suffering makes you egoist: acute pain increases acceptance rates and reduces fairness during a bilateral ultimatum game. *PLoS One* 6**,** e26008.

Marco-Pallares, J., Kramer, U.M., Strehl, S., Schroder, A., and Munte, T.F. (2010). When decisions of others matter to me: an electrophysiological analysis. *BMC Neuroscience* 11**,** 86.

Martin, L.E., Potts, G.F., Burton, P.C., and Montague, P.R. (2009). Electrophysiological and hemodynamic responses to reward prediction violation. *Neuroreport* 20**,** 1140-1143.

Masten, C.L., Morelli, S.A., and Eisenberger, N.I. (2011). An fMRI investigation of empathy for 'social pain' and subsequent prosocial behavior. *Neuroimage* 55**,** 381-388.

Mealey, L., Daood, C., and Krage, M. (1996). Enhanced memory for faces of cheaters. *Ethology and Sociobiology* 17**,** 119-128.

Miltner, W.H.R., Braun, C.H., and Coles, M.G.H. (1997). Event-Related Brain Potentials Following Incorrect Feedback in a Time-Estimation Task: Evidence for a “Generic” Neural System for Error Detection. *Journal of cognitive neuroscience* 9**,** 788-798.

Moll, J., Krueger, F., Zahn, R., Pardini, M., De Oliveira-Souza, R., and Grafman, J. (2006). Human fronto–mesolimbic networks guide decisions about charitable donation. *Proceedings of the National Academy of Sciences* 103**,** 15623-15628.

Munier, B., and Costin, Z. (2002). High Stakes and Acceptance Behavior in Ultimatum Bargaining: A Contribution from an International Experiment. *Theory and Decision* 53**,** 187-207.

Nguyen, C.M., Koenigs, M., Yamada, T.H., Teo, S.H., Cavanaugh, J.E., Tranel, D., and Denburg, N.L. (2011). Trustworthiness and negative affect predict economic decision making. *Journal of Cognitive Psychology* 23**,** 748-759.

Nieuwenhuis, S., Holroyd, C.B., Mol, N., and Coles, M.G. (2004a). Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. *Neurosci Biobehav Rev* 28**,** 441-448.

Nieuwenhuis, S., Yeung, N., Holroyd, C.B., Schurger, A., and Cohen, J.D. (2004b). Sensitivity of Electrophysiological Activity from Medial Frontal Cortex to Utilitarian and Performance Feedback. *Cerebral cortex* 14**,** 741-747.

O'doherty, J., Kringelbach, M.L., Rolls, E.T., Hornak, J., and Andrews, C. (2001a). Abstract reward and punishment representations in the human orbitofrontal cortex. *Nat Neurosci* 4**,** 95-102.

O'doherty, J., Rolls, E.T., Francis, S., Bowtell, R., and Mcglone, F. (2001b). Representation of pleasant and aversive taste in the human brain. *Journal of neurophysiology* 85**,** 1315-1321.

O'doherty, J.P. (2004). Reward representations and reward-related learning in the human brain: insights from neuroimaging. *Curr Opin Neurobiol* 14**,** 769-776.

Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9**,** 97-113.

Pedroni, A., Langer, N., Koenig, T., Allemand, M., and Jäncke, L. (2011). Electroencephalographic Topography Measures of Experienced Utility. *The Journal of Neuroscience* 31**,** 10474-10480.

Pfabigan, D.M., Alexopoulos, J., Bauer, H., and Sailer, U. (2011). Manipulation of feedback expectancy and valence induces negative and positive reward prediction error signals manifest in event-related brain potentials. *Psychophysiology* 48**,** 656-664.

Phan, K.L., Sripada, C.S., Angstadt, M., and Mccabe, K. (2010). Reputation for reciprocity engages the brain reward center. *Proceedings of the National Academy of Sciences* 107**,** 13099-13104.

Pillutla, M.M., and Murnighan, J.K. (1996). Unfairness, Anger, and Spite: Emotional Rejections of Ultimatum Offers. *Organizational behavior and human decision processes* 68**,** 208-224.

Plassmann, H., O'doherty, J., and Rangel, A. (2007). Orbitofrontal cortex encodes willingness to pay in everyday economic transactions. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 27**,** 9984-9988.

Polezzi, D., Daum, I., Rubaltelli, E., Lotto, L., Civai, C., Sartori, G., and Rumiati, R. (2008). Mentalizing in economic decision-making. *Behavioral Brain Research* 190**,** 218-223.

Potts, G.F., Martin, L.E., Burton, P., and Montague, P.R. (2006). When things are better or worse than expected: the medial frontal cortex and the allocation of processing resources. *Journal of cognitive neuroscience* 18**,** 1112-1119.

Prabhakaran, V., Narayanan, K., Zhao, Z., and Gabrieli, J.D. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience* 3**,** 85-90.

Rabin, M. (1993). Incorporating Fairness into Game Theory and Economics. *American Economic Review* 83**,** 1281-1302.

Rigoni, D., Polezzi, D., Rumiati, R., Guarino, R., and Sartori, G. (2010). When people matter more than money: an ERPs study. *Brain Res Bull* 81**,** 445-452.

Rilling, J.K., and Sanfey, A.G (2011). The neuroscience of social decision-making. *Annual Review Psychology* 62**,** 23-48.

Rilling, J.K., Sanfey, A.G., Aronson, J.A., Nystrom, L.E., and Cohen, J.D. (2004). Opposing BOLD responses to reciprocated and unreciprocated altruism in putative reward pathways. *Neuroreport* 15**,** 2539-2543.

Rolls, E.T. (2005). *Emotion Explained.* Oxford University Press.

Rolls, E.T., Kringelbach, M.L., and De Araujo, I.E. (2003a). Different representations of pleasant and unpleasant odours in the human brain. *Eur J Neurosci* 18**,** 695-703.

Rolls, E.T., O'doherty, J., Kringelbach, M.L., Francis, S., Bowtell, R., and Mcglone, F. (2003b). Representations of Pleasant and Painful Touch in the Human Orbitofrontal and Cingulate Cortices. *Cerebral cortex* 13**,** 308-317.

Sanfey, A.G. (2007). Social Decision-Making: Insights from Game Theory and Neuroscience. *Science* 318**,** 598-602.

Sanfey, A.G., Rilling, J.K., Aronson, J.A., Nystrom, L.E., and Cohen, J.D. (2003). The neural basis of economic decision-making in the Ultimatum Game. *Science* 300**,** 1755-1758.

Schmitt, M., Baumert, A., Gollwitzer, M., and Maes, J. (2010). The Justice Sensitivity Inventory: Factorial Validity, Location in the Personality Facet Space, Demographic Pattern, and Normative Data. *Social Justice Research* 23**,** 211-238.

Schmitt, M., Gollwitzer, M., and Arbach, D. (2004). "Justice sensitivity : assessment and location in the personality space". (Saarbrücken: Universitäts- und Landesbibliothek).

Schultz, W. (1999). The Reward Signal of Midbrain Dopamine Neurons. *Physiology* 14**,** 249-255.

Schultz, W. (2006). Behavioral theories and the neurophysiology of reward. *Annual Review Psychology* 57**,** 87-115.

Schultz, W. (2010). Dopamine signals for reward value and risk: basic and recent data. *Behavioral and Brain Functions* 6**,** 24.

Schultz, W., Dayan, P., and Montague, P.R. (1997). A neural substrate of prediction and reward. *Science* 275**,** 1593-1599.

Selten, R. (1965). *Die Strategiemethode zur Erforschung des eingeschränkt rationalen Verhaltens im Rahmen eines Oligopolexperimentes.* Seminar für Mathemat. Wirtschaftsforschung u. Ökonometrie.

Seo, H., and Lee, D. (2007). Temporal filtering of reward signals in the dorsal anterior cingulate cortex during a mixed-strategy game. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 27**,** 8366-8377.

Shiv, B., Grant, S., and Mcgraw, P. (2005). Decision Neuroscience. *Marketing Letters* 16**,** 375-386.

Singer, T., Seymour, B., O'doherty, J., Kaube, H., Dolan, R.J., and Frith, C.D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science* 303**,** 1157-1162.

Slonim, R., and Roth, A.E. (1998). Learning in High Stakes Ultimatum Games: An Experiment in the Slovak Republic. *Econometrica* 66**,** 569-596.

Small, D.M., Zatorre, R.J., Dagher, A., Evans, A.C., and Jones-Gotman, M. (2001). Changes in brain activity related to eating chocolate: from pleasure to aversion. *Brain* 124**,** 1720-1733.

Smith, D.V., and Huettel, S.A. (2010). Decision neuroscience: neuroeconomics. *Wiley Interdisciplinary Reviews: Cognitive Science* 1**,** 854-871.

Solnick, S.J., and Schweitzer, M.E. (1999). The Influence of Physical Attractiveness and Gender on Ultimatum Game Decisions. *Organizational behavior and human decision processes* 79**,** 199-215.

Stephenson, W.A., and Gibbs, F.A. (1951). A balanced non-cephalic reference electrode. *Electroencephalography and clinical neurophysiology* 3**,** 237-240.

Sutter, M., Kocher, M., and Strauß, S. (2003). Bargaining under time pressure in an experimental ultimatum game. *Economics Letters* 81**,** 341-347.

Tabibnia, G., Satpute, A.B., and Lieberman, M.D. (2008). The sunny side of fairness: preference for fairness activates reward circuitry (and disregarding unfairness activates self-control circuitry). *Psychol Sci* 19**,** 339-347.

Takagishi, H., Takahashi, T., Toyomura, A., Takashino, N., Koizumi, M., and Yamagishi, T. (2009). Neural correlates of the rejection of unfair offers in the impunity game. *Neuro Endocrinol Lett* 30**,** 496-500.

Thaler, R.H. (1988). Anomalies: The Ultimatum Game. *Journal of Economic Perspectives* 2**,** 195-206.

Thoma, P., and Bellebaum, C. (2012). Your error?s got me feeling - How empathy relates to the electrophysiological correlates of performance monitoring. *Frontiers in Human Neuroscience* 6.

Thomas, N., Baumert, A., and Schmitt, M. (2010). "Justice Sensitivity as a Risk and Protective Factor in Social Conflicts," in *Justice and Conflicts. Theoretical and Empirical Contributions,* eds. E. Kals & J. Maes. Springer-Verlag Berlin Heidelberg), 107-120.

Tricomi, E., Rangel, A., Camerer, C.F., and O/'Doherty, J.P. (2010). Neural evidence for inequality-averse social preferences. *Nature* 463**,** 1089-1091.

Van Schie, H.T., Mars, R.B., Coles, M.G., and Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience* 7**,** 549-554.

Vanneste, S., Verplaetse, J., Van Hiel, A., and Braeckman, J. (2007). Attention bias toward noncooperative people. A dot probe classification study in cheating detection. *Evolution and Human Behavior* 28**,** 272-276.

Vogt, B.A., Berger, G.R., and Derbyshire, S.W. (2003). Structural and functional dichotomy of human midcingulate cortex. *Eur J Neurosci* 18**,** 3134-3144.

Vogt, B.A., Finch, D.M., and Olson, C.R. (1992). Functional Heterogeneity in Cingulate Cortex: The Anterior Executive and Posterior Evaluative Regions. *Cerebral cortex* 2**,** 435-443.

Von Neumann, J., and Morgenstern, O. (1944). *Theory of Games and Economic Behavior.* Princeton: Princeton University Press.

Wessel, J.R., Danielmeier, C., Morton, J.B., and Ullsperger, M. (2012). Surprise and error: common neuronal architecture for the processing of errors and novelty. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 32**,** 7528-7537.

Wu, Y., Zhou, Y., Van Dijk, E., Leliveld, M.C., and Zhou, X. (2011). Social Comparison Affects Brain Responses to Fairness in Asset Division: An ERP Study with the Ultimatum Game. *Front Hum Neurosci* 5**,** 131.

Zink, C.F., Pagnoni, G., Chappelow, J., Martin-Skurski, M., and Berns, G.S. (2006). Human striatal activation reflects degree of stimulus saliency. *Neuroimage* 29**,** 977-983.

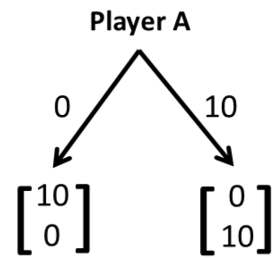
Zink, C.F., Pagnoni, G., Martin, M.E., Dhamala, M., and Berns, G.S. (2003). Human striatal response to salient nonrewarding stimuli. *The Journal of neuroscience : the official journal of the Society for Neuroscience* 23**,** 8092-8097.

Appendix

Economics games

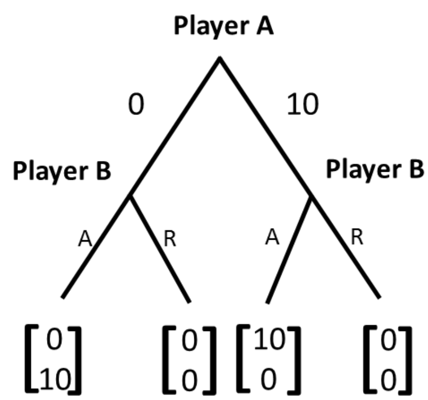
Dictator Game

The Dictator Game is the simplest two-person game capturing real altruism. In this game a person A is endowed with a certain amount of money, which he/she has to share with person B. Person B has to accept any amount offered, thus has no power in this game. Assuming that individuals are selfish individuals B should get nothing.



Ultimatum Game

The Ultimatum Game is an extended version of the Dictator Game. However, in contrast to the Dictator Game, the Responder, respectively the Player B, can decide whether he accepts or rejects the proposed division. In case he accepts the money is allocated accordingly, otherwise, if rejected both receive nothing. Similar to the Dictator Game A should send the lowest possible amount to B and B should accept every amount offered.



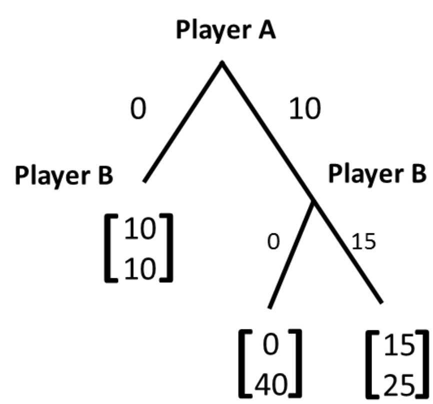
Third-Party Punishment Game

In the Third-Party Punishment Game, there are three players, A, B, and C. Player A is endowed with a sum of money and has to decide how much to give to player B, the dummy-player, who has no endowment. Up to this point it is similar to the Dictator Game.

The third player C, who is endowed with a smaller sum of money, observes this allocation and has the possibility to spend some money to punish player A. Due to the fact that punishment is costly, without punishing player C gets a fair share. A selfish player C would never punish because punishment is costly, therefore the third-party punishment game captures altruistic punishment.

Trust Game

In the two-person Trust Game either each player or only the investor is endowed with a certain amount of money. Player A, the investor, can send money to player B, the trustee. The money A sends to B is then quadrupled by the investigator. Now B can decide how much of the quadrupled money he would like to send back to A. Game theory predicts that B sends nothing back to A and thus, A should in a first step keep all the money.



Prisoners` Dilemma Game

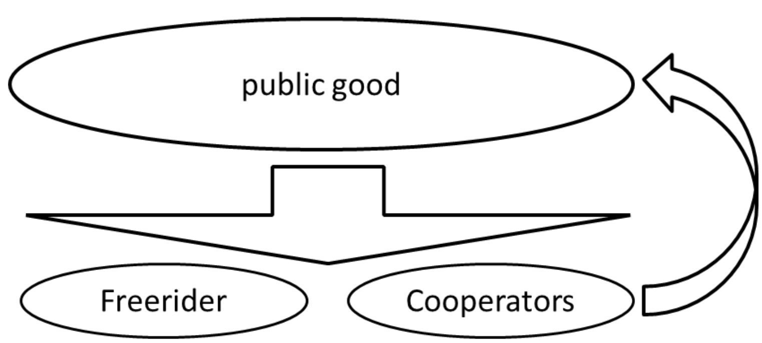
In the Prisoners` Dilemma Game two players choose simultaneously between the two strategies: defect (D) or cooperate (C). If a player chooses C, he can either receive a reward (R), if the other player chooses C as well. Otherwise if the other player chooses D, he receives the so called sucker´s payoff (S). If both players choose D, they receive the punishment (P). A player using D receives payoff T (temptation) if the other player cooperates or P if the other defects.

The ranking of the payoff – T>R>P>S – is essential for a prisoners` dilemma game. Since, T>R and P>S the best strategy would be to defect.

P1 / P2	**Cooperate**	**Defect**
Cooperate	R = 10 / R = 10	T = 15 / S = 1
Defect	S = 1 / T = 15	P = 5 / P = 5

Public Good Game

The Game can be performed with any number of players, who are endowed with a certain amount of money they can contribute to a joint project. Thus, each player has to decide how much money he/she would like to spend or how much money he/she would like to keep. None of the players is forced to contribute. Nevertheless, the "public good" will be, e.g., doubled by the investigator and all players profit equally irrespective of what they spent.



Instruction (Proposer)

Instruktion: Ultimatum-Spiel

Du nimmst nun an einem Experiment teil dessen Ziel es ist, das Entscheiden in gewinnorientierten Situationen zu erfassen.

Die Spielregeln

In diesem Spiel gibt es drei Personen (X, Y und Z) und einen Geldbetrag von 12 € bzw. 15 €. Spieler X entscheidet wie er diesen Geldbetrag untereinander aufteilen möchte. Danach kann Spieler Y entscheiden ob er dieses Angebot annimmt oder ablehnt. Nimmt Y das Angebot an, erhält jeder Spieler den von X angebotenen Anteil des Geldbetrages. Lehnt Y das Angebot von X ab, gehen alle Spieler leer aus. Der dritte Spieler Z hat keinen Einfluss auf den Spielverlauf, muss jedoch bei der Verteilung berücksichtigt werden.

Du bist Spieler X. Auf dem Antwortblatt findest du 20 vorgefertigte Verteilungen. Wähle für die beiden Beträge (12 und 15 €) je einen Verteilung aus, die du den beiden anderen Spielern (Y und Z) anbieten möchtest.

Anschließend werden 40 verschiedenen Personen in der Rolle von Y bzw. Z dein Foto und dein Angebot vorgelegt, und Y entscheidet, ob er diese Angebote annimmt oder ablehnt.

Gewinn

Dein Gewinn ergibt sich aus der Summe der angenommenen Angebote. Jener Spieler, welcher den höchsten Gewinn erzielt erhält 20 €.

Entscheidung 1				Entscheidung 2			
Angebot in der Rolle von X	Verteilung von 12 € an X, Y, und Z			Angebot in der Rolle von X	Verteilung von 15 € an X, Y, und Z		
	X	Y	Z		X	Y	Z
	4	2	6		5	2	8
	4	6	2		5	8	2
	4	4	4		5	5	5
	4	1	7		6	2	7
	4	7	1		6	7	2
	10	1	1		13	1	1
Name:		Alter:		E-mail:			

Instructions (Responder)

Instruktion: Ultimatum-Spiel

In diesem Spiel gibt es drei Spieler (Anbieter, Spieler 1 und Spieler 2) und einen Geldbetrag von 12, 15 oder 18 €. Der Anbieter entscheidet wie er diesen Geldbetrag untereinander aufteilen möchte. Danach kann Spieler 1 entscheiden, ob er dieses Angebot annimmt oder ablehnt. Nimmt jener das Angebot an, erhält jeder Spieler den vom Anbieter angebotenen Anteil des Geldbetrages. Lehnt er das Angebot ab, gehen alle Spieler leer aus. Spieler 2 hat keinen Einfluss auf den Spielverlauf, muss jedoch bei der Verteilung berücksichtigt werden.

Im Vorfeld dieses Experiments haben 81 Personen jeweils zwei Angebote mit unterschiedlichen Beträgen (12, 15, oder 18 €) abgegeben. Zu Beginn eines Blockes siehst du Fotos der Anbieter, danach folgen die Angebote. Nach jedem Angebot erscheinen am unteren Teil des Bildschirmes zwei Kästchen mit den Antwortmöglichkeiten „annehmen“ oder „ablehnen“. In welchem der beiden Kästchen die jeweilige Antwortmöglichkeit steht variiert während dem Experiment. Solltest du jene Antwortmöglichkeit wählen die rechts am Bildschirm steht drücke bitte die rechte Taste. Solltest du jene Antwortmöglichkeit wählen die links am Bildschirm steht drücke bitte die linke Taste. Nach dem Tastendruck erscheint die Rückmeldung über die tatsächliche Aufteilung und ein neuer Durchgang beginnt. Du siehst wieder die Fotos der Anbieter für den folgenden Block.

Spieler 2 sieht während des gesamten Experiments auf seinem Bildschirm dasselbe wie Spieler 1. Nach manchen Angeboten erscheint eine Frage, diese ist von Spieler 2 zu beantworten. Für jede richtige Antwort gibt es zusätzlich 0,50 €.

Bezahlung: Die Summe des Gewinnes der Anbieter wird über alle Versuchspersonen errechnet, wobei nur jene 5 Anbieter Geld gewinnen können, die den höchsten Gewinn erzielten. Für alle drei Spieler gilt, dass nicht alle sondern 4 zufällig ausgewählte Durchgänge bezahlt werden.

Abstract

Emotions play a crucial role in the decision making process. Usually the interplay between emotional and social factors and their impact on decision making is studied using two-person bargaining games like the ultimatum game. Nevertheless, in real life decisions are hardly made in an uncoupled dyad, instead there are others influencing our decisions either by their mere presence or because decisions bear consequences for them too. One major problem in understanding the decision making processes in games with more than two players is that it is still unclear who the relevant players are, or under what circumstances others influence our decision making process.

Studies investigating the standard ultimatum game have shown that unfair compared to fair offers are accompanied by a negative-going deflection in the ongoing electroencephalogram (EGG) with peak activation about 250ms after the onset of the offer. It is assumed that this component, termed the medial frontal negativity (MFN), reflects the subjective value of a given reward or punishment. The aim of the project at hand was to investigate how the amount of money the other player receives, the physical proximity between players, and the power of players affect the processing of the different kinds of offers or the subjective value of offers as indicated by MFN amplitudes.

In order to address this issue systematically two studies were conducted. Both studies used the three-person ultimatum game and EEG as a method. During the experiment offers about how to split up a certain amount of money between the players of the game (proposer, responder and dummy-player), were presented to the recipients (responder and dummy-player). Offers made by the so-called proposers were collected prior to the EEG experiment. Following the presentation of the offer the responder had the possibility to accept or reject the offer. In case the offer was accepted, money was allocated as proposed. Otherwise, if rejected, none of the players received any money in this round. The third person, respectively the dummy-player, had no direct bearing on the game.

In the first study players were anonymous to each other. EEG was recorded from participants playing in the role of the responder. The presence of the dummy-player was simulated. It was given the impression that the dummy-player is a real person, who's EEG, however, is recorded in another EEG chamber. In the second study the very same paradigm was applied, however, the EEG of the responder and the dummy-player was recorded simultaneously, while sitting in the same room. This way it was possible to investigate the influence of agency on the processing of fair and unfair treatment of oneself and the respective other.

As indicated by the amplitude of the MFN, in the complete anonymous condition responders did not differentiate between fair and unfair offers towards the powerless third. Whereas, unfair offers compared to fair offers towards themselves were followed by more pronounced MFN amplitudes. Interestingly, offers comprising an unfair amount to the responder himself and a high or fair amount to the dummy-player were followed by the most pronounced amplitude and thus, one might assume that those offers were least preferable. Furthermore, we found a relation between MFN amplitudes and rejection rate of unfair offers. In the second experiment, a somewhat different picture emerges. An interaction between treatment of oneself and the respective other was found for both participants (players). Whereas, responders preferred all offers were at least one of the two received a fair amount, dummy-players favored offers where they received more than the responder. MFN amplitudes in both groups of subjects were correlated with the reported levels of justice sensitivity. Taken together, results indicated that fair and unfair treatment of someone else changes the way humans evaluate how they are being treated themselves. However, physical proximity and agency are two important determinates that account for alterations in processing.

Zusammenfassung

Gefühle spielen eine zentrale Rolle bei der Entscheidungsfindung. Bei der Untersuchung des Zusammenspiels von emotionalen und sozialen Faktoren und deren Einfluss auf unsere Entscheidungen macht man sich in der Regel Zwei-Personen-Spiele, wie das Ultimatum-Spiel, zu Nutze. Dennoch werden in der Realität selten Entscheidung innerhalb einer entkoppelten Dyade gemacht, stattdessen sind oft auch andere beteiligt, die unsere Entscheidungen beeinflussen, entweder durch ihre bloße Anwesenheit oder weil Entscheidungen auch Folgen für sie mit sich bringen. Ein großes Problem beim Verständnis der Entscheidungsprozesse in Spielen mit mehr als zwei Spielern ist, dass unklar ist, wer die relevanten Akteure sind oder unter welchen Umständen andere die Entscheidungsfindung beeinflussen.

In vorangegangenen Arbeiten zum Zwei-Personen-Ultimatum-Spiel konnte gezeigt werden, dass unfaire Angebote im Gegensatz zu fairen Angeboten von einer negativ verlaufenden Ablenkung im Elektroenzephalogramm (EGG) mit einem Amplitudenmaximum bei 250 ms nach der Präsentation des Angebots begleitet werden. Es wird davon ausgegangen, dass diese Komponente, die sogenannte mediale frontale Negativität (MFN), den subjektiven Wert einer bestimmten Belohnung oder Bestrafung widerspiegelt. Ziel des vorliegenden Projektes war es zu untersuchen, in wie weit sich unfaire Angebote an einen unbeteiligten Dritten, auf die Ausprägung der MFN auswirken; abhängig von der räumliche Nähe zwischen den Spielern und der Macht der einzelnen Spieler.

Um dieser Frage systematisch nachzugehen wurden zwei Studien durchgeführt. In beiden Studien wurde im Gegensatz zu den bisherigen Studien das Drei-Personen-Ultimatum-Spiel verwendet. Während des Experiments wurden den Teilnehmern Angebote präsentiert, d.h. Vorschläge wie man einen bestimmten Betrag zwischen den Spieler (Anbieter, Antwortender und Dummy) aufteilen sollte. Die Angebote wurden von den sogenannten Anbietern gemacht und vor dem eigentlichen Experiment erhoben. Nach der Präsentation des Angebotes hatte der Antwortende die Möglichkeit das Angebot abzulehnen oder anzunehmen. Im Fall, dass das Angebot angenommen wurde, wurde das Geld wie vorgeschlagen verteilt, andern Falls, bei

einer Ablehnung erhielt keiner der Spieler Geld in dieser Runde. Die dritte Person bzw. der Dummy-Spieler hatte keinen direkten Einfluss auf das Spiel.

In der ersten Studie waren die Spieler anonym zueinander. Die Teilnehmer, deren EEG aufgezeichnet wurde, spielten in der Rolle des Antwortenden (Responder), die Anwesenheit des Dummy wurde simuliert. Es wurde der Eindruck vermittelt, dass der Dummy-Spieler eine reale Person ist, dessen EEG ebenfalls, jedoch in einer anderen EEG-Kammer aufgezeichnet wird. In der zweiten Studie kam dasselbe Paradigma zur Anwendung, jedoch wurde das EEG des Antwortenden und des Dummys simultan aufgezeichnet, während sie im selben Raum saßen. Auf diese Weise war es möglich, den Einfluss der Möglichkeit zu Handeln auf die Verarbeitung von fairem und unfairem Verhalten gegenüber einem selbst und gegenüber dem jeweils anderen zu untersuchen.

Wie durch die Amplitude der MFN angezeigt, unterschieden die Antwortenden nicht zwischen fairen und unfairen Angeboten gegenüber dem machtlosen Dritten. Unfaire Angebote im Vergleich zu fairen Angeboten für einen selbst wurden von stärker ausgeprägten MFN Amplituden gefolgt. Interessanterweise zeigte sich, dass ein unfairer Betrag für den Antwortenden selbst, bei einem gleichzeitig hohen oder fairen Betrag für den Dummy-Spieler, mit der am höchsten ausgeprägten MFN Amplitude einhergeht und man davon ausgehen kann, dass jene Angebote von den Antwortenden am wenigsten favorisiert wurden. Darüber hinaus fanden wir einen Zusammenhang zwischen der Amplitude der MFN und den Ablehnungsraten eines unfairen Angebotes. Im zweiten Experiment fand sich eine Wechselwirkung in Bezug auf die unterschiedlichen experimentellen Manipulationen. Während die Antwortenden jedes Angebot bevorzugten in dem mindestens einer der beiden einen fairen Betrag erhalten hatte, favorisierten die Dummy-Spieler jene Angebote in denen sie mehr als die Antwortenden erhielten. Die Amplitude der MFN korrelierte in beiden Gruppen mit der angegebenen Sensitivität für Gerechtigkeit. Zusammengenommen zeigen die Ergebnisse, dass faires/unfaires Verhalten gegenüber einem anderen die Art und Weise verändern, wie Menschen die Behandlung von sich selbst bewerten. Körperliche Nähe und die Handlungsmöglichkeiten sind dabei zwei wesentliche Determinanten, die diese Prozesse beeinflussen.

Presentation of the project

Next to the two publications presented in chapter 5 and 6, parts of this project were presented at international conferences, symposia, or summer schools:

Poster presentations and Abstracts:

1. 49th Annual Meeting of the Society for Psychophysiological Research, October 21-24, 2009, Berlin, Germany.

2. International Symposium on the Neural Basis of Decision Making, April 20-22, 2009, De Poort, Groesbeek, the Netherlands.

3. "Junge Forschende im Dialog" Posteraustellung an der Fakultät für Psychologie, July 02, 2010, Vienna, Austria.

Oral Presentations:

1. Akademie der Wissenschaft, January 23th , 2009, Vienna, Austria

2. Mei:CogSci Student Conference, June 20th , 2009, Bratislava, Slovakia

3. Cognitive, Affective, and Nociceptive Functioning of the Anterior Cingulate Cortex, November 25-28, 2010, Oppurg, Germany

4. Mind, Brain Imaging, and Neuroethics Research Unit , University of Ottawa, Institute of Mental Health Research, October 19th , 2011, Ottawa, Canada

Curriculum Vitae

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Education

09/2012	Summer School: "The Visceral Mind: A hands-on course in the neuroanatomy of cognition", Bangor University, Wales
09/2011	Two month research visit at the University of Ottawa, Institute of Mental, Mind, Brain Imaging, and Neuroethics Research Unit (Training in Analyses of fMRI data), Canada
11/2010	Autumn School "Cognitive, Affective, and Nociceptive Functioning of the Anterior Cingulate Cortex, University of Jena, Germany
10/2009	"Introduction to time-frequency analysis", pre-congress workshop at the 49th Annual SPR Meeting, Berlin, Germany
2009-2010	Post-graduate courses in Clinical Psychology
03/2008	Interdisciplinary College IK2008; Focus Theme: Cooperation; Günne, Germany
Since 2008	PhD student at the Brain Research Laboratory, Faculty of Psychology, University of Vienna, Austria
2007-2008	6-month research visit at the Hungarian Academy of Science, Institute for Psychology, Department of Experimental Psychology
2006-2008	Middle European Interdisciplinary Master Program in Cognitive Science

1999-2006 University of Vienna, Faculty of Psychology, Master-thesis on "Neural correlates of strategic decision making"

Places of Employment

Since 2011 Research associate at the Medical University of Vienna, Austria, Department of ^ Psychoanalysis and Psychotherapy

2010-2011 Clinical psychologists (in training) at the General Hospital of Vienna, Austria, Department of Neurology

2010-2011 Lecturer at the University of Vienna, Austria, Department of Clinical and Biological Psychology

2008-2009 Project Scientist at the University of Vienna, Austria, Department of Clinical and Biological Psychology

Peer-reviewed Publications

Alexopoulos, J., Pfabigan, D.M., Lamm, C., Bauer, H., and Fischmeister, F.P. (2012). Do we care about the powerless third? An ERP study of the three-person ultimatum game. *Frontiers in Human Neuroscience* 6, 59.

Pfabigan D.M., Alexopoulos J., Bauer H., Lamm C. and Sailer U. (2011). All about the money – external performance monitoring is affected by monetary, but not by socially conveyed feedback cues in more antisocial individuals. *Frontiers in Human Neuroscience, 5, 100*

Pfabigan, D. M., Alexopoulos, J., Bauer, H. and Sailer, U. (2010). Manipulation of feedback expectancy and valence induces negative and positive reward prediction error signals manifest in event-related brain potentials. *Psychophysiology,48(5), 656-664*

Pfabigan, D. M., Alexopoulos, J., Kryspin-Exner, I. & Sailer, U. (2010). Effects of antisocial personality traits on event-related potentials during face processing. *International Journal of Psychophysiology*, 77, 277-278.

Schreiner, T., Alexopoulos, J., Pfabigan, D. M. & Sailer, U. (2010). Facial cues affect the feedback negativity to offers in the Ultimatum Game. An EEG investigation. *International Journal of Psychophysiology*, 77, 337.

Alexopoulos, J., Goeschl F., (2010) Fairness considerations are activated by social information: The feedback negativity in the context of the Ultimatum Game. *International Journal of Psychophysiology*, 77/3, 336

Alexopoulos, J., Pfabigan, D., Fischmeister, F.P.S. & Bauer, H. (2009). Do we care about the powerless third? *Psychophysioloy*, 46, 112.

Pfabigan, D., Alexopoulos, J., Sailer, U., (2009) Antisocial Personality Traits and Feedback Processing – An ERP Study. *Psychophysiology,* 46, 78

Scholarship

2007 research grant from the Austrian Academy of Science

2007 ERASMUS travel grant for 6-month research visit in Hungary

2011 Full scholarship for Autumn School: "Cognitive, Affective, and Nociceptive Functioning of the Anterior Cingulate Cortex" in Oppurg, Germany organized by Friedrich-Schiller-University, Jena, Germany and funded by the Deutsche Forschungsgemeinschaft (DFG)

2011 travel-stipend by the Medical University of Vienna, Department of Psychoanalysis and Psychotherapy for a 2-month research visit at the Mind, Brain Imaging, and Neuroethics Research Unit, University of Ottawa, Institute of Mental Health Research

2012 Full scholarship for Summer School: "The Visceral Mind: A hands-on course in the neuroanatomy of cognition", Bangor University, Wales, UK funded by The Wales Institute of Cognitive Neuroscience and The James S. McDonnell Foundation