Event related potentials reveal fairness in willingness-to-share

Alessandra Lintas [1] *, Sarat Chandra Vysyaraju [2], Manon Jaquerod [1], and Alessandro E. P. Villa [1]

[1] NeuroHeuristic Research Group, University of Lausanne, Quartier Dorigny, 1015 Lausanne, Switzerland
[2] Department of Electrical Engineering, Columbia University, New York, NY USA
http://www.neuroheuristic.org

Abstract. Willingness-to-share is tested in an Ultimatum Game where the participants iteratively play a role of Proposer and Responder sharing a virtual amount of money. We test the hypothesis that brain activity associated with small *vs.* large share offered by the Proposer can be detected by event related potentials (ERPs). We observed that differences between wretched and prodigal offers in ERPs latencies, amplitudes and locations appeared along the antero-posterior midline at the time of Proposer's invite to make the offer, that is before the actual offer was made. Differences in ERPs associated with the offered amount of the share were localized at parietal areas when the offer was accepted. We discuss the outcome of these results for reward learning processes.

Keywords: EEG, Neuroeconomics, Reward circuit, Decision making

1 Introduction

In the "Theory of the Consumer" it is assumed that rational individuals maximize the consumption of real goods given a limited availability of nominal goods (money) [14, 15]. According to Game Theory, the subgame perfect equilibrium in the Ultimatum Game (UG) occurs if the proposer offers the smaller possible amount (in order to save as much as possible), and the responder accepts any amount (because a small amount is better than nothing). Proposers tend to offer rather fair offers and responders tend to reject offers that are judged as unfair [1, 16] despite this being an irrational behavior with respect to gain maximization [8, 13]. This deviation from "rational" strategies that are suggested by game-theoretic analysis can be explained by the fact that humans being in a multi-stimulus and multi-target environment have been conditioned to act so. Such environment includes "irrational" concepts driven by emotions in decision making such as fairness and "social sharing" that involve the description of an emotional event by the person who experienced it to another person in a socially shared language [4, 9]. A specific component, N2-P3, of the event related potential (ERP) is associated with the activity in the Anterior Cingulate

* Corresponding Author: alessandra.lintas@unil.ch

A. Lintas et al. (Eds.): ICANN 2017, LNCS 10613, pp. 191–198, 2017.

Cortex (ACC) generated by the conflict detection of willingness on honest and deceptive responses [19]. In the experimental framework of the Ultimatum Game Responders' behavior and brain activity have been extensively investigated, but Proposers' strategies received less attention. In a recent study, a specific negative wave (the medial frontal negativity) was selectively evoked in Proposer's ERP by the advantageous comparison to fair offers [17].

In the present study we test the hypothesis that wretched and prodigal amounts offered by the Proposers are driven by the activation of different brain circuits at the time of the offering invite. We present new findings that show that differences associated with the offered amount can be detected from the time of Proposer's invite to make an offer till the communication of Responder's acceptance of that offer. We discuss how the identification of the mechanisms associated with the perception of fairness may influence the concept of reinforcement learning.

2 Material and Methods

Forty-eight healthy native French speakers, right-handed participants volunteered to participate in the study and provided written consent for their participation in line with the Declaration of Helsinki [18]. The Ultimatum Game (UG) is an anonymous, single-shot two-player game, in which the "Proposer" has a certain sum of money at his disposal and must propose a share to the "Responder" [7]. If the Responder accepts the proposal, the share is done accordingly. If the Responder refuses, both players end up with nothing. Participants were told to play the UG with virtual money trying to maximize their gain as much as possible. All had normal or corrected-to-normal vision, none reported a history of sustained head injury or neurological disease, and all were naive to the UG.

Fig. 1 illustrates the experimental procedure along each Proposer's trial : The trial started (event at time 0) with the pressure of the spacebar of the computer keyboard. The participants maintained their gaze on the central fixation cross during a preparatory period of 2000 ms. At the end of this interval (event **S**), the invite message "Please, make your offer." appeared (in French) on the center of the display. By pressing a digit (event **PT**), from 1 to 9 on the numerical keypad, the Proposer selected the x amount of the offer, within a maximum allowed time of 10 seconds. This event was immediately followed by the display of the confirmation message "You offered x." (in French). The decision made by the other player (event **PR**) was conveyed to the proposer through a face diagram (smiley) that either smiled (offer accepted) or frowned (offer rejected) appearing on the center of the display. A new trial started by pressing the spacebar at least 1 second after the smiley. The sequence of the trials was self-paced by the participant, who played the role of Proposer for 3 blocks of 30 consecutive trials, alternated with 30 consecutive trials playing the role of Responder.

Event-related potentials (ERPs) triggered by events **S**, **PT** and **PR** were analyzed from recording sites Fz, Cz and Pz during all Proposer's trials, as described elsewhere [5]. The trials were separated post-hoc, following Proposer's

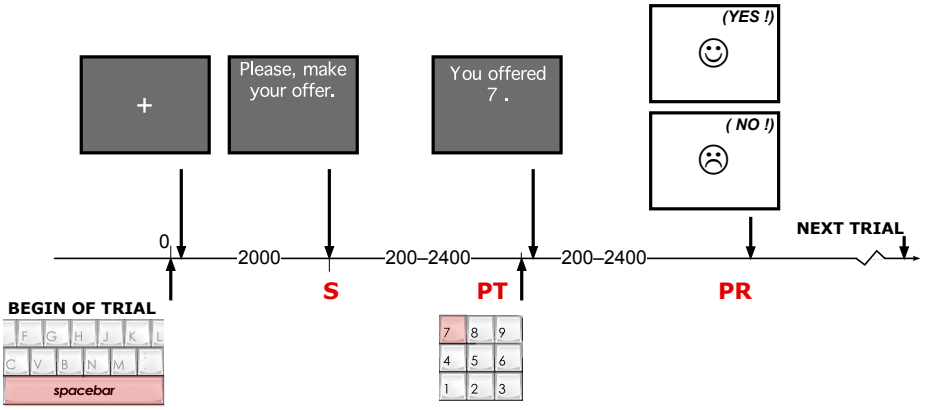

Fig. 1. Illustration of the Ultimatum Game task along one trial for the Proposer. At Proposer's invite (**S**): the participant received the invitation to offer an amount to the Responder. At Proposer's choice (**PT**) the participant digitized the value of the amount offered to the Responder on a numeric keypad. At Responder's decision (**PR**) the Proposer saw the display of the Responder's choice to accept (smiley emoticon, with a YES! message) or to reject (pouting emoticon, with a NO! message) the offer. Time intervals are in ms.

choice to offer a low (unfair or wretched, up 30% of the amount) or a high (fair or prodigal, more than 70% of the amount) share. Trials for wretched offers (values 1,2, or 3) and prodigal offers (values 7,8, or 9) were pooled together for each Participant. Then, in order to reduce the variability of the individual curves, we pooled the curves of 12 participants together. This means that eventually we obtained four grand average ERPs for each condition. Hence, the comparisons between mean values between two conditions were computed with Student's t-tests ($t(8)$), with N=4 for each condition and a total degree of freedom df=8.

3 Results

At the time of Proposer's invite (**S**), we observed differences in ERPs along the antero-posterior axis, as a function of the offer to come whether wretched or prodigal, with larger amplitudes and longer latencies in the frontal areas for prodigal *vs.* wretched offers (Fig. 2). Notice that prodigal offers elicit a positive wave at Fz immediately after the trigger onset, *i.e.* after receiving the invite to make an offer. The N2-P3 complex is a ERP component associated with the attentional load characterized by a negative wave immediately followed by a positive wave occurring approximately at a latency of 200 ms after the triggering event. Table 1 shows that N2 latencies tended always to be longer for prodigal offers at all sites along the midline, with a significance level below threshold for Fz (203 ± 4 ms and 173 ± 8 ms for prodigal and wretched offers, respectively; $t(8) = 3.517$, $p = .01$). The delay of 700 ms after the invite corresponds roughly

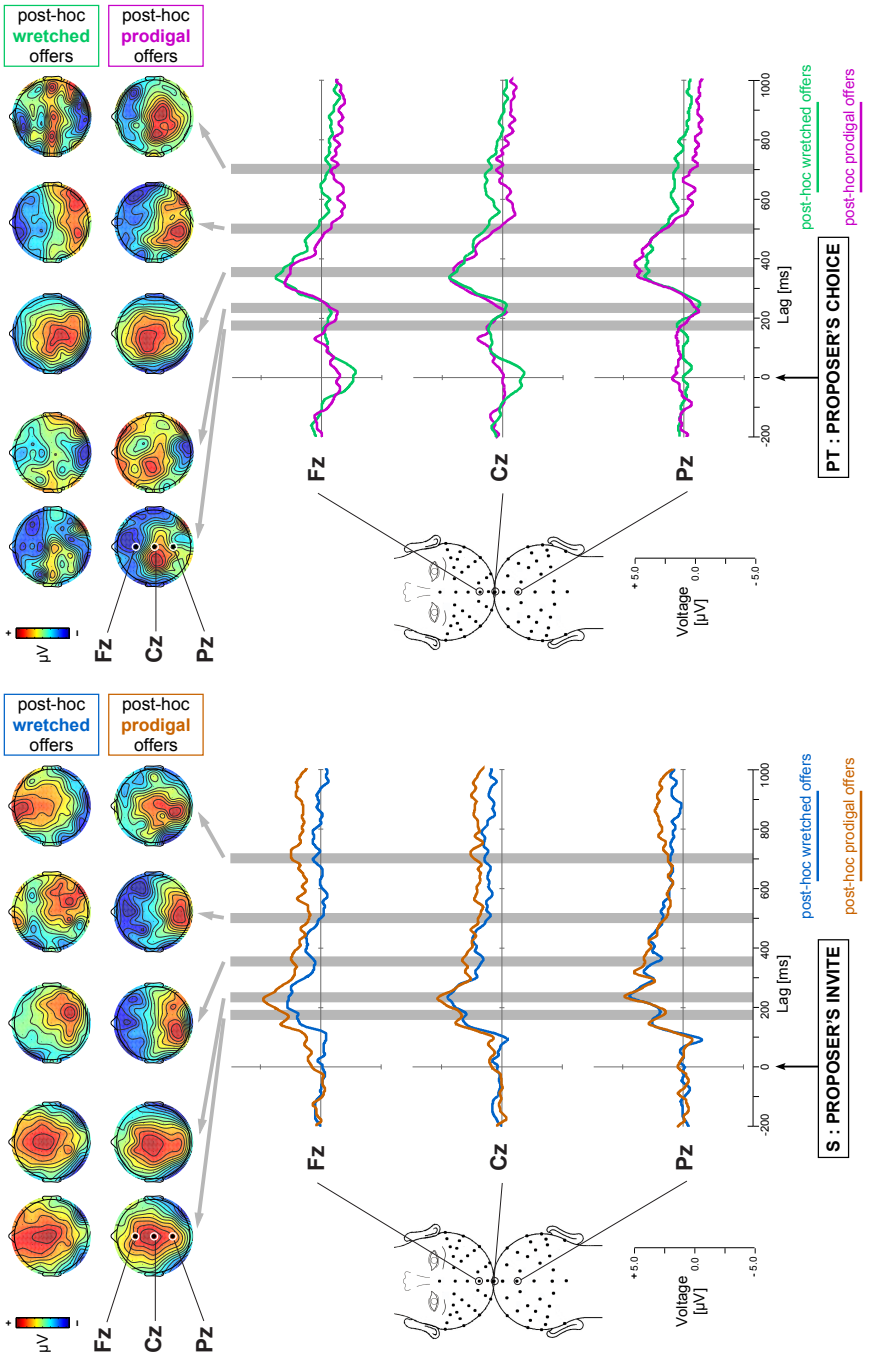

Fig. 2. Grand average ERPs at Fz, Cz, and Pz for trials corresponding to wretched and prodigal offers (separated post-hoc) triggered by Proposer's invite (S), when the Proposer received the invitation to offer an amount to the Responder (left panels) and by Proposer's choice (PT), when the proposer pressed the digit on the keypad corresponding to the offer made to the Responder (right panels). Upper panels show the topological maps of the ERPs at delays of 180, 220, 350, 500, and 700 ms after the trigger.

Table 1. N2 peak latency [ms] of the ERPs trials evoked by Proposer's invite (S) and Proposer's choice (PT) calculated for wretched and prodigal trials separated post-hoc. We report the median (mean±SEM). (*) denotes a level of significance $p < 0.05$.

	Proposer's invite (S)		Proposer's choice (PT)	
	wretched offer	prodigal offer	wretched offer	prodigal offer
Fz	178 (173±8)*	204 (203±4)*	235 (235±8)	237 (238±8)
Cz	185 (190±8)	198 (198±5)	241 (239±8)	224 (231±9)
Pz	193 (191±6)	199 (216±22)	253 (257±9)	269 (271±15)

at time when the cortical activity follows the decision of the selected offer and the motor action towards the numeric keypad is building up. Figure 2 shows that the topography of the potential at 700 ms is characterized by positive waves centered on the frontal areas for wretched offers and positive waves centered on the parieto-occipital areas for prodigal offers. Topological differences for ERP components appeared after the Proposer received the Responder's decision (event PR) to accept or reject the prodigal or the wretched offer (Fig. 3). In case of rejection, the amount of the offer did not appear to evoke significant differences in the ERP components. On the contrary, in case of offer acceptance different ERPs were evoked at all sites as a function of the wretched or prodigal offer. For the electrode Pz the N2 latency was larger for wretched offers (Table 2), $t(8) = 2.838$, $p = .03$) After the N2-P3 complex the acceptance of wretched offers evoked a large positivity that extended for about 1 second after the triggering event (the black curves in the left panels of Figure 3).

4 Discussion

It is rationale to expect that in the Ultimatum Game the Proposer offers the smallest possible amount and the Responder accepts any amount. However, it is observed that Responders tend to reject an unfair offer, which is explained by a bias towards the maximization gain in UG associated with positive social factors like common ethical principles and friendship, but also negative factors as fear of the perceived consequences of having one's offer rejected, and guilt related to concerns for the opponents' outcomes [2, 10, 6].

The N2-P3 complex is associated with attentional load and in patients suffering of hyperactivity and attention deficit changes in response inhibition affect this ERP component [11]. In our study we observed that the activity in frontal areas developed immediately after the Proposer received the invite for prodigal offers 'to come': the waves are larger and N2 peaked later than at the other sites. Hence, it may suggest a broader network activity develops as soon as the Proposer expresses the willingness to offer a prodigal amount. The extension of that network might be associated with the mental expectations of offering a large share and the consequence of a lesser gain for oneself. Offers in bargaining are

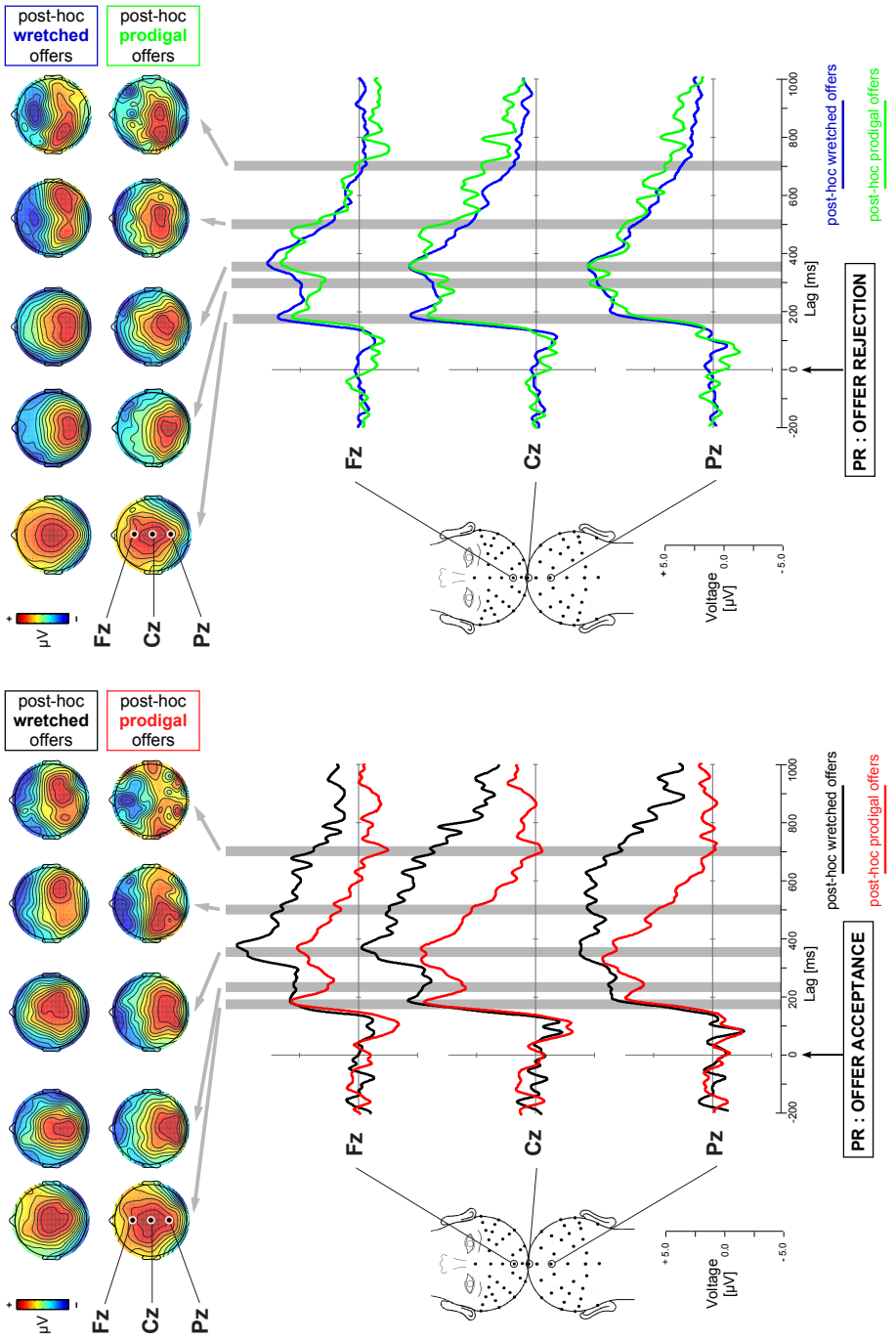

Fig. 3. Grand average ERPs at Fz, Cz, and Pz for trials corresponding to wretched and prodigal offers (separated post-hoc) triggered by the display of Responder's decision (PR), either acceptance of the offer (left panels), or rejection of the offer (right panels). Upper panels show the topological maps of the ERPs at delays of 180, 220, 350, 500, and 700 ms after the trigger.

Table 2. N2 peak latency [ms] of the ERPs trials triggered by the feedback response of the Responder's decision (PR). We report the median (mean±SEM). (*) denotes a level of significance $p < 0.05$.

	Proposer receiving Responser's decision (PR)			
	Offer acceptance		Offer rejection	
	wretched offer	prodigal offer	wretched offer	prodigal offer
Fz	278 (273±15)	293 (295±15)	249 (254±13)	267 (271±15)
Cz	266 (259±18)	270 (271±13)	245 (256±15)	269 (267±11)
Pz	268 (272±7)*	242 (245±6)*	251 (259±15)	261 (269±9)

likely to be guided by the emotions that proposers anticipate when contemplating their offers [12]. Our study has shown that in case of acceptance of wretched offers, the ERPs waves evoked in the Proposer's brain are characterized by a larger amplitude and the latency of N2 peak is shorter than in the case of acceptance of prodigal offers. This is in agreement with the interpretation that an extended circuit is activated by the acceptance of wretched offers. Increased activity in dorsal ACC was recently reported in associated with higher expectation violations [3] and differences in the ERPs generated by unfair and fair offers were related to the Proposer's ACC activity while performing the UG [17].

Reinforcement learning has acquired popularity in the machine learning community. It is based on the assumptions, that under bounded rationality when learning process lead to near optimal decisions from the training experience, single-agent and multi-agent planning will lead to automated decision-making. The results of this study are coherent with the hypothesis that expectation and evaluation of the consequences of bargaining activate specific neural activity strongly associated with the willingness-to-share and the emotions that amplify it. The observation that brain circuits do not simply follow the rules of making a decision in a contextual scene so as to maximize some notion of cumulative reward should raise questions about how to integrate multidimensional components of a reward (e.g., the face-value of the amount, the social interaction, the emotions) which simply do not add up as assumed to be in a novel approach of machine learning.

Acknowledgments. The authors acknowledge the support by the Swiss National Science Foundation grant n. CR13I11_38032_1.

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