Electrophysiological markers of fairness and selfishness revealed by a combination of Dictator and Ultimatum Games

Ali M. Miraghaie *,[1,3], Hamidreza Pouretemad *,[5], Alessandro E. P. Villa [3,] 0000−0002−4684−0027, Mohammad A. Mazaheri [5], Reza Khosrowabadi [2] and Alessandra Lintas *,[3,4,] 0000−0003−3516−7073

1 Shahid Beheshti University, Faculty of Psychology, Deneshjou Bouleverd, Evin Tehran, Iran
2 Institute for Cognitive and Brain Science, Shahid Beheshti University, Tehran, Iran
3 NeuroHeuristic Research Group, HEC-Lausanne, University of Lausanne, Quartier UNIL-Chamberonne, Switzerland
4 LABEX, HEC-Lausanne, University of Lausanne, Quartier UNIL-Chamberonne, Switzerland
5 Dept. of Clinical & Health Psychology, Shahid Beheshti University, Tehran, Iran.
* Correspondence: alessandra.lintas@unil.ch, sam.miraghaie@gmail.com, pouretemad.h@gmail.com

Abstract: In the framework of neuroeconomics, Event Related Potentials (ERPs) were recorded during a combination of a Dictator Game (DG), in which the participants always played the role of Allocators, and an Ultimatum Game (UG), in which the participants always played the role of Responders. Behavioral analysis showed that the majority of participants were characterized by very low levels of altruistic decision making, which included two homogenous groups of individuals, one expressing fairness (GrpF, about 26%) and one selfish behavior (GrpS, about 20%). In the analysis of both games, an early negativity (N1) in the fronto-central cortical sites distinguished the GrpF and GrpS participants. The subsequent P2 wave component appeared more associated with the characteristics of the stimulus than with its behavioral value. During UG, we observed that a medial frontal negativity (MFN) occurred earlier and with greater amplitude in GrpS than in GrpF, which depended to a large extent to a spiteful punishment when the Responder refused offers less favorable for himself. The late positive component (LPC) of ERP recorded in posterior-parietal cortical sites was evoked earlier and with greater amplitude during UG than in DG and, in both games, LPC was evoked earlier and with greater amplitude in GrpS than in GrpF. Our results bring new evidence to the existence of different circuits activated by the evaluation of fair and unfair proposals in participants characterized by different expressions of perceived fairness, thus suggesting that particular brain dynamics could be associated with moral decisions.

Keywords: Fairness; Cooperation; EEG; N1; P2; MFN; Late positive potential; Spiteful punishment; Costly punishment

---

1. Introduction

The maximization of individual's own gain is considered to represent the main behavioral drive during an economic transaction. However, the balance of individuals' self-interest and acceptance of others' benefit is a common observation based on culturally shaped moral phenomena such as fairness and altruism [1–4]. Unrelated individuals try to ensure fairness to others in daily life, and hope to get fair treatment and cooperation in return [5,6]. Strong reciprocity model, as one of the strategies for maintaining and urging people to commit to the norms, has many practical and effective use in the light of cooperation [7,8] and people act differently in diverse societies to apply it [9]. Cooperation induced by the sacrifice of one's own self-interest in punishing violations of the social norm defines the so-called altruistic punishment [10–13]. A different kind of punishment, so-called spiteful punishment, appears when an individual spends personal resources to punish one or several other individuals who behave against his presumed interest within the context of collective norms and rules [14–17].

The Ultimatum Game (UG) has been one of the most prolific experimental tasks aimed at investigating the nature of human fairness over the last decades [18]. A typical UG involves two players, the Proposer, who offers how to share an endowment in two parts, and the Responder, who can either accept the offer to share it accordingly or to reject it with both players receiving a zero payoff. Empirical studies have demonstrated that Proposers typically offered approximately 40% (fair offers) of the total amount at stake, with Responders being more likely to reject 20% or less of positive, albeit low (unfair) offers [19,20]. Rejection of an unfair offer at UG might be triggered by cooperative and popular motivations or it can be considered to be an expression of a costly punishment aimed at enforcing the social norm of fairness [21–24]. This argument has been used to support the strong reciprocity model of the evolution of cooperation [25–27], but competitive and spiteful motivation associated with less prosocial attitude have also been suggested [16,28]. The Dictator Game (DG) task [29,30] is basically a single player game because the Proposer (called the Allocator in DG) determines at his own will whether to send a fraction (ranging from nothing to all) of the initial endowment to the Responder (called the Recipient in DG). The Recipient plays a passive role and has no influence over the outcome of the game. It has been observed that the vast majority of Allocators give something to the Recipients, usually about 20% of the amount at stake, despite the fact that Allocators have no reason to give up some of the money. [19,30].

Neural correlates of the violations of social norms and expectations have been investigated by electrophysiology and brain imaging studies [20,31–40]. Among the electrophysiological signals, it is important to mention the P2 (or P200) positive component, peaking at approximately 180–260 ms after stimulus onset [41]. An increased P2 has been observed in participants informed by the opponent's low social status playing UG [42] and in participants who feel gratification in response to rewarding results but also by seeing the opponent player's bad luck [43]. An event-related potential (ERP) wave component peaking near 250-350 ms after the stimulus presentation, characterized by a medial-frontal negativity (MFN), is likely to be generated in the anterior cingulate cortex (ACC) and to be associated with some evaluation of fairness [44–47]. Enhanced MFN with unfair offers and anger, with midfrontal theta band activation, predicted less "costly punishment" [48]. The lesser fair the offers in UG the larger the amplitude of the elicited MFN [32,34,37,49] and the longer its peak latency at parietal level in the Proposers receiving the feedback information [50]. In DG, MFN is associated with disadvantageous inequitable offers [47], but it is also dependent on the recipients' social status and altruistic tendency [40,51,52]. In Responders playing UG, a positive wave (P300) peaked in the interval 300-600 at centro-parietal electrode sites in association with outcome evaluation [53,54]. Additionally, P300 was larger in Responders to a fair offer made by an unknown Proposer in comparison with the same payoff offered by a socially known and close individual [36,50,55]. A late positive component (LPC) observed at a latency of 450-650 ms was sometimes termed late positive potential and often regarded as a sustained P300 response. The LPC appeared mostly over central and parietal areas and it is thought to be associated with emotion-driven decision making and with processing of motivating stimuli such as after accepting fair endowment shares [40,56,57]. It was also reported that the amplitude of LPC tended to be larger and located more frontally after response rejection of wretched offers in Responders playing UG [37].

Contactless monetary transactions are rapidly increasing in all socio-cultural environments and in the absence of effective face-to-face negotiations it seems crucial to gain a better understanding of decision-making processes. An unanswered question from previous studies it is if in individuals who reject wretched offers there is a difference in brain activity among those who behave in a fair or unfair way. This question and its counterpart —i.e., whether in individuals who accept wretched offers there is a difference between those who behave fairly or unfairly— have been investigated in this study with an original design combining DG and UG. The cooperation was tested in a DG where a participant played the role of Allocator and in UG where the same participant played the role of Responder. The combination of DG and UG allowed us to separate the individuals' profiles following an index of altruism determined during UG and an index of selfishness determined during DG. This

classification led to clusterize individuals who shared a common strategy. Two representative groups corresponded to participants expressing a conceit behavior during UG, but distinguished by their level, either very low or very high, of selfishness during DG. A third representative group was characterized by a rather high level of selfishness and by a moderate to neutral level of altruism. A careful analysis of P2, MFN, and LPC latencies and amplitudes revealed independent or interacting factors associated with the outcome of decision making. To our knowledge, this is the first study to carry out a systematic comparison of these major ERP wave components in the same participants performing both DG and UG neuroeconomic games.

2. Method

2.1. Participants

Forty-four volunteer healthy young male adults were recruited via posted announcement at the university campus of the Shahid Beheshti University of Tehran (Iran), but only 39/44 completed the protocol. Then, our sample of participants was composed by $N = 39$ volunteers aged between 18 and 32 years old (M=22.5, SEM=0.5). All participants followed an academic education (8 undergraduate, 22 postgraduate and 9 PhD students) and all were right-handed with normal or corrected-to-normal vision. The research protocol was approved by the mandatory Ethics Committees requested by Shahid Beheshti University and with written informed consent from all participants, in accordance with the latest version of the Declaration of Helsinki [58]. Prior to the experimental session, all participants were interviewed to asses that they were not reporting any neurological or neuropsychiatric diseases and not taking any psychoactive medication. The whole experiment lasted between 2 and 2 and half hours. The participants were compensated for their time with a fixed amount of cash (200,000 IRR, Iranian Rials, approximately corresponding to 4 USD). In addition, the participants received performance-based cash rewards (comprised between 200,000 and 800,000 IRR) corresponding to the cumulative outcome of the UG and DG earned at the end of the experimental session.

2.2. Experimental procedure

The participants were seated comfortably in a sound-attenuated, electrically shielded, and dimly lit cabin with the instruction to maintain their gaze on a white fixation cross at the center of a 32-inch computer screen at a viewing distance of about 100 cm. At the begin of the recording session, the EEG was recorded during 2 min while the participants kept the eyes closed and during 2 min while they fixated a cross on the center of the computer screen. The participants were randomly assigned in two groups, those who played UG at first and those who played DG at first. Each game started with 10 trials of practice. After completing the first game, a short break (5-10 min) was set to allow the participant to get acquainted with the rules of the second game.

Each game was composed of 5 blocks with 48 trials each (240 trials for each game) and the participants took a break after each block. Each trial started with a fixation cross appearing for 800-1200 ms. Then, a pie chart (14 cm in diameter on a 32-inch computer screen) representing the endowment at stake divided in two colored pieces, appeared on the screen for 1200 ms. The red piece of the pie corresponded always to the participant's payoff of the endowment share. The participant had up to 3000 ms to make the decision either to accept the endowment subdivision represented by the pie chart —by pressing the 'K' letter of the computer keyboard with the medium finger of the right hand– or to reject it —by pressing the 'H' letter with the index finger of the same hand. During this interval, a schematic drawing appeared on the computer screen with a 'thumb up' emoji above a letter 'K' on the right and a 'thumb down' emoji above a letter 'H' on the left. After making the decision, the players fixated the cross for 800-1200 ms.

At the end of each trial, the outcome of the game with the payoff earned by the participant and his opponent was presented on the computer screen for 2000 ms. The stimulus presentation and data acquisition were performed using PsychLab and EEG8 amplifiers (Precision Instruments,

Glastonbury, Somerset, BA6 8AQ, UK). The statistical analyses were performed using the R language and environment for statistical computing [59,60].

2.3. Dictator Game

In the Dictator Game of this study, the Allocator/Proposer could not impose a priori the amount to be divided with the other player (the Recipient/Responder), but he had to refuse or agree with a randomly selected endowment share appearing on the computer screen. As in a usual Dictator Game, the Recipient/Responder was completely passive and had to accept whatever amount was imposed by the Allocator/Proposer. Both players received zero payoff if the Allocator/Proposer refused the randomly selected endowment share. All participants played the role of Allocator/Proposer and they were informed that the Recipient/Responder was an anonymous player located elsewhere. The participants played 240 trials subdivided into five blocks of 48 trials. The endowment shares were randomly selected among five ([Allocator/Proposer] : [Recipient/Responder]) endowment shares {(50:50), (60:40), (70:30), (80:20), (90:10)} —a fraction (80:20) meaning 80% of the amount for the participant playing the role of Allocator/Proposer and 20% for the other player. A single block of 48 trials was not necessarily balanced for the five possible fractions, but the complete sequence of 240 (5×48) trials was uniformly distributed, such that the sequence contained the same number of trials for each pre-determined endowment share. In this version of DG, the performance-based cash reward of the Participant (always playing the role of Allocator/Proposer) was determined by the average payoff of all accepted endowment shares. Figure 1 presents a schematic illustration of the time course of two DG trials.

2.4. Ultimatum Game

All participants played the role of Responder, who could either accept or reject the endowment share appearing on the computer screen. In case of acceptance, each player received a payoff according to the proposed split, otherwise both players did not receive anything. The overall sequence of 240 trials was subdivided into five blocks of 48 trials with five (Proposer:Responder) endowment shares {(50:50), (60:40), (70:30), (80:20), (90:10)} —a fraction (80:20) meaning 80% of the endowment for the Proposer and 20% for the Participant playing the role of Responder. The trials were uniformly randomly distributed such that the complete sequence contained the same number of trials for each pre-determined endowment share. The performance-based cash reward of the participant —always playing the role of Responder— was determined, as usually in UG, by the total payoff of all accepted endowment shares. Figure 2 presents a schematic illustration of the time course of two UG trials.

2.5. EEG recording and ERP processing

The electroencephalogram (EEG) of each Participant was recorded using 32 scalp dry titanium/titanium nitride (Ti/TiN) electrodes, mounted on a headcap (international 10/20 layout) referenced to the left mastoid bone. Electrophysiological signals were sampled at $1024\ Hz$ and filtered with a band-pass of $0.1 - 200$ Hz, with electrode impedances kept near $5\ k\Omega$ for all recordings. The analysis was performed using the EEGLAB_v12 [61]). and ERPLAB_v7 toolboxes [62]) of MATLAB 2017b (The Mathworks, Inc., Natick, MA, USA). Raw data were preprocessed with a band-pass IIR Butterworth filter from 0.1 to 32 Hz ($-36dB$/octave roll off). Blink, saccade and eyelid artifact components were corrected or set to zero, based on their respective shape and topography after using Independent Component Analysis (ICA) [63]. Epochs time-locked to markers were obtained after off-line segmentation of the continuous EEG. The epochs were defined for the interval between -200 through 800 ms around the trigger and corrected to baseline 200 ms prior to marker. Noisy data were rejected after further visual inspection of the epochs for contamination by muscular or electrode artifacts. We analyzed three ERP components defined by the positive peak at approximately 180–240 ms after the trigger (P2), the most negative component observed in the 260-400 ms interval post trigger (MFN), and the most positive peak observed in the 430-630 ms interval post trigger (LPC).

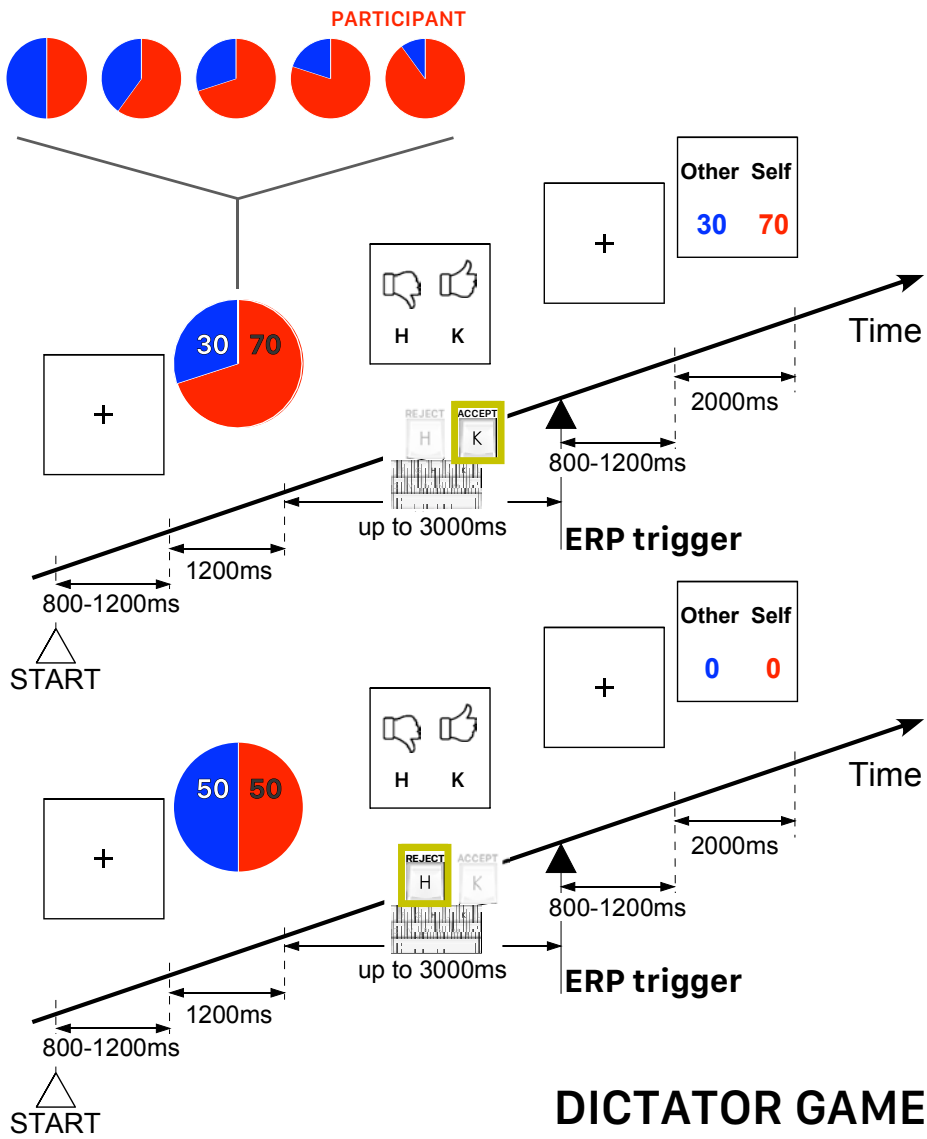

Figure 1. Schematic illustration of the time course of the Dictator Game task. The participant always played the role of Allocator/Proposer with the possibility to accept or refuse an endowment share randomly presented on the computer screen. The upper panel shows a trial when the Allocator/Proposer agreed with the randomly proposed share —in this example, 70% for the participant and 30% for the other player. The lower panel shows a trial when both players ended with a zero payoff because the Allocator/Proposer refused the randomly proposed share (50:50).

2.6. Statistical analyses

The statistical software R v4.0.5 [64], was used for all the analyses with packages `WRS2` [65], `effectsize` [66], `rstatix` [67] and `sjstats` [68]. In general, the grouped values were reported as (median, mean ±SEM). The factor analysis was performed after assuming the null hypothesis of homoscedasticity (i.e., equal variances) in the data samples and it was tested with the Levene's test. The standard Type-III ANOVA was used for factor analysis if the value of Levene's test statistics was not significant and the generalized eta squared (η^2_G) was used to estimate the effect size. The magnitude of effect sizes was labeled as follows: negligible as "(.)": $\eta^2_G < 0.01$; small as "(s)": $0.01 \leq \eta^2_G < 0.06$; medium as "(m)": $0.06 \leq \eta^2_G < 0.14$; large as "(L)": $0.14 \leq \eta^2_G$. For independent two-samples test with equal variances the Student's t-test was used with effect size assessed by Cohen's d with magnitudes:

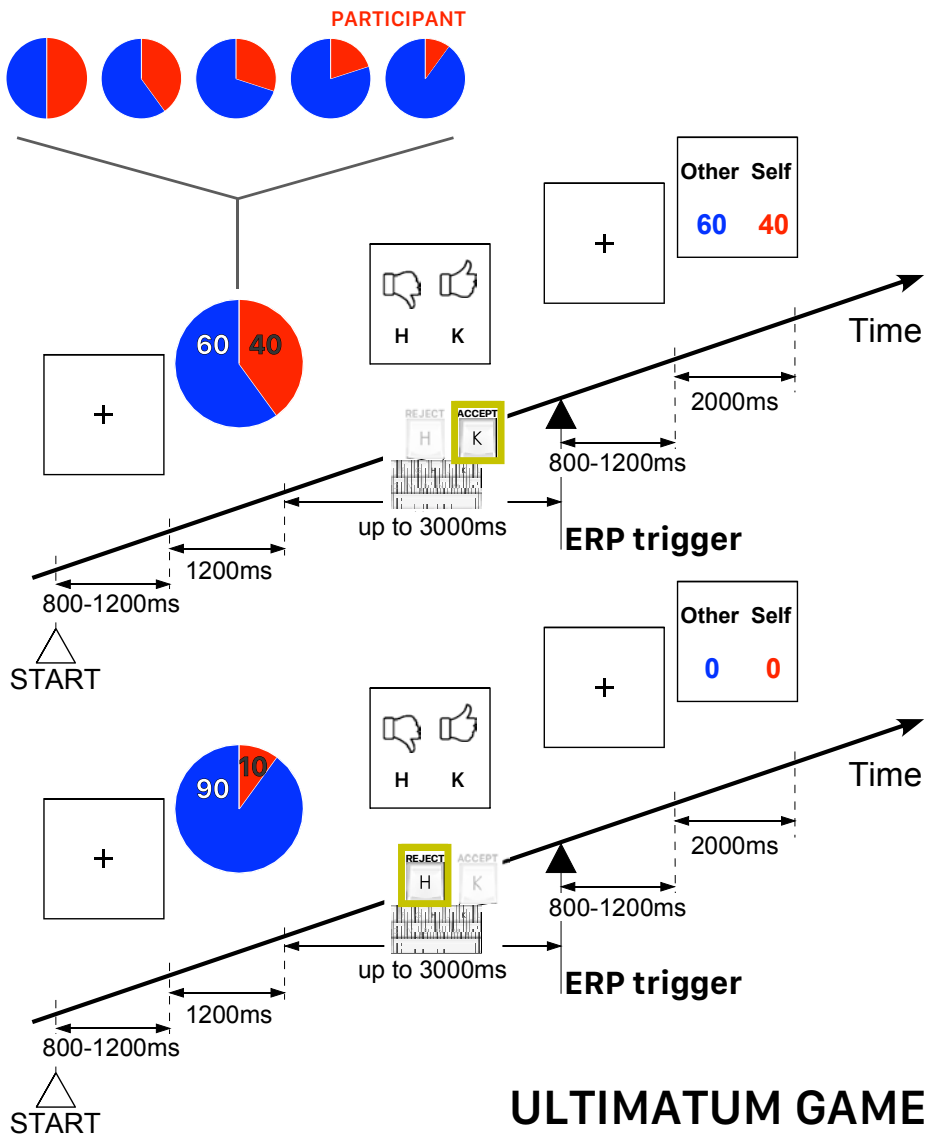

Figure 2. Schematic illustration of the time course of the Ultimatum Game task. The Participant always played the role of Responder and could either accept or reject the endowment share randomly presented on the computer screen. The upper panel shows a trial when a Participant accepted the randomly proposed share—in this example, 60% for the other player, i.e. the Virtual Proposer, and 40% for the Participant playing the role of Responder. The lower panel shows a trial when a Participant rejected the randomly proposed share—in this example, 90% for the Virtual Proposer and 10% for the Participant—thus ending with a zero payoff for both players.

negligible as "(.)": $d < 0.2$; small as "(s)": $0.2 \leq d < 0.5$; medium as "(m)": $0.5 \leq d < 0.8$; large as "(L)": $0.8 \leq d$.

In case homoscedasticity was rejected, we applied robust versions of ANOVA, i.e., heteroscedastic one-way ANOVA for medians and two- and three-way ANOVAs with trimmed means at level 0.2 with effect size assessed by $\widehat{\xi}$ with magnitudes: negligible as "(.)": $\widehat{\xi} < 0.1$; small as "(s)": $0.1 \leq \widehat{\xi} < 0.3$; medium as "(m)": $0.3 \leq \widehat{\xi} < 0.5$; large as "(L)": $0.5 \leq \widehat{\xi}$. The Mann–Whitney test was used for the unpaired two-groups comparisons with effect size assessed by r and magnitudes: negligible as "(.)": $r < 0.1$; small as "(s)": $0.1 \leq r < 0.3$; medium as "(m)": $0.3 \leq r < 0.5$; large as "(L)": $0.5 \leq r$.

3. Results

3.1. Behavioral analysis

On average (M±SEM), the participants to the Dictator Game completed 237.3±0.7 out of 240 trials. This difference is due to the fact that, in a few trials, some participants did not make the decision (to agree or refuse the allocation of the endowment share) within the maximum interval of 3000 ms. The valid DG trials were subdivided in three sets: (i) DG selfish behavior including the trials when the participant playing the role of Allocator/Proposer agreed with the most favorable allocations for himself {(90:10), (80:20)} (i.e. 90% or 80% of the share for himself) and refused the least favorable splits {(60:40), (50:50)}; (ii) DG neutral behavior including all trials (both agreed and refused) with endowment share (70:30); (iii) DG fair behavior including the trials when the participant playing the role of Allocator/Proposer agreed with less favorable allocations for himself {(60:40), (50:50)} (i.e. 60% or 50% of the share for himself) and refused the most favorable splits {(90:10), (80:20)}. Hence, on the basis of the number (Nb.) of trials belonging to these three sets, we computed the index $DG_{selfishness}$ (in the range [-1,+1]), such that the higher the index the more selfish the behavior, defined as follows:

$$DG_{selfishness} = \frac{(\mathrm{Nb}_{(DG\ selfish\ behavior)} - \mathrm{Nb}_{(DG\ fair\ behavior)})}{(\mathrm{Nb}_{(DG\ selfish\ behavior)} + \mathrm{Nb}_{(DG\ fair\ behavior)})} \quad . \tag{1}$$

In the Ultimatum Game, all participants played the role of Responder and completed 238.1±0.4 trials. The behavioral analysis during UG was based on the subdivision of valid trials in the next three sets: (i) UG altruistic behavior including the trials when the Responder accepted the least favorable offers for himself {(90:10), (80:20)} (i.e. 10% or 20% of the share for himself) and rejected the equitable splits {(60:40), (50:50)}; (ii) UG neutral behavior including all trials (both accepted and rejected) offering an endowment share (70:30); (iii) UG conceit behavior including the trials when the Responder accepted the equitable offers {(60:40), (50:50)} and rejected the least favorable offers {(90:10), (80:20)}. Notice that in this version of UG, the equitable splits {(60:40), (50:50)} corresponded also to the most favorable payoffs that a Responder could expect to receive. In a way similar to DG, we computed an index termed $UG_{altruism}$ (in the range [-1,+1]) based on the the number of trials in each set, such that the higher the index the more altruistic the behavior, defined as follows:

$$UG_{altruism} = \frac{(\mathrm{Nb}_{(UG\ altruistic\ behavior)} - \mathrm{Nb}_{(UG\ conceit\ behavior)})}{(\mathrm{Nb}_{(UG\ altruistic\ behavior)} + \mathrm{Nb}_{(UG\ conceit\ behavior)})} \quad . \tag{2}$$

On the basis of both indexes $DG_{selfishness}$ and $UG_{altruism}$, we performed an agglomerative hierarchical clustering using the function `hclust` set with a metric Euclidean distance and the complete-linkage option of the standard `stats` package of R [64]. At the begin, the procedure considered the possibility of 39 clusters, i.e. one cluster for each participant. Then, the algorithm analyzed iteratively the outcome of the clustering such that the number of clusters decreased at each step and and the procedure finally stabilized and stopped with four clusters, labeled 'GrpS', 'GrpB', 'GrpC', 'GrpF'. The procedure was repeated with different random seeds at the beginning. Then, we identified an additional cluster labeled 'GrpA' formed by those individuals that could not be attributed uniquely to one of the four stable clusters. Table 1 reports the behavioral features of the clusters of participants and cluster 'GrpA' was composed by three participants whose behavior was intermediate between 'GrpS' and 'GrpB'.

One stable cluster of participants, 'GrpF', tended to express a conceit behavior during UG but a low level of selfishness during DG. Cluster 'GrpS' corresponded to participants with a very high value of $DG_{selfishness}$ and the lowest level of $UG_{altruism}$. Cluster 'GrpB' corresponded to participants with a medium–low $UG_{altruism}$ index and medium–high $DG_{selfishness}$ index. The most heterogeneous group, 'GrpC', corresponded to participants with variable $UG_{altruism}$ and medium–low $DG_{selfishness}$.

Table 1. Relative frequencies of the behavioral responses to the Dictator Game and Ultimatum Game and the corresponding behavioral indexes $DG_{selfishness}$ and $UG_{altruism}$ of the five groups of participants sorted after an agglomerative hierarchical clustering procedure described in the text. The reported values are median, mean±SEM.

	$N = 39$	'GrpS' ($n = 8$)	'GrpA' ($n = 3$)	'GrpB' ($n = 10$)	'GrpC' ($n = 8$)	'GrpF' ($n = 10$)
Dictator Game						
Selfish behavior (%)		79 77± 1	65 68± 6	69 69± 3	45 49± 4	3 9± 3
Neutral behavior (%)		20 20± 0	20 19± 0	20 20± 0	20 20± 0	20 20± 0
Fair behavior (%)		1 3± 1	15 13± 6	11 11± 3	35 31± 4	77 71± 3
$DG_{selfishness}$		0.98 0.93±0.03	0.60 0.69±0.14	0.73 0.71±0.07	0.13 0.24±0.10	-0.92 -0.79±0.07
Ultimatum Game						
Altruistic behavior (%)		1 4± 2	13 13± 4	24 25± 2	28 29± 7	1 2± 1
Neutral behavior (%)		20 20± 0	20 20± 0	20 20± 0	20 20± 0	20 20± 0
Conceit behavior (%)		79 76± 2	67 67± 4	56 55± 2	52 51± 7	79 78± 1
$UG_{altruism}$		-0.97 -0.89±0.05	-0.69 -0.68±0.10	-0.40 -0.39±0.05	-0.29 -0.26±0.18	-0.97 -0.95±0.01

Figure 3 shows the scatterplot of the 39 participants distributed on a 2D feature space defined by the corresponding values of $UG_{altruism}$ and $DG_{selfishness}$.

3.2. Electrophysiological results

Figure 4 shows the grand average ERPs for all trials recorded at fronto-central (FCz and Fz) and posterior-parietal sites (Pz and CPz) triggered by the stimulus onset in both games and followed by a response (accept or reject) for all 39 participants grouped together. The visual inspection of the grand-averaged waveforms showed several components, which were generally observed in both games and at various scalp locations, but their amplitudes varied greatly as a function of the participant and of the recording site. The earliest component was a negative wave (N1) ranging in latency between 110 and 160 ms post trigger, particularly visible at fronto-central sites, and at FCz in particular. The N1 component was tiny and noisy in the ERP of several participants, which led us to discard this wave from further quantitative analysis. This wave was followed by P2, a positive component peaking at approximately 220 ms post trigger and by a negative wave peaking within the interval 260-400 ms after trigger onset. Notice that the amplitude (between the peak of P2 and the immediately successive trough) of this negative component was larger at fronto-central sites for both games (Fig. 4), which led us to consider this wave being the medial frontal negativity (MFN). At posterior-parietal sites, the shape and latency of this negativity wave was different and the component was termed N2. A positive wave extending from 400 to 650 ms after trigger onset followed MFN/N2 (Fig. 4). This extended positivity was characterized by two successive peaks, which might be identified as putative P3 and late positive potential. The amplitude of this positivity was larger at posterior-parietal site and at this site the value of the potential of the second peak was higher than the first peak. For this reason, we considered the second peak at posterior-parietal site as being the most representative of the extended positivity and termed it as late positive component (LPC).

The most homogenous groups defined by the behavioral analysis were 'GrpB', 'GrpF', and 'GrpS'. We analyzed the ERPs of all these groups, but the attention was mainly focused on the groups of selfish (GrpS) and fair participants (GrpF). The earliest wave N1 was characterized by a large variability among participants and trials. In order to carry out a quantitative analysis of this wave and a comparison between UG and DG, we pooled all trials together, irrespective of the endowment share and of participants' decision, and we measured the grand averaged peak latencies and peak

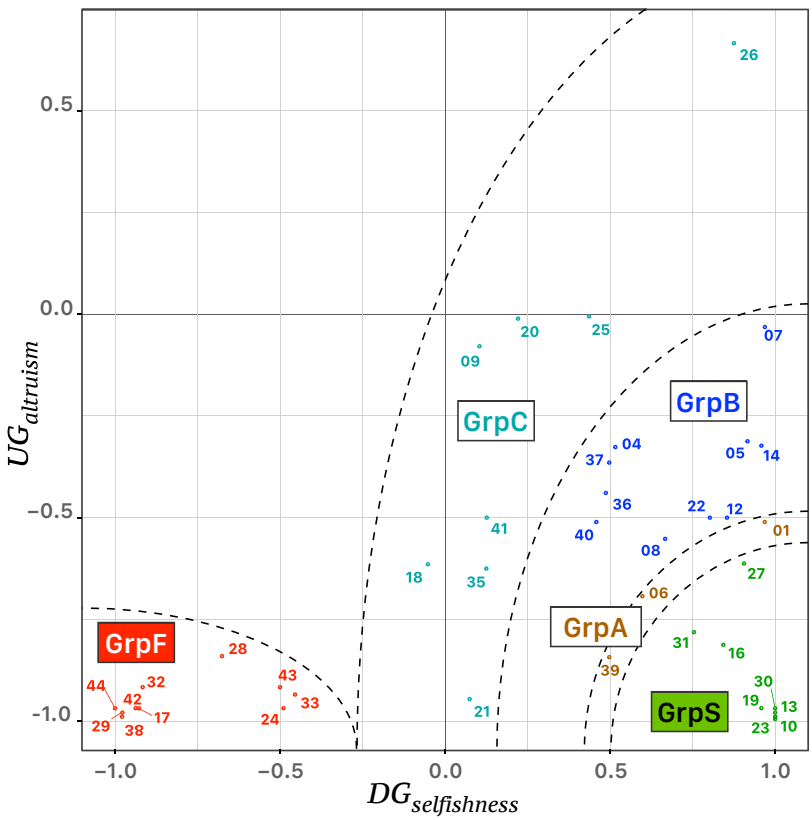

Figure 3. Scattergram of the behavioral analysis of 39 participants, identified by their identification tag, distributed in a 2D feature space defined by the corresponding values of $UG_{altruism}$ and $DG_{selfishness}$. Five clusters of colored points were identified on the bases of an agglomerative hierarchical clustering procedure, i.e. 'GrpS' (green), 'GrpA' (brown), 'GrpB' (blue), 'GrpC' (turquoise), and 'GrpF' (red). The dashed lines corresponding to ideal separatrix lines in the feature space are plotted only to facilitate the identification of the clusters.

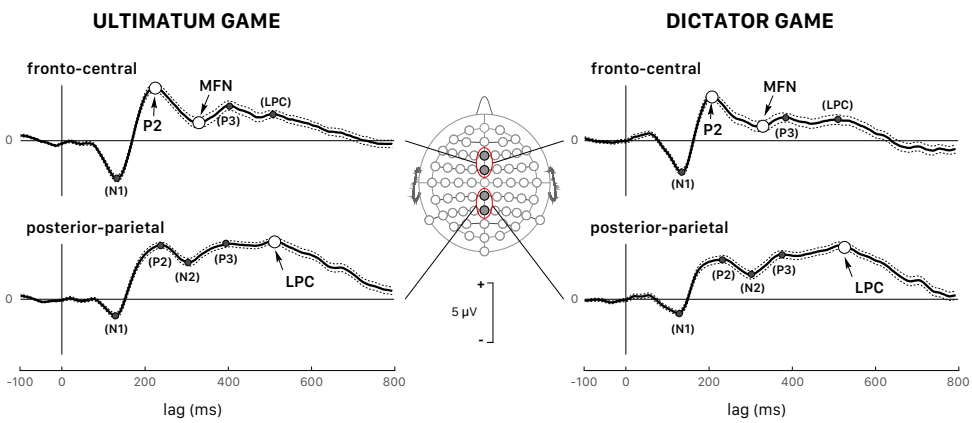

Figure 4. Grand grand average (all 39 participants and all trials pooled together) of the ERPs triggered by stimulus presentation during the Ultimatum Game (left panels) and the Dictator Game (right panels). The dotted lines show the confidence intervals determined by the standard error of the mean (SEM). All peaks indicated with arrows correspond to the wave components whose latency and peak were analyzed in detail: P2 and medial frontal negativity (MFN) at the fronto-central sites (Fz and FCz, upper panels) and the late positive component (LPC) at the posterior-parietal sites (Pz and PCz, lower panels). All peaks identified within parentheses indicate the wave components that were not further analyzed quantitatively.

potentials (referred also as peak voltages). Two independent measurements of the latency and voltage of N1 were performed by three trained experimenters for each participant included in GrpF and GrpS. These measurements are summarized in Table 2. Figure 5 shows the grand average ERPs for pooled trials of GrpF and GrpS participants. The N1 of fair participants (GrpF) were characterized by deeper negativity and longer latency than selfish participants (GrpS). This difference held for both games and for both measurements, with a level of significance always $p < .01$ and medium to large effect sizes (Table 2). In contrast, no significant difference was observed between DG and UG for N1 within each group of participants.

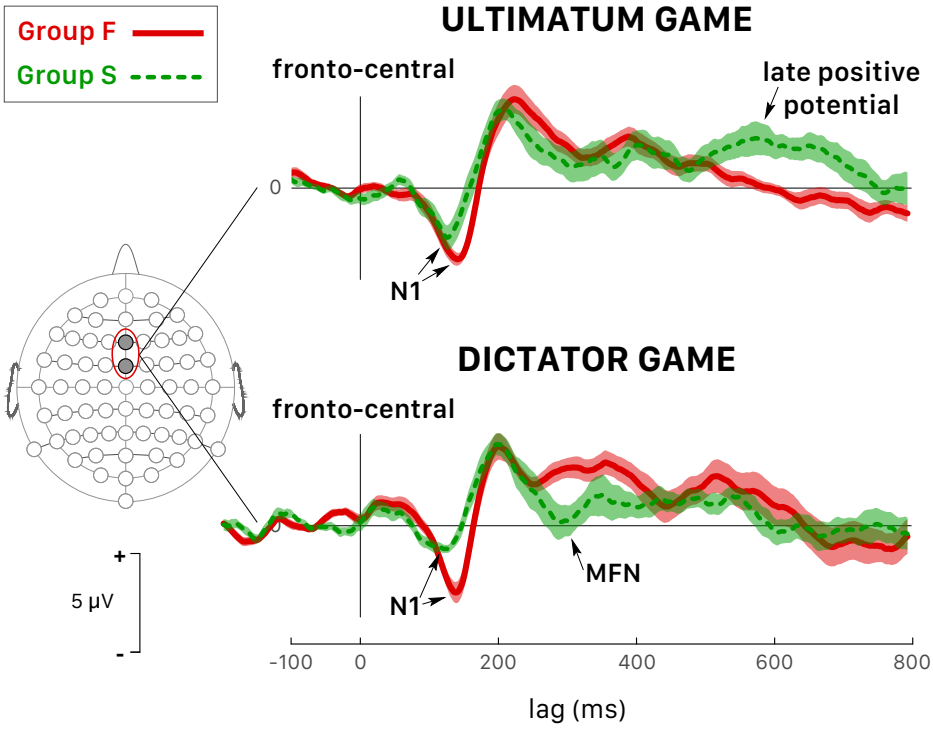

Figure 5. Grand grand average (all 39 participants and all trials pooled together) of the ERPs recorded at Fz and FCz (pooled together) for participants of GrpF (red solid curves) and GrpS (green dashed curves) during the Ultimatum Game (top panel) and the Dictator Game (bottom panel). The colored bands show the confidence intervals determined by the standard error of the mean (SEM). Notice the consistent differences between the groups of participants at the level of N1 during both games.

Figure 5 shows two other striking differences between GrpF and GrpS participants. Firstly, during DG only, the MFN was almost absent in the ERP recorded in the group of fair participants. Secondly, during UG only, a sustained late positive potential appeared in the group of selfish participants and was absent in GrpF. Such late positive component at fronto-central sites suggests that its source was likely to be different from the usual LPC at the posterior-parietal sites. These observations highlight different brain dynamics between the participants of GrpF and GrpS, but these curves were obtained with a super pool of trials, including all trials regardless of the amount of the endowment, the decision-making process and the related payoff, if any.

In order to carry out a more refined quantitative analysis of P2, MFN and LPC, and a comparison between UG and DG, we measured peak average latencies and potentials at the the fronto-central sites for P2 and MFN (upper panels in Fig. 4) and at the posterior-parietal sites for LPC (lower panels in Fig. 4). For each game, the ERPs measurements were performed in four different conditions (2×2 factors, i.e. Response (DG: 'agreed', 'refused'; UG: 'accept', 'reject') × behavior (DG: 'selfish', 'fair'; UG: 'conceit', 'altruistic'). In all participants, the wave components were not always clearly

Table 2. ERP wave component N1. The table reports the median, mean ±SEM values of the peak latency (in ms) and voltage (in μV) of N1 recorded at the fronto-central area (Fz and FCz pooled together) of fair (GrpF) and selfish (GrpS) participants, irrespective of the endowment share and of participants' decision. A one-way factor analysis was performed with only the factor participants' groups. The table reports the outcome of this analysis (p-value and magnitude of the corresponding effect size in parenthesis, (.): negligible; (s):small; (m): moderate; (L): large), as well as the p-value of the Levene's test. The Levene's test for heteroscedascity (if $p < .05$, the null hypothesis that the variances are unequal cannot be rejected) indicates whether a standard or a robust ANOVA was performed.

	DG: Allocator		UG: Responder	
	N1		N1	
Factor	*Latency* [ms]	Voltage [μV]	*Latency* [ms]	Voltage [μV]
Participants' groups				
'GrpF'	138.1 139.0±1.2	-2.76 -3.00±0.27	140.1 140.1±2.1	-3.38 -3.60±0.17
'GrpS'	129.9 127.7±2.3	-1.89 -1.77±0.16	126.8 127.5±2.4	-2.04 -2.48±0.33
Factor analysis: p (eff. size)	< .01 (L)	< .01 (L)	< .001 (m)	< .001 (m)
Levene's test: (p)	(< .001)	(< .001)	(.63)	(< .01)

distinguishable neither in all channels nor in all conditions. Then, two independent measurements of the peaks and amplitudes were performed by three trained experimenters for each participant's condition. Eventually, the factor analysis included the dependent variables 'latency' and 'voltage' of P2, MFN, and LPC wave components with 2 levels of factor 'game' (DG, UG) × 3 levels of factor 'group' (GrpB, GrpF, GrpS). In general, the variances were unequal across the groups and the robust ANOVA was performed to assess the significance of the factors.

All main effects were significant to some degree for both dependent variables of the three main wave components, with the exception of $\text{P2}_{voltage}$ which was not statistically different between UG and DG ($F(1,940) = 0.46$, $p = 0.50$). Regardless of the game, the most significant main effects for factor group were observed on the latency of MFN ($F(2,396) = 28.40$, $p < 0.001$, effect size $\widehat{\xi} = 0.34$), in particular with $\text{MFN}_{latency_\text{GrpS}} = 306.2 \pm 1.9$ ms $< \text{MFN}_{latency_\text{GrpF}} = 319.1 \pm 1.8$ ms ($U = 62546$, $n_1 = 366, n_2 = 288$, $p < 0.001$, $r = 0.16$), and on the value of LPC voltage ($F(2,412) = 52.86$, $p < 0.001$, $\widehat{\xi} = 0.35$), with $\text{LPC}_{voltage_\text{GrpS}} = 6.19 \pm 0.18$ μV $> \text{LPC}_{voltage_\text{GrpF}} = 4.37 \pm 0.24$ μV ($U = 33686$, $n_1 = 360, n_2 = 294$, $p < 0.001$, $r = 0.31$). However, in addition to the observation in Figure 5, we found that the factor game had also an important effect on LPC regardless of the participants' groups ($F(1,1030) = 69.05$, $p < 0.001$, $\eta^2_G = 0.07$). The factor analysis showed that $\text{LPC}_{latency_\text{UG}} = 519.6 \pm 2.0$ ms was shorter than $\text{LPC}_{latency_\text{DG}} = 543.8 \pm 2.2$ ms ($t(1030) = 8.31$, $p < 0.001$, $d = 0.52$). We observed also $\text{LPC}_{voltage_\text{UG}} = 5.63 \pm 0.20$ μV was larger than $\text{LPC}_{voltage_\text{DG}} = 4.34 \pm 0.16$ μV (Mann–Whitney $U = 108533$, $n_1 = n_2 = 516$, $p < 0.001$, $r = 0.16$). The effects of factor game on decision-making processes were multiple and complex. In the next two subsections we present the most salient results on the ERP wave components for each game, separately.

3.2.1. Dictator Game

In the Dictator Game, the factor analysis included 2 levels of 'response' (agreed, refused) × 2 levels of 'behavior' ('selfish', 'fair'). This means that we considered separately four sets of trials: (i) the 'selfish' trials with the Allocator/Proposer in 'agreement' with the randomly selected shares {(90:10), (80:20)} (i.e. 90% or 80% of the share for the Allocator/Proposer); (ii) the 'selfish' trials with the Allocator/Proposer 'refusing' the least favorable (in the current task design) endowment shares for himself, i.e. {(60:40), (50:50)}; (iii) the 'fair' trials with the Allocator/Proposer in 'agreement' with the endowment shares {(60:40), (50:50)}; (iv) the 'fair' trials with the Allocator/Proposer 'refusing' the most favorable endowment shares for himself, i.e. {(90:10), (80:20)}.

Table 3. Dictator Game. All participant played the role of Allocators. Peak Latency (in ms) and voltage (in μV) of P2 and MFN recorded at the fronto-central area and LPC recorded at the posterior-parietal area. Same legend of Table 2.

Dictator Game	Allocator					
	P2		MFN		LPC	
Factor	*Latency* [ms]	Voltage [μV]	*Latency* [ms]	Voltage [μV]	*Latency* [ms]	Voltage [μV]
Response choice						
Agreed	211.3 217.4±1.7	4.99 4.76±0.26	310.6 315.6±2.9	-1.13 -1.24±0.35	540.1 544.4±3.5	5.66 4.95±0.25
Refused	219.8 220.7±1.5	4.92 5.37±0.27	343.3 343.0±2.4	-0.46 -0.88±0.29	534.5 543.3±2.6	3.96 3.79±0.21
Factor analysis: p (eff. size) Levene's test: (p)	.14 (.) (.31)	.11 (.) (.16)	< .001 (m) (.10)	.43 (.) (.14)	.58 (.) (< .05)	< .001 (s) (.10)
Participants' behavior						
Fair	214.3 222.3±1.8	5.28 5.55±0.31	330.7 327.4±2.8	-0.37 -1.35±0.37	582.0 564.9±3.9	4.00 3.96±0.27
Selfish	216.2 216.3±1.4	4.68 4.66±0.23	327.8 331.5±2.7	-1.05 -0.80±0.28	530.7 526.4±1.6	4.92 4.66±0.20
Factor analysis: p (eff. size) Levene's test: (p)	< .01 (s) (.15)	.12 (.) (< .05)	.30 (.) (.95)	.23 (.) (.07)	< .001 (L) (< .001)	< .01 (s) (< .01)
Participants' groups						
'GrpB'	222.2 223.6±1.8	5.29 5.09±0.30	347.9 352.7±3.2	-2.80 -2.64±0.40	522.2 524.2±3.3	4.04 3.69±0.30
'GrpF'	209.9 213.1±1.4	4.97 4.97±0.30	306.8 314.1±3.0	0.44 0.23±0.33	566.9 565.2±2.8	3.28 3.77±0.24
'GrpS'	214.8 221.0±2.7	3.92 5.19±0.43	316.3 316.9±2.8	0.16 -0.49±0.39	534.3 542.4±4.5	5.93 6.02±0.25
Factor analysis: p (eff. size) Levene's test: (p)	< .001 (s) (< .001)	.90 (.) (.51)	< .001 (L) (.18)	< .001 (m) (< .01)	< .001 (m) (.41)	< .001 (m) (< .001)

For wave P2, the two-way ANOVA 'response' × 'behavior' showed small effect sizes for the main factors and for the interaction term on $P2_{latency}$ ($F(1,482) = 5.65$, $p < 0.05$, $\eta^2_G = 0.02$). The effect size of the interaction term was moderate for $P2_{voltage}$ ($F(1,482) = 30.49$, $p < 0.001$, effect size $\eta^2_G = 0.06$). In the case when the Allocator/Proposer refused the most favorable (selfish) {(90:10), (80:20)} endowment shares, the P2 wave tended to occur approximately 10 ms earlier and with a smaller peak by 2.5 μV than after refusal of fair shares {(60:40), (50:50)}. The differences were significant between latencies with $P2_{latency} = 215.4 \pm 1.8$ ms —when refusing selfish shares— vs. $P2_{latency} = 226.5 \pm 2.5$ ms —when refusing fair shares— ($t(250) = 3.69$, $p < 0.001$, $d = 0.47$) and between voltages with $P2_{voltage} = 4.02 \pm 0.31$ μV —when refusing selfish shares— vs. $P2_{voltage} = 6.85 \pm 0.43$ μV —when refusing fair shares— ($t(250) = 5.43$, $p < 0.001$, $d = 0.68$). In agreement with these observations, the analysis for factor 'group' of Table 3 showed that group 'GrpF' participants were characterized by $P2_{latency} = 213.1 \pm 1.4$ ms shorter by about 10 ms with respect to the other groups. On the opposite, the analysis for the single factor 'behavior' was less clear because the pooled trials for fair behavior included the trials after the Allocator/Proposer agreed with any fair endowment share, as well as the trials after refusal of the most favorable payoffs (and no player receiving any payoff).

The two-way ANOVA 'response' × 'behavior' showed a clear effect on the peak latency of MFN, with $MFN_{latency} = 295.4 \pm 3.0$ ms —when the Allocator/Proposer agreed with fair shares {(60:40), (50:50)}— much shorter than $MFN_{latency} = 353.6 \pm 3.6$ ms —after agreement of selfish endowment {(90:10), (80:20)}— (Mann–Whitney $U = 1542$, $n_1 = 108, n_2 = 132$, $p < 0.001$, $r = 0.68$). Figure 6 shows the averaged ERPs of each participants' group after the agreement or refusal of the most representative endowment shares. The factor analysis (Table 3) showed nothing significant for factor 'behavior' and a strong effect for factor 'group' due to the significant difference between GrpB and the other two groups. This difference held for both $MFN_{latency}$ and $MFN_{voltage}$. It is interesting to note that the behavioral analysis (Table 1) showed that GrpB was characterized by relatively more altruism in comparison to GrpF and GrpS.

Regardless of the decision made by the Allocator/Proposer (agreement or refusal), the peak latencies of LPC were approximately 35 ms shorter after receiving any proposal of selfish endowment

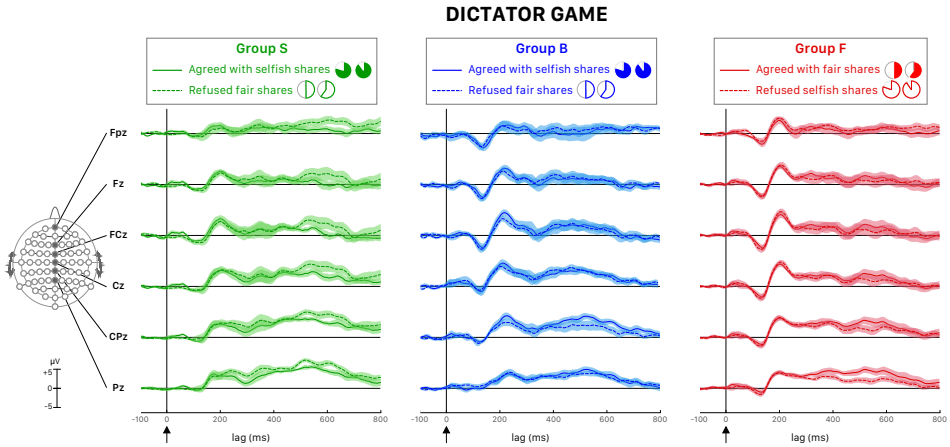

Figure 6. Analysis of the most representative trials for three groups of participants during the Dictator Game. All participants played the role of Allocator/Proposer. Averaged ERPs (and ±SEM bands) for the main midline electrodes triggered (arrow at time zero) by the presentation of the endowment share proposed to the Allocator. The post-hoc analysis allowed to sort the trials following the Allocator's decision making. In the left and middle panels, curves with solid trait correspond to the averaged ERPs after the Allocator agreed with selfish shares {(90:10), (80:20)} (i.e., 90% or 80% of the share for the Allocator/Proposer) and curves with dashed trait correspond to the averaged ERPs after the Allocator refused the fair shares {(60:40), (50:50)} (i.e., 60% or 50% of the share for the Allocator/Proposer) for participants of GrpS (green curves on the left) and GrpB (blue curves in the middle). For participants of GrpF (red curves), the right panels show solid curves corresponding to the averaged ERPs after agreeing with fair shares and dashed curves after refusing selfish shares.

share ($F(1,170) = 82.45$, $p < 0.001$, $\widehat{\xi} = 0.61$). We observed $\text{LPC}_{latency} = 521.9 \pm 2.0$ ms and $\text{LPC}_{latency} = 530.6 \pm 2.4$ ms —after refusal and agreement of a selfish share, respectively— shorter than $\text{LPC}_{latency} = 565.8 \pm 4.0$ ms and $\text{LPC}_{latency} = 563.9 \pm 7.5$ ms —after refusal and agreement of a fair share, respectively. The differences among the groups (Table 3) showed shorter latency and larger peak voltage for selfish (GrpS) than fair (GrpF) participants. The differences between participants of these groups were very clear in Figure 6 showing the averaged ERPs after the Allocator/Proposer agreed with the most representative shares of the corresponding group. In GrpS, we observed $\text{LPC}_{latency} = 542.4 \pm 4.5$ ms and $\text{LPC}_{amplitude} = 6.02 \pm 0.25$ μV in comparison to $\text{LPC}_{latency} = 565.2 \pm 2.8$ ms and $\text{LPC}_{amplitude} = 3.77 \pm 0.24$ μV for the GrpF participants.

3.2.2. Ultimatum Game

In the Ultimatum Game, we considered separately four sets of trials: (i) the 'altruistic' trials with the Responder 'accepting' less favorable endowment shares {(90:10), (80:20)} (i.e., the Responder received only 10% or 20% of the share); (ii) the 'altruistic' trials with the Responder 'rejecting' equitable (the most favorable in the current task design) offers {(60:40), (50:50)}; (iii) the 'conceit' trials with the Responder 'accepting' the offers {(60:40), (50:50)} (i.e., the Responder received 40% or 50% of the share); (iv) the 'conceit' trials with the Responder 'rejecting' less favorable endowment shares {(90:10), (80:20)}. Whatever offer was rejected by the Responder, either 'altruistic' or 'conceit', ended the trial with both players without any payoff.

The factor analysis with 2 levels 'response' (accept, reject) × 2 levels 'behavior' ('altruistic', 'conceit'), shows a significant main effect for 'response' on $\text{P2}_{latency}$ ($F(1,482) = 35.45$, $p < 0.001$, effect size $\eta^2_G = 0.07$), which is confirmed also in the one-way ANOVA (Table 4). The shortest latencies $\text{P2}_{latency} = 206.5 \pm 4.0$ ms were observed when the Responder rejected the less favorable offers {(90:10), (80:20)} with respect to $\text{P2}_{latency} = 223.5 \pm 1.7$ ms —when rejecting the equitable offers {(60:40), (50:50)}— (Mann-Whitney test, $U = 2459$, $n_1 = 48, n_2 = 144$, $p < 0.01$, $r = 0.22$) and to

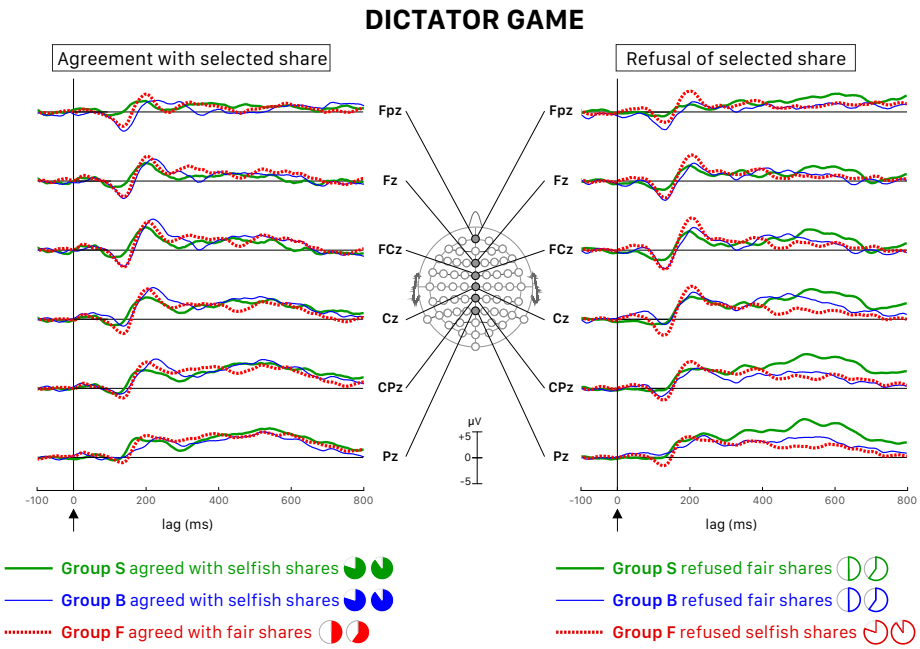

Figure 7. Averaged ERPs for the main midline electrodes triggered (arrow at time zero) by the presentation of the endowment share proposed to the Allocator. The post-hoc analysis allowed to sort the trials following the Allocator's decision making. The left panels show the averaged ERPs for the most representative trials when the Allocator agreed with the proposal, which was selfish shares {(90:10), (80:20)} for participants pooled in groups GrpS (selfish participants, thick green curves) and GrpB (thin blue curves), and fair shares {(60:40), (50:50)} for participants pooled in group GrpF (fair participants, dotted red lines) The right panels show the averaged ERPs for the most representative trials when the Allocator refused the randomly selected endowment share, which was refusal of fair shares {(60:40), (50:50)} for groups GrpS (thick green curves) and GrpB (thin blue curves), and refusal of selfish shares {(90:10), (80:20)} for group GrpF (dotted red lines).

$P2_{latency} = 230.1 \pm 2.6$ ms —when accepting the less favorable offers— ($U = 3889.5$, $n_1 = 48, n_2 = 114$, $p < 0.001$, $r = 0.33$).

The one-way ANOVA (Table 4) showed that the peak latency of MFN was strongly affected by both factors 'response' and 'behavior', in agreement with the significant independent main effect of 'response' in the two-way ANOVA. We observed $MFN_{latency} = 303.0 \pm 2.9$ ms —when the Responder accepted altruistic offers {(90:10), (80:20)}— shorter than $MFN_{latency} = 330.9 \pm 2.1$ ms —after acceptance of conceit offers {(60:40), (50:50)}— (Mann-Whitney $U = 5711.5$, $n_1 = 132, n_2 = 168$, $p < 0.001$, $r = 0.42$). The difference in latency between acceptance of conceit offers and rejection ($MFN_{latency} = 310.9 \pm 2.2$ ms) was also significant ($U = 19110.5$, $n_1 = 162, n_2 = 168$, $p < 0.001$, $r = 0.35$). With rejected and accepted trials in the same pool, we observed shorter latencies after receiving altruistic offers (Table 4, one-way ANOVA of factor 'behavior'). Regardless of the decision to accept or reject the offer, the factor analysis for $MFN_{amplitude}$ showed that MFN peaked significantly lower after receiving an altruistic offer (Table 4). Figure 8 shows the ERPs during acceptance of equitable shares (the most favorable shares in the current task design) and rejection of the less favorable shares. In this figure, the ERPs of GrpS participants (left panels, green curves) clearly show the effect of the response choice at the level of MFN, in contrast with the other groups. In addition, the analysis of main factor 'group' (Table 4) showed that selfish participants (GrpS) were characterized by much shorter latency of MFN (tested by Mann-Whitney test $U = 10247$, $n_{GrpS} = 156, n_{GrpF} = 174$, $p < 0.001$, $r = 0.21$) than fair participants (GrpF), with $MFN_{latency} = 297.1 \pm 2.4$ ms and $MFN_{latency} = 324.3 \pm 2.0$ ms, respectively.

Table 4. Ultimatum Game. All participant played the role of Responders. Peak latency (in ms) and voltage (in μV) of P2 and MFN recorded at the fronto-central area and LPC recorded at the posterior-parietal area. Same legend of Table 2.

Ultimatum Game	Responder					
	P2		MFN		LPC	
Factor	*Latency* [ms]	Voltage [μV]	*Latency* [ms]	Voltage [μV]	*Latency* [ms]	Voltage [μV]
Response choice						
Accept	223.4 226.3±1.5	5.28 5.26±0.24	322.3 318.6±1.9	-0.05 -0.65±0.32	517.3 521.8±2.2	5.59 5.56±0.20
Reject	218.1 218.3±1.6	4.73 5.28±0.41	301.7 303.3±1.9	-1.00 -1.75±0.47	513.9 516.7±3.5	5.53 5.72±0.37
Factor analysis: p (eff. size) Levene's test: (p)	< .001 (s) (.33)	.07 (s) (< .001)	< .001 (m) (< .01)	.22 (s) (< .01)	.35 (.) (< .001)	.99 (.) (< .001)
Participants' behavior						
Altruistic	223.2 223.1±2.3	5.53 6.17±0.54	292.9 296.7±2.2	-3.50 -3.37±0.59	528.2 530.7±4.2	6.38 6.77±0.43
Conceit	219.7 222.9±1.2	4.85 4.78±0.17	319.8 321.0±1.6	0.67 0.19±0.22	514.4 513.3±1.9	4.86 4.99±0.18
Factor analysis: p (eff. size) Levene's test: (p)	.85 (.) (< .001)	.13 (s) (< .001)	< .001 (L) (.32)	< .001 (m) (< .001)	< .001 (m) (< .001)	< .001 (m) (< .001)
Participants' groups						
'GrpB'	223.0 222.3±1.8	5.00 4.88±0.25	314.1 312.9±2.5	-0.37 -0.47±0.41	515.4 516.2±2.8	5.23 5.61±0.31
'GrpF'	225.0 225.3±1.7	5.29 6.16±0.52	320.1 324.3±2.0	1.11 -1.04±0.52	514.5 509.5±3.2	3.93 5.01±0.41
'GrpS'	215.1 221.0±2.3	4.82 4.78±0.37	301.7 297.1±2.4	-2.38 -1.98±0.46	522.3 534.7±4.1	6.73 6.35±0.26
Factor analysis: p (eff. size) Levene's test: (p)	.30 (.) (.39)	< .05 (s) (< .01)	< .001 (m) (< .001)	.08 (s) (.68)	< .001 (s) (< .001)	< .001 (m) (< .001)

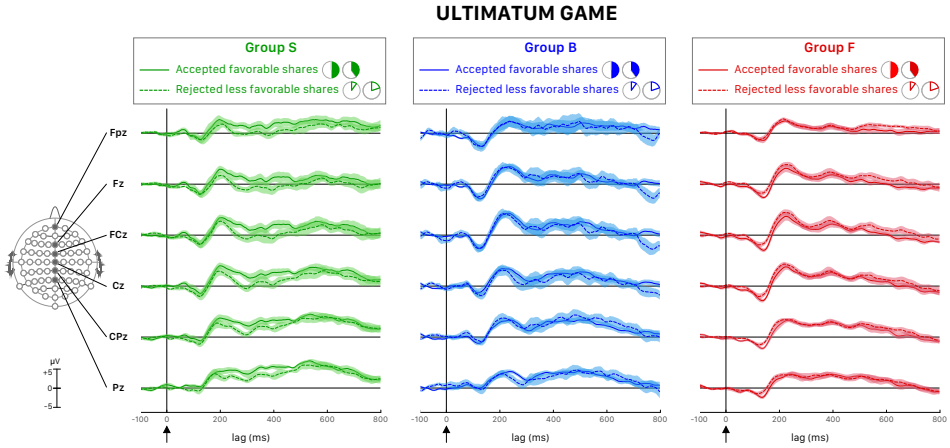

Figure 8. Analysis of 'conceit' trials during the Ultimatum Game. All participants played the role of Responder. Averaged ERPs (and ±SEM bands) for the main midline electrodes triggered (arrow at time zero) by the presentation of the endowment share to the Responder. The post-hoc analysis allowed to sort the trials following Responder's decision making. Curves with solid trait correspond to the averaged ERPS for trials when the Responder accepted the favorable shares {(60:40), (50:50)} (i.e., 40% or 50% of the share is kept by the participant) and the curves with dashed trait correspond to the trials when the Responder rejected less favorable endowment shares for himself {(90:10), (80:20)} and both players got nothing. The left panels show the ERPs of GrpS (green curves), the middle panels show the ERPs of GrpB (blue curves) and the right panels show the ERPs of GrpF (red curves) participants.

The latencies of LPC (Table 4) were about 15 ms shorter ($F(1, 148) = 24.75$, $p < 0.001$, $\widehat{\xi} = 0.36$) after receiving conceit offers {(60:40), (50:50)}, regardless of the decision made by the Responder (acceptance or rejection of the offer). Likewise, the peak voltage of LPC (Table 4) was 1.6 μV smaller

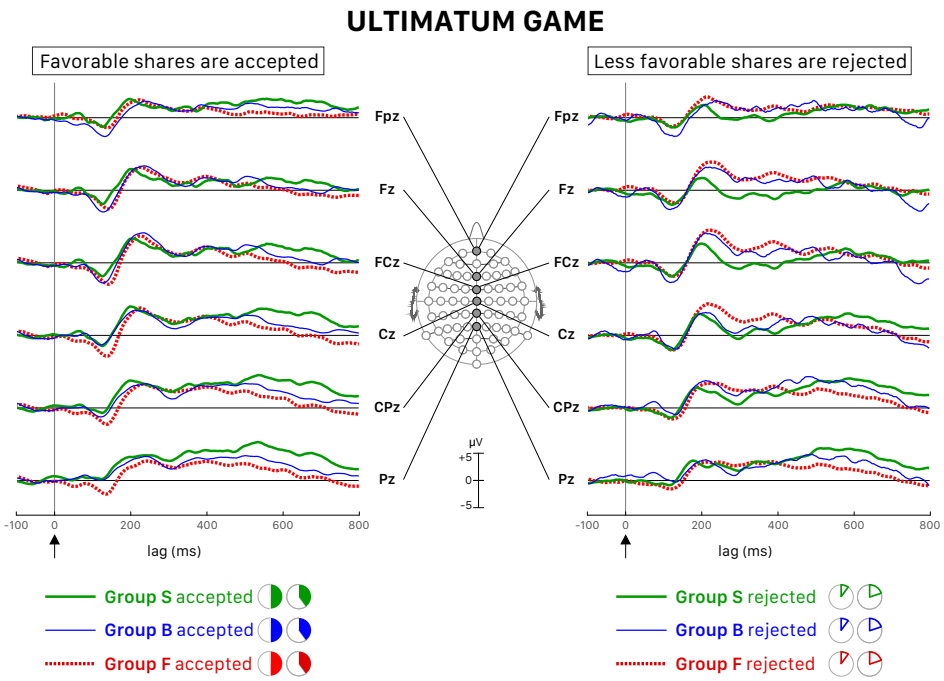

Figure 9. Analysis of 'conceit' trials during the Ultimatum Game. All participants played the role of Responder. Averaged ERPs for the main midline electrodes triggered (arrow at time zero) by the presentation of the endowment share to the Responder. The post-hoc analysis allowed to sort the trials following Responder's decision making. On the left, the curves with solid trait correspond to the trials when the Responder accepted the favorable shares {(60:40), (50:50)} (i.e., 40% or 50% of the share is kept by the participant). On the right, the curves with dashed trait correspond to the trials when the Responder rejected less favorable endowment shares for himself {(90:10), (80:20)} and both players got nothing. ERPs were pooled for participants of group GrpS (thick green curves), GrpB (thin blue curves) and GrpF (dotted red lines).

($F(1,169) = 13.41$, $p < 0.001$, $\widehat{\xi} = 0.30$) after receiving conceit offers and regardless of the decision. The effect of the main factor 'group' on both $\text{LPC}_{latency}$ ($F(2,196) = 7.95$, $p < 0.001$, $\widehat{\xi} = 0.25$) and $\text{LPC}_{amplitude}$ ($F(2,201) = 18.52$, $p < 0.001$, $\widehat{\xi} = 0.33$) showed that selfish participants (GrpS) were characterized by longer $\text{LPC}_{latency}$ ($U = 10247$, $n_{GrpS} = 156, n_{GrpF} = 174$, $p < 0.001$, $r = 0.21$) and larger $\text{LPC}_{voltage}$ ($U = 10011$, $n_{GrpS} = 156, n_{GrpF} = 174$, $p < 0.001$, $r = 0.23$) with respect to the group of fair participants. The differences of LPC between GrpS and GrpF are illustrated by Figure 9, which shows also that LPC curves for GrpB were somehow in-between.

4. Discussion

Human life is characterized by situations where the maximization of the individual payoff in face-to-face negotiations is challenged by the socio-cultural environment that contributed to shape moral phenomena such as altruism and fairness [3] and by the social distance to the other party, which affects the subjective perception of justice [36]. In the context of an increasing number of contactless monetary transactions, our study aimed to test the hypothesis whether the characteristic patterns of brain activity —recorded by ERPs— were associated with the behavioral profiles of individuals determined by [69–74] a combination of Dictator and Ultimatum Game performances in the absence of effective human interactions between the parties. The analysis of the major ERP wave components showed that our observations were in agreement with several findings reported in the literature, which were focused on only one of those classical neuroeconomic games. Furthermore, the identification of two homogeneous groups of selfish and fair participants allowed to report more precisely the activity

patterns associated with clearly modeled behaviors characterized by spiteful and costly punishments, which are respectively positively and negatively correlated with impulsive choices [20,33,75].

4.1. Behavioral results

The hierarchical cluster analysis based on performance indexes $UG_{altruism}$ and $DG_{selfishness}$ identified several groups of individuals. The most representative and homogeneous groups were formed by individuals expressing a conceit behavior during UG and with a low level of selfishness during DG ('GrpF', a proportion equal to 10/39), participants with medium-low $UG_{altruism}$ and medium-high $DG_{selfishness}$ ('GrpB', 10/39), and participants with highest values of $DG_{selfishness}$ and lowest levels of $UG_{altruism}$ ('GrpS', 8/39).

In the UG, it is rationale to expect that the Proposer offers the smallest possible amount and the Responder accepts any offer. In this study, all participants played the role of Responder and expressed conceitedness to some extent, because the most favorable splits for the Responder were {(60:40), (50:50)} —with 40% or 50% of the share for the Responder himself. In the literature, the fact that many Responders tend to reject an unfair offer it is explained by a bias towards profit maximization in UG in association with positive social factors such as common ethical principles and friendship, by negative factors such as fear of the perceived consequences of having one's offer rejected, and from the sense of guilt linked to worries about the opponent's outcome [76–78]. To test a Responder's attitude from selfless/altruistic to truly greedy, even in the absence of a face-to-face interaction, UG's task design would have to include splits {(40:60), (30:70)} as well as the most inequitable endowment shares {(10:90), (20:80)} —splits that provide 90% or 80% of the amount to the participant who plays the role of Responder. We are aware of the limitations of the task design chosen in this study which was driven by a compromise between the total duration of the experiment and the number of test repetitions that are necessary to get meaningful ERPs for both neuroeconomic games.

The rejection of the least favorable offers by the Responder —i.e., {(90:10), (80:20)}— is considered to be the expression of a punishment towards a selfish Proposer [79,80] and was interpreted either as a spiteful punishment [15] or as costly —rather than altruistic— punishment [17,81]. We observed almost identical behavioral responses of participants in groups GrpS and GrpF during UG (Table1). However, when the role of these participants became Allocator in DG, their behavior was completely opposed, which led to characterize a group of selfish (GrpS) and fair (GrpF) participants. The characterization of these groups suggests that the rejection of unequal offers in UG was driven by spiteful punishment in GrpS and costly punishment in GrpF. It should be noted that in DG, the participants have always played the role of Allocator, who is the player who imposes an endowment share on the other party, whereas in UG the participants have always played the role of Responder, who is in a passive position expecting to receive fair offers [32,49].

In addition to the GrpF participants, several GrpC participants expressed a tendency towards a selfless attitude, maybe even altruism. However, considering GrpS, GrpA and GrpB together, spiteful behavior appears as the most common, while not as overwhelming as one might expect. A single altruistic decision is likely to lack any rewarding meaning or benefit for an individual, unless its repetition over time proves it is truly beneficial and even costly punishment can help fairness overcome selfishness [1,10,82]. This feature of learned behavior is in contrast to the spiteful punishment exercised by participants who feel emotionally aroused when exposed to an unfair proposal. It is recognized that the evolution of fairness is promoted by spitefulness but it is inhibited by altruism [2,10,83].

4.2. Socio-cultural dimension

Spiteful punishment, a kind of anti-social punishment, is applied in various ways and its diversity concerns the psychological and social dimensions of regional-cultural values [84]. The socio-cultural dimension of our sample of participants, made up of young Iranian males with an academic education is likely to be considered for a better interpretation of behavioral analysis. Behavioral differences have been observed in association with cross-country differences in socio-economic status and respect for

authority [85,86]. High levels of cooperation and altruistic behavior can be observed in societies where people face economic disparities and poor social standing, and where they are exposed to punitive behavior if they violate certain norms and are treated as inappropriate [10,87,88].

Despite the evidence of altruistic tendencies in the Iranian people, such as willingness to pay for health services [89], organ donation [90], blood donation [91], moral sensitivity of nurses [92,93], the identification of the mechanisms associated with the perception of fairness has never been carefully investigated. Our results show that despite spitefulness seemed to prevail over fairness, we have indeed observed a sizable sample of participants expressing costly/altruistic punishment and a tendency to altruistic behavior. The choice to test participants without including both genders avoided the introduction of a gender effect discussed elsewhere in the literature [94–97]. We are confident that the participants included in this study did not introduce a strong behavioral bias towards one or the other extreme of the behaviors observed in the neuroeconomic games [86,98,99].

4.3. Fronto-central N1

In ERP studies, the latency and amplitude of a cortical wave component vary with the processing speed and the amount of cognitive resources required to reach the necessary degree of information processing for completion a certain mental task [100]. The earliest ERP wave component that we have analyzed is the N1 negative component, much larger at fronto-central sites, in the 110–160 ms time window after trigger onset. A fronto-central negativity at early processing stages (130–160ms) was initially associated with a visual categorization task aimed at processing a functional rather than perceptual representation of the visual stimulus [101,102]. In a visual-motor awareness task, an N1 component peaking at 130 ms was described on medial prefrontal areas, while participants expected a stimulus for decision making on whether to act or not to act [103].

In this study, we observed that this component did not vary between the games, but it was associated with the group of participants. On the one side, the N1 peak occurred earlier and with a smaller amplitude among the selfish participants (GrpS). On the other side, the group of fair participants (GrpF) was characterized by an increased latency of about 10 ms and a greater amplitude compared to GrpS. Such early frontal activation is consistent with the literature that supports the notion of a top-down prefrontal control of decision making [104] by suggesting that N1 reflects a proactive cognitive control to access the procedural knowledge necessary to enable the selected motoric patterns [102,103,105]. In our tasks, the visual cues carry a cognitive value associated with the costs and benefits determined by the behavioral/personality traits of each individual. Hence, we can interpret the N1 difference between GrpF and GrpS participants as the first evidence in ERPs between participants who have otherwise expressed costly and spiteful forms of punishment. Longer latencies and larger amplitudes in GrpF are compatible with a top-down control of a rather rich and less stereotyped set of initial activity patterns for fair participants. Our results are also in agreement with an anterior N1 enhancement assumed to reflect the cost of a modality change and readjustment of attentional weight-setting in order to optimize target detection [106,107]. It is important to distinguish the frontal N1 discussed here from the well known and described N1 component at occipital and temporal scalp sites associated with visual-spatial selective attention [108,109].

4.4. Fronto-central P2

The P2 wave peaked in the range of 180 to 260 ms and was most salient in the fronto-central area, where a top-down process using previous experience and expectations is indicative of stimulus evaluation rather than response production [110,111]. In previous decision-making studies, it was suggested that P2 is modulated by the degree of predictability of the outcomes [49] and by the social context [42,112]. In the Dictator Game, the latency of P2 for Allocators who rejected selfish endowment shares was shorter than during the rejection of fair shares. This is further evidence that participants who expressed costly and spiteful forms of punishment show significant differences in ERPs. We also observed that $P2_{voltage}$ for GrpS Allocators who rejected fair sharing was greater than when they rejected selfish

allocations. In GrpF, $P2_{voltage}$ was higher during trials when the Allocator agreed with selfish payoffs rather than fair endowments. These decisions were somewhat contrary to the characteristic trait of the behavioral strategy of each group.

It seems rational to suggest that in DG a selfish player required more cognitive resources when he refused to allocate a fair share and a fair player required more cognitive resources when he agreed to assign a selfish profit. In UG, the latency of P2 for trials ending without any payoff —i.e., when the Responder rejected the offer— was shorter than for trials when the Responder accepted the offer. In addition, there was an interesting difference between GrpS and GrpS participants. In GrpS, the latency was shorter when rejecting conceit offers as opposed to GrpF characterized by shorter latencies when rejecting altruistic offers. In the literature, few recent papers have reported increased P2 in response to rewarding contextual outcomes, which include satisfaction when observing the opponent's misfortune [43,113]. This is in accordance with our observation of a greater amplitude of P2 in GrpS participants for the rejection of altruistic offers compared to the rejection of conceit offers. Interestingly, GrpB participants, who showed an index $UG_{altruism}$ higher than in GrpS and GrpF, were characterized by a higher P2 peak for rejecting conceit than altruistic offers.

4.5. Medial Frontal Negativity

The MFN is a wave component that has been observed in association with some assessment of fairness [44–47], social status and altruistic bias [40,51,52,114], but only one study has reported quantitative ERP results in Allocators during DG [47]. However, these studies did not clearly distinguish between behavioral groups. In UG, we observed that the latencies of MFN were shorter for GrpS compared to GrpF, shorter for rejected offers than accepted and shorter for altruistic behaviors than conceit. In DG, the latencies of MFN were shorter when the Allocator got a payoff —i.e., the Allocator agreed with the proposed endowment share. Additionally, Allocators belonging to less altruistic groups (GrpF and GrpS) showed much shorter MFN latencies than GrpB when the Allocator made a decision regarding a selfish and unequal endowment share. In general, our results appear in accordance with the interpretation of a short latency of MFN as a sign of an emotional response, which required little cognitive evaluation and expressed reckless mental processing [115–119]. This is also in agreement with the presumed generation of MFN in the ACC in association with emotional regulation [120–123].

The amplitude of MFN is usually considered increased by advantageous unfairness in neuroeconomic games [46,49,52,57,124]. During DG, we observed that when Allocators belonged to GrpS and rejected fair endowment shares, MFN amplitudes were greater than in GrpF. For GrpS in particular, the refusal of a fair split in DG has elicited larger MFN waves than the refusal of selfish endowment shares. In UG, MFN amplitudes in fair participants (GrpF) were greater when the Responder accepted less favorable offers than equitable ones. These results support the hypothesis that in UG the MFN amplitude of Responders is likely to be associated with the expectation of fairness on the part of the Proposers. Thus, the perception of the offers by the Responders —all participants of this study played the role of Responders— depended on the behavioral group, and not on the absolute value of the endowment share [47,52,114,125].

4.6. Posterior-parietal late positive component

LPC is another ERP component closely related to relevant motivational stimuli and the subsequent sustained allocation of attention [56,57,126], and to the saliency of an outcome also in social comparisons [127–129]. Recent evidence provided by the analysis of a modified Dictator Game exploring the role of players' social status [40] revealed that LPC amplitude was more sensitive to the interaction of the recipient's status and fairness — i.e., with a tendency of greater amplitude triggered by unfair endowment shares for a high-status Recipient and greater amplitude triggered by fair splits for a medium-status Recipient. Evidence reported in the literature indicates that LPC-associated activity is likely to be generated by a widespread network of cerebral sources including the frontal lobe, the cingulate cortex and the parietal regions involved in attention control [130–133]. Based on this

information, the hypothesis could be advanced that there is some continuity of brain activity exists between MFN and LPC. However, a careful analysis of the differences between GrpF and GrpS does not support a simple extension of that continuity across the time interval of 200-600 ms.

During UG and DG, MFN latencies varied similarly for GrpS and GrpF participants but strong differences were observed for LPC. For GrpF participants, the results for LPC latencies were similar to those observed for MFN latencies. In UG, LPC latencies during rejection of a fair split (in our project, this was the most favorable payoff) were shorter than the rejection of less favorable offers. In DG, LPC latencies when GrpF Allocators refused to assign the most favorable payoffs for themselves were longer than latencies when rejecting less favorable payoffs. The comparison of MFN and LPC amplitudes when GrpF participants made a negative decision —i.e., no payoff for both players— showed no differences. In contrast, during UG, not only were LPC latencies for GrpF participants longer than those for GrpS (the opposite of MFN latencies), but latencies for rejection of equitable (more favorable) splits by GrpS participants were longer than rejection of less favorable offers. During DG, LPC latencies for GrpS Allocators who have rejected the most favorable payoffs for themselves were shorter than refusing less favorable payoffs —the opposite order for GrpF participants. The differences between homogeneous groups of selfish and fair participants support the hypothesis that LPC at posterior-parietal sites reflects a processing stage that evaluates norms of fairness [57] in association with saliency interacting with context [127,134–136].

4.7. Conclusion

This study has presented a novel combination of Dictator (DG) and Ultimatum Game (UG) with the aim of investigating whether ERP markers support the hypothesis that spiteful and costly punishments can be differentiated. We have presented evidence that different groups of participants can be identified on the basis of their performance at the combination of DG and UG. Two groups of participants, both with little tendency towards altruism, were characterized by a selfish or fair attitude during DG. The analysis of the middle frontal negativity (MFN) suggests that selfish participants are likely to exhibit spiteful punishment positively related to impulsive choice. The differences in the late positive component (LPC) observed between the groups can be interpreted that the costly punishment behavior enabled by GrpF participants must be stable to make sense and requires less attention than GrpS participants, whose cognitive-behavioral contradiction requires more attention and the activation of a larger cerebral network to complete the information processing necessary to make a decision. In conclusion, this study brings an original contribution and new evidence to the existence of different circuits activated by the evaluation of fair and unfair proposals in participants characterized by different expressions of perception of fairness.

Author Contributions: Conceptualization, AMM, HP, MAM, RK; formal analysis, HP, MAM, AL; funding acquisition, HP, AL; clinical investigation, MAM; methodology, AMM, HP, AL; project administration, MAM, HP, AL; supervision, HP, AL, AEPV; validation, HP, AL, AEPV, AL; visualization, AEPV, AL; writing original draft, AMM, AEPV, AL; writing-review and editing, AEPV, AL.

Funding: This research was partially supported by the Swiss National Science Foundation grant n. IZSEZ0_183401 to AEPV.

Acknowledgments: The authors extend their gratitude and acknowledgements to all study participants and study team members for their time and energy spent on this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Rachlin, H. Altruism and selfishness. Behav Brain Sci 2002, 25, 239–296.
2. Fehr, E.; Rockenbach, B. Human altruism: economic, neural, and evolutionary perspectives. Curr Opin Neurobiol 2004, 14, 784–90.
3. Altman, M. The ethical economy and competitive markets: Reconciling altruistic, moralistic, and ethical behavior with the rational economic agent and competitive markets. J. Econ. Psychol. 2005, 26, 732–757.
4. Henrich, J.; Ensminger, J.; McElreath, R.; Barr, A.; Barrett, C.; Bolyanatz, A.; Cardenas, J.C.; Gurven, M.; Gwako, E.; Henrich, N.; Lesorogol, C.; Marlowe, F.; Tracer, D.; Ziker, J. Markets, religion, community size, and the evolution of fairness and punishment. Science 2010, 327, 1480–4.
5. Rand, D.G.; Nowak, M.A. Human cooperation. Trends Cogn Sci 2013, 17, 413–25.
6. Kocher, M.; Martinsson, P.; Visser, M. Social background, cooperative behavior, and norm enforcement. J Econ Behav Organ 2012, 81, 341–354.
7. Gintis, H.; Bowles, S.; Boyd, R.; Fehr, E. Explaining altruistic behavior in humans. Evol Human Behav 2003, 24, 153–172.
8. Stallen, M.; Sanfey, A.G. The cooperative brain. Neuroscientist 2013, 19, 292–303.
9. Herrmann, B.; Thöni, C.; Gächter, S. Antisocial punishment across societies. Science 2008, 319, 1362–7.
10. Fehr, E.; Gächter, S. Altruistic punishment in humans. Nature 2002, 415, 137–40.
11. Fowler, J.H. Altruistic punishment and the origin of cooperation. Proc Natl Acad Sci U S A 2005, 102, 7047–9.
12. Du, E.; Chang, S.W.C. Neural components of altruistic punishment. Front Neurosci 2015, 9, 26.
13. Balafoutas, L.; Nikiforakis, N.; Rockenbach, B. Altruistic punishment does not increase with the severity of norm violations in the field. Nat Commun 2016, 7, 13327.
14. Jensen, K. Punishment and spite, the dark side of cooperation. Philos Trans R Soc Lond B Biol Sci 2010, 365, 2635–50.
15. Marlowe, F.W.; Berbesque, J.C.; Barrett, C.; Bolyanatz, A.; Gurven, M.; Tracer, D. The 'spiteful' origins of human cooperation. Proc Biol Sci 2011, 278, 2159–64.
16. Brañas-Garza, P.; Espín, A.M.; Exadaktylos, F.; Herrmann, B. Fair and unfair punishers coexist in the Ultimatum Game. Sci Rep 2014, 4, 6025–6025.
17. Yamagishi, T.; Li, Y.; Fermin, A.S.R.; Kanai, R.; Takagishi, H.; Matsumoto, Y.; Kiyonari, T.; Sakagami, M. Behavioural Differences and Neural Substrates of Altruistic and Spiteful Punishment. Sci Rep 2017, 7, 14654.
18. Güth, W.; Schmittberger, R.; Schwarze, B. An experimental analysis of ultimatum bargaining. J Econ Behav Organ 1982, 3, 367–388.
19. Camerer, C.F. Behavioral game theory: Experiments in strategic interaction; Princeton University Press: Princeton, NJ, 2003; p. 568.
20. Sanfey, A.G.; Rilling, J.K.; Aronson, J.A.; Nystrom, L.E.; Cohen, J.D. The neural basis of economic decision-making in the Ultimatum Game. Science 2003, 300, 1755–1758.
21. Fehr, E.; Schmidt, K. A Theory Of Fairness, Competition, and Cooperation. Quarterly Journal of Economics 1999, 114, 817–868.

22. Henrich, J.; McElreath, R.; Barr, A.; Ensminger, J.; Barrett, C.; Bolyanatz, A.; Cardenas, J.C.; Gurven, M.; Gwako, E.; Henrich, N.; Lesorogol, C.; Marlowe, F.; Tracer, D.; Ziker, J. Costly punishment across human societies. Science 2006, 312, 1767–70.
23. Fehr, E.; Fischbacher, U. Third-party punishment and social norms. Evol Human Behav 2004, 25, 63–87.
24. Hewig, J.; Kretschmer, N.; Trippe, R.H.; Hecht, H.; Coles, M.G.; Holroyd, C.B.; Miltner, W.H. Why humans deviate from rational choice. Psychophysiology 2011, 48, 507–514.
25. Bear, A.; Rand, D.G. Intuition, deliberation, and the evolution of cooperation. Proc Natl Acad Sci U S A 2016, 113, 936–41.
26. Righi, S.; Takács, K. Social Closure and the Evolution of Cooperation via Indirect Reciprocity. Sci Rep 2018, 8, 11149.
27. Chen, W.; Wu, T.; Li, Z.; Wang, L. Evolution of fairness in the mixture of the Ultimatum Game and the Dictator Game. Physica A: Statistical Mechanics and its Applications 2019, 519, 319–325.
28. Kirchsteiger, G. The role of envy in ultimatum games. J Econ Behav Organ 1994, 25, 373–389.
29. Kahneman, D.; Knetsch, J.L.; Thaler, R. Fairness as a Constraint on Profit Seeking: Entitlements in the Market. Am Econ Rev 1986, 76, 728–741.
30. Artinger, F.; Exadaktylos, F.; Koppel, H.; Sääksvuori, L. Fairness in simple bargaining games: the role of empathy and theory of mind. Jena Economic Research Paper 2010, 2010-037.
31. Spicer, J.; Galvan, A.; Hare, T.A.; Voss, H.; Glover, G.; Casey, B. Sensitivity of the nucleus accumbens to violations in expectation of reward. Neuroimage 2007, 34, 455–61.
32. Boksem, M.A.S.; De Cremer, D. Fairness concerns predict medial frontal negativity amplitude in ultimatum bargaining. Social Neuroscience 2010, 5, 118–125.
33. Rilling, J.K.; Sanfey, A.G. The neuroscience of social decision-making. Annu Rev Psychol 2011, 62, 23–48.
34. Wu, Y.; Leliveld, M.C.; Zhou, X. Social distance modulates recipient's fairness consideration in the dictator game: an ERP study. Biol Psychol 2011, 88, 253–62.
35. Luo, Y.; Wu, T.; Broster, L.S.; Feng, C.; Zhang, D.; Gu, R.; Luo, Y.J. The temporal course of the influence of anxiety on fairness considerations. Psychophysiology 2014, 51, 834–842.
36. Yu, R.; Hu, P.; Zhang, P. Social distance and anonymity modulate fairness consideration: An ERP study. Sci Rep 2015, 5, 13452.
37. Mesrobian, S.K.; Bader, M.; Götte, L.; Villa, A.E.P.; Lintas, A. Imperfect Decision Making and Risk Taking Are Affected by Personality. In Decision Making: Uncertainty, Imperfection, Deliberation and Scalability; Guy, T.V.; Kárný, M.; Wolpert, D.H., Eds.; Springer: Cham, 2015; Vol. 538, Studies in Computation Intelligence, chapter 6, pp. 145–184.
38. Peterburs, J.; Voegler, R.; Liepelt, R.; Schulze, A.; Wilhelm, S.; Ocklenburg, S.; Straube, T. Processing of fair and unfair offers in the ultimatum game under social observation. Sci Rep 2017, 7, 44062.
39. Cueva, C.; Roberts, R.E.; Spencer, T.J.; Rani, N.; Tempest, M.; Tobler, P.N.; Herbert, J.; Rustichini, A. Testosterone administration does not affect men's rejections of low ultimatum game offers or aggressive mood. Horm Behav 2017, 87, 1–7.
40. Cui, F.; Wang, C.; Cao, Q.; Jiao, C. Social hierarchies in third-party punishment: A behavioral and ERP study. Biol Psychol 2019, 146, 107722.
41. Rigoni, D.; Polezzi, D.; Rumiati, R.; Guarino, R.; Sartori, G. When people matter more than money: an ERPs study. Brain Res Bull 2010, 81, 445–452.
42. Hu, J.; Cao, Y.; Blue, P.R.; Zhou, X. Low social status decreases the neural salience of unfairness. Front Behav Neurosci 2014, 8, 402.
43. Falco, A.; Albinet, C.; Rattat, A.C.; Paul, I.; Fabre, E. Being the chosen one: social inclusion modulates decisions in the ultimatum game. An ERP study. Soc Cogn Affect Neurosci 2019, 14, 141–149.
44. Botvinick, M.; Nystrom, L.E.; Fissell, K.; Carter, C.S.; Cohen, J.D. Conflict monitoring versus selection-for-action in anterior cingulate cortex. Nature 1999, 402, 179–181.
45. Gehring, W.J.; Willoughby, A.R. The medial frontal cortex and the rapid processing of monetary gains and losses. Science 2002, 295, 2279–2282.
46. Alexopoulos, J.; Pfabigan, D.M.; Lamm, C.; Bauer, H.; Fischmeister, F.P. Do we care about the powerless third? An ERP study of the three-person ultimatum game. Front Hum Neurosci 2012, 6, e00059.

47. Li, J.; Pan, J.; Zhu, C. Inter-brain Synchronization Is Weakened by the Power to Reject Offers in Bilateral Bargaining Games. SSRN eLibrary 2020, p. e3617843.
48. Rodrigues, J.; Liesner, M.; Reutter, M.; Mussel, P.; Hewig, J. It's costly punishment, not altruistic: Low midfrontal theta and state anger predict punishment. Psychophysiology 2020, 57, e13557.
49. Polezzi, D.; Lotto, L.; Daum, I.; Sartori, G.; Rumiati, R. Predicting outcomes of decisions in the brain. Behav Brain Res 2008, 187, 116–22.
50. Lintas, A.; Vysyaraju, S.C.; Jaquerod, M.; Villa, A.E.P. Event Related Potentials Reveal Fairness in Willingness-to-share. Lect Notes Comput Sci 2017, 10613, 191–198.
51. Sun, L.; Tan, P.; Cheng, Y.; Chen, J.; Qu, C. The effect of altruistic tendency on fairness in third-party punishment. Front Psychol 2015, 6, 820.
52. Mayer, S.V.; Rauss, K.; Pourtois, G.; Jusyte, A.; Schönenberg, M. Behavioral and electrophysiological responses to fairness norm violations in antisocial offenders. Eur Arch Psychiatry Clin Neurosci 2019, 269, 731–740.
53. Polezzi, D.; Sartori, G.; Rumiati, R.; Vidotto, G.; Daum, I. Brain correlates of risky decision-making. Neuroimage 2010, 49, 1886–1894.
54. San Martín, R. Event-related potential studies of outcome processing and feedback-guided learning. Front Hum Neurosci 2012, 6, 304.
55. Harris, A.; Young, A.; Hughson, L.; Green, D.; Doan, S.N.; Hughson, E.; Reed, C.L. Perceived relative social status and cognitive load influence acceptance of unfair offers in the Ultimatum Game. PLoS One 2020, 15, e0227717.
56. Ito, T.A.; Larsen, J.T.; Smith, N.K.; Cacioppo, J.T. Negative information weighs more heavily on the brain: the negativity bias in evaluative categorizations. J Pers Soc Psychol 1998, 75, 887–900.
57. Wu, Y.; Zhou, Y.; van Dijk, E.; Leliveld, M.C.; Zhou, X. Social Comparison Affects Brain Responses to Fairness in Asset Division: An ERP Study with the Ultimatum Game. Front Hum Neurosci 2011, 5, 131.
58. World Medical Association.. World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA 2000, 284, 3043–3045.
59. R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, 2013.
60. Venables, W.N.; Ripley, B.D. Modern Applied Statistics with S, 4th ed.; Statistics and Computing, Springer-Verlag New York: 498 pp., 2002.
61. Delorme, A.; Makeig, S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods 2004, 134, 9–21.
62. Lopez-Calderon, J.; Luck, S.J. ERPLAB: an open-source toolbox for the analysis of event-related potentials. Front Hum Neurosci 2014, 8, 213.
63. Plöchl, M.; Ossandón, J.P.; König, P. Combining EEG and eye tracking: identification, characterization, and correction of eye movement artifacts in electroencephalographic data. Front Hum Neurosci 2012, 6, 278–301.
64. Team, R.C. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, 2020.
65. Mair, P.; Wilcox, R. Robust statistical methods in R using the WRS2 package. Behav Res Methods 2020, 52, 464–488.
66. Makowski.; Dominique.; Lüdecke.; Daniel. The report package for R: Ensuring the use of best practices for results reporting. CRAN 2019. R package.
67. Kassambara, A. rstatix: Pipe-Friendly Framework for Basic Statistical Tests, 2020. R package version 0.6.0.
68. Lüdecke, D. sjstats: Statistical Functions for Regression Models (Version 0.18.1), 2021.
69. Nagel, R. Rationality and emotions in ultimatum bargaining: Comment. Annales d'Economie et de Statistique 2001, pp. 33–39.
70. De Martino, B.; Kumaran, D.; Seymour, B.; Dolan, R.J. Frames, biases, and rational decision-making in the human brain. Science 2006, 313, 684–7.
71. Fellner, G.; Güth, W.; Maciejovsky, B. Satisficing in financial decision making -a theoretical and experimental approach to bounded rationality. J Math Psychol 2009, 53, 26–33.

72. Güth, W. The Generosity Game and Calibration of Inequity Aversion. Journal of Socio-Economics 2010, 39, 155–157.
73. De Neys, W.; Novitskiy, N.; Geeraerts, L.; Ramautar, J.; Wagemans, J. Cognitive control and individual differences in economic ultimatum decision-making. PLoS One 2011, 6, e27107.
74. Fiori, M.; Lintas, A.; Mesrobian, S.; Villa, A.E.P. Effect of Emotion and Personality on Deviation from Purely Rational Decision-Making. In Decision Making and Imperfection; Guy, V.T.; Kárný, M.; Wolpert, D., Eds.; Springer: Berlin, Heidelberg, 2013; pp. 129–161.
75. Rodrigues, J.; Nagowski, N.; Mussel, P.; Hewig, J. Altruistic punishment is connected to trait anger, not trait altruism, if compensation is available. Heliyon 2018, 4, e00962.
76. Carver, C.S.; Miller, C.J. Relations of serotonin function to personality: Current views and a key methodological issue. Psychiatry Res 2006, 144, 1–15.
77. Marchetti, A.; Castelli, I.; Harlé, K.M.; Sanfey, A.G. Expectations and outcome: The role of Proposer features in the Ultimatum Game. J Econ Psychol 2011, 32, 446 – 449.
78. Gaertig, C.; Moser, A.; Alguacil, S.; Ruz, M. Social information and economic decision-making in the ultimatum game. Front Neurosci 2012, 6, 103–103.
79. Forber, P.; Smead, R. The evolution of fairness through spite. Proc Biol Sci 2014, 281, 20132439.
80. Ma, Q.; Hu, Y.; Jiang, S.; Meng, L. The undermining effect of facial attractiveness on brain responses to fairness in the Ultimatum Game: an ERP study. Frontiers in neuroscience 2015, 9, 1–17.
81. Brethel-Haurwitz, K.M.; Stoycos, S.A.; Cardinale, E.M.; Huebner, B.; Marsh, A.A. Is costly punishment altruistic? Exploring rejection of unfair offers in the Ultimatum Game in real-world altruists. Scientific reports 2016, 6.
82. Gächter, S.; Renner, E.; Sefton, M. The long-run benefits of punishment. Science 2008, 322, 1510.
83. Zhang, Y.; Fu, F. Strategy intervention for the evolution of fairness. PLoS One 2018, 13, e0196524.
84. Sylwester, K.; Herrmann, B.; Bryson, J.J. Homo homini lupus? Explaining antisocial punishment. J Neurosci Psychol Econ 2013, 6, 167–188.
85. Inglehart, R. Culture and democracy. In Culture Matters: How Values Shape Human Progress; Harrison, L.; Huntington, S., Eds.; Basic Books: New York, 2000; pp. 80–97.
86. Oosterbeek, H.; Sloof, R.; de Kuilen. G, V. Cultural Differences in Ultimatum Game Experiments : Evidence from a Meta-Analysis. Experimental Economics 2004, 7, 171–188.
87. Nowak, M.A. Five rules for the evolution of cooperation. Science 2006, 314, 1560–3.
88. Egas, M.; Riedl, A. The economics of altruistic punishment and the maintenance of cooperation. Proc Biol Sci 2008, 275, 871–8.
89. Javan-Noughabi, J.; Kavosi, Z.; Faramarzi, A.; Khammarnia, M. Identification determinant factors on willingness to pay for health services in Iran. Health Econ Rev 2017, 7, 40.
90. Abbasi, M.; Kiani, M.; Ahmadi, M.; Salehi, B. Knowledge and Ethical Issues in Organ Transplantation and Organ Donation: Perspectives from Iranian Health Personnel. Ann Transplant 2018, 23, 292–299.
91. Javadzadeh Shahshahani, H.; Yavari, M.T.; Attar, M.; Ahmadiyeh, M.H. Knowledge, attitude and practice study about blood donation in the urban population of Yazd, Iran, 2004. Transfus Med 2006, 16, 403–9.
92. Borhani, F.; Abbaszadeh, A.; Mohamadi, E.; Ghasemi, E.; Hoseinabad-Farahani, M.J. Moral sensitivity and moral distress in Iranian critical care nurses. Nurs Ethics 2017, 24, 474–482.
93. Amiri, E.; Ebrahimi, H.; Namdar Areshtanab, H.; Vahidi, M.; Asghari Jafarabadi, M. The Relationship between Nurses' Moral Sensitivity and Patients' Satisfaction with the Care Received in the Medical Wards. J Caring Sci 2020, 9, 98–103.
94. Eckel, C.C.; Grossman, P.J. Are Women Less Selfish Than Men? Evidence From Dictator Experiments. The Economic Journal 2001, 108, 726–735.
95. Servátka, M. Separating reputation, social influence, and identification effects in a dictator game. Europ. Econ. Rev. 2009, 53, 197–209.
96. García-Gallego, A.; Georgantzís, N.; Jaramillo-Gutiérrez, A. Gender differences in ultimatum games: Despite rather than due to risk attitudes. J Econ Behav Organ 2012, 83, 42–49.
97. Li, S.; Qin, X.; Houser, D. Revisiting gender differences in ultimatum bargaining: experimental evidence from the US and China. Journal of the Economic Science Association 2018, 4, 180–190.

98. Henrich, J.; Boyd, R.; Bowles, S.; Camerer, C.; Fehr, E.; Gintis, H.; McElreath, R.; Alvard, M.; Barr, A.; Ensminger, J.; Henrich, N.S.; Hill, K.; Gil-White, F.; Gurven, M.; Marlowe, F.W.; Patton, J.Q.; Tracer, D. "Economic man' in cross-cultural perspective: behavioral experiments in 15 small-scale societies. Behav Brain Sci 2005, 28, 795–815.
99. Chuah, S.H.; Hoffmann, R.; Jones, M.; Williams, G. Do cultures clash? Evidence from cross-national Ultimatum Game experiments. J Econ Behav Organ 2007, 64, 35–48.
100. Fabiani, M.; Gratton, G.; Coles, M.G.H. Event-related brain potentials: Methods, theory and application. In Handbook of psychophysiology; Cambridge University Press, 2000; pp. 53–84.
101. Antal, A.; Kéri, S.; Kovács, G.; Janka, Z.; Benedek, G. Early and late components of visual categorization: an event-related potential study. Brain Res Cogn Brain Res 2000, 9, 117–9.
102. Proverbio, A.M.; Del Zotto, M.; Zani, A. The emergence of semantic categorization in early visual processing: ERP indices of animal vs. artifact recognition. BMC Neurosci 2007, 8, 24.
103. Di Russo, F.; Berchicci, M.; Bianco, V.; Perri, R.L.; Pitzalis, S.; Quinzi, F.; Spinelli, D. Normative event-related potentials from sensory and cognitive tasks reveal occipital and frontal activities prior and following visual events. Neuroimage 2019, 196, 173–187.
104. Fuster, J.M. The Prefrontal Cortex, 5th ed.; 460 pages, Academic Press, 2015.
105. Petit, L.S.; Pegna, A.J.; Harris, I.M.; Michel, C.M. Automatic motor cortex activation for natural as compared to awkward grips of a manipulable object. Exp Brain Res 2006, 168, 120–30.
106. Töllner, T.; Gramann, K.; Müller, H.J.; Eimer, M. The anterior N1 component as an index of modality shifting. J Cogn Neurosci 2009, 21, 1653–69.
107. Hsieh, S.; Wu, M. Electrophysiological correlates of preparation and implementation for different types of task shifts. Brain Res 2011, 1423, 41–52.
108. Kutas, M.; Iragui, V.; Hillyard, S.A. Effects of aging on event-related brain potentials (ERPs) in a visual detection task. Electroencephalogr Clin Neurophysiol 1994, 92, 126–39.
109. Mangun, G.R. Neural mechanisms of visual selective attention. Psychophysiology 1995, 32, 4–18.
110. Potts, G.F. An ERP index of task relevance evaluation of visual stimuli. Brain Cogn 2004, 56, 5–13.
111. Rauss, K.; Pourtois, G. What is Bottom-Up and What is Top-Down in Predictive Coding? Front Psychol 2013, 4, 276.
112. Liu, Y.; Huang, J. Does Power Corrupt? The Evidence from Event-Related Potentials. Open Journal of Social Sciences 2015, 03, 109–116.
113. Weiss, M.; Mussel, P.; Hewig, J. The value of a real face: Differences between affective faces and emojis in neural processing and their social influence on decision-making. Soc Neurosci 2020, 15, 255–268.
114. Van der Veen, F.; Sahibdin, P. Dissociation between medial frontal negativity and cardiac responses in the ultimatum game: Effects of offer size and fairness. Cogn Affect Behav Neurosci 2011, 11, 516–525.
115. Brookhuis, K.; Mulder, G.; Mulder, L.; Gloerich, A.; Van Dellen, H.; Van Der Meere, J.; Ellermann, H. Late positive components and stimulus evaluation time. Biol Psychol 1981, 13, 107–123.
116. Kok, A. Event-related-potential (ERP) reflections of mental resources: a review and synthesis. Biol Psychol 1997, 45, 19–56.
117. Codispoti, M.; Ferrari, V.; Bradley, M.M. Repetition and event-related potentials: distinguishing early and late processes in affective picture perception. J Cogn Neurosci 2007, 19, 577–86.
118. Fukushima, H.; Hiraki, K. Whose loss is it? Human electrophysiological correlates of non-self reward processing. Soc Neurosci 2009, 4, 261–75.
119. Boksem, M.A.; Kostermans, E.; De Cremer, D. Failing where others have succeeded: Medial Frontal Negativity tracks failure in a social context. Psychophysiology 2011, 48, 973–979.
120. Etkin, A.; Egner, T.; Kalisch, R. Emotional processing in anterior cingulate and medial prefrontal cortex. Trends Cogn Sci 2011, 15, 85–93.
121. Stevens, F.L.; Hurley, R.A.; Taber, K.H. Anterior cingulate cortex: unique role in cognition and emotion. J Neuropsychiatry Clin Neurosci 2011, 23, 121–5.
122. Kanske, P.; Kotz, S.A. Emotion triggers executive attention: anterior cingulate cortex and amygdala responses to emotional words in a conflict task. Hum Brain Mapp 2011, 32, 198–208.
123. García-Cabezas, M.Á.; Barbas, H. Anterior Cingulate Pathways May Affect Emotions Through Orbitofrontal Cortex. Cereb Cortex 2017, 27, 4891–4910.

124. Wang, G.; Li, J.; Li, Z.; Wei, M.; Li, S. Medial frontal negativity reflects advantageous inequality aversion of proposers in the ultimatum game: An ERP study. Brain Res 2016, 1639, 38–46.
125. Spapé, M.; Harjunen, V.; Ahmed, I.; Jacucci, G.; Ravaja, N. The semiotics of the message and the messenger: How nonverbal communication affects fairness perception. Cogn Affect Behav Neurosci 2019, 19, 1259–1272.
126. Bamford, S.; Broyd, S.J.; Benikos, N.; Ward, R.; Wiersema, J.R.; Sonuga-Barke, E. The late positive potential: a neural marker of the regulation of emotion-based approach-avoidance actions? Biol Psychol 2015, 105, 115–123.
127. Sun, S.; Yu, R.; Wang, S. Outcome saliency modulates behavioral decision switching. Sci Rep 2020, 10, 14288.
128. Zhang, H.; Gu, R.; Yang, M.; Zhang, M.; Han, F.; Li, H.; Luo, W. Context-based interpersonal relationship modulates social comparison between outcomes: an event-related potential study. Soc Cogn Affect Neurosci 2021, 16, 439–452.
129. Sharif, L.; Marusak, H.A.; Peters, C.; Elrahal, F.; Rabinak, C.A. Trustworthiness and electrocortical processing of emotionally ambiguous faces in student police officers. Psychiatry Res Neuroimaging 2021, 307, 111237.
130. Sabatinelli, D.; Lang, P.J.; Keil, A.; Bradley, M.M. Emotional perception: correlation of functional MRI and event-related potentials. Cereb Cortex 2007, 17, 1085–91.
131. McDonald, J.J.; Green, J.J. Isolating event-related potential components associated with voluntary control of visuo-spatial attention. Brain Res 2008, 1227, 96–109.
132. Scharmüller, W.; Leutgeb, V.; Schäfer, A.; Köchel, A.; Schienle, A. Source localization of late electrocortical positivity during symptom provocation in spider phobia: an sLORETA study. Brain Res 2011, 1397, 10–18.
133. Sun, S.; Zhen, S.; Fu, Z.; Wu, D.A.; Shimojo, S.; Adolphs, R.; Yu, R.; Wang, S. Decision ambiguity is mediated by a late positive potential originating from cingulate cortex. Neuroimage 2017, 157, 400–414.
134. Minnix, J.A.; Versace, F.; Robinson, J.D.; Lam, C.Y.; Engelmann, J.M.; Cui, Y.; Brown, V.L.; Cinciripini, P.M. The late positive potential (LPP) in response to varying types of emotional and cigarette stimuli in smokers: a content comparison. Int J Psychophysiol 2013, 89, 18–25.
135. Stolz, C.; Endres, D.; Mueller, E.M. Threat-conditioned contexts modulate the late positive potential to faces-A mobile EEG/virtual reality study. Psychophysiology 2019, 56, e13308.
136. Bauer, E.A.; Thomas, G.; MacNamara, A. The controllability of aversive and neutral pictures: an event-related potential study. Behav Brain Res 2021, 408, 113265.