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Betrayal or engagement: EEG time indices of cooperation at the prisoner's dilemma

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Summary findings

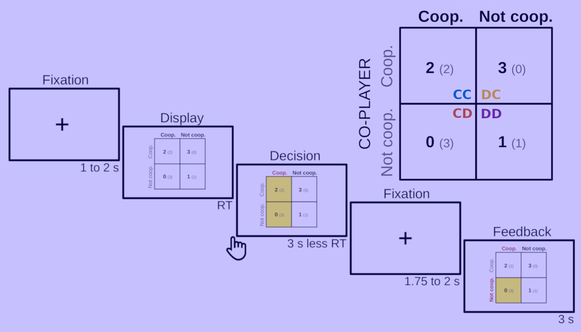
Earliest brain signatures of choice at iterated prisoner's dilemma (iPD) gameplay are analyzed by electroencephalography (EEG). Three feedback components serve to indicate a player's tendency to cooperate at the next round of the game. 'Sucker's payoff' (worst outcome) elicits the fastest, transient indices, whereas (game-optimal) mutual cooperation entails the most delayed modulations.

Background

→ Neurobiological mechanisms of cooperation remain unknown, with crucial impact over organized social life. The iterated prisoner's dilemma (iPD) is a formalism addressing cooperation[1]. Current insights emphasize a distinction between intuitive versus deliberative cooperation[2,3]. Yet it is unclear how is the distinction potentially supported over neural time.

→ EEG studies of the iPD have been primarily based on hyperscanning - dyadic measures from simultaneously interacting partners[4,5]. The possibility of measuring individuals' EEG responses in order to predict cooperation during the game was however recently raised[6].

Methods



→ 30 participants (16 female; mean age 22.3 y ± 2.9 SD) completed 200 rounds of the game at EEG sessions, against a probabilistic algorithm representing a confederate co-player, and were instructed to maximize earnings.

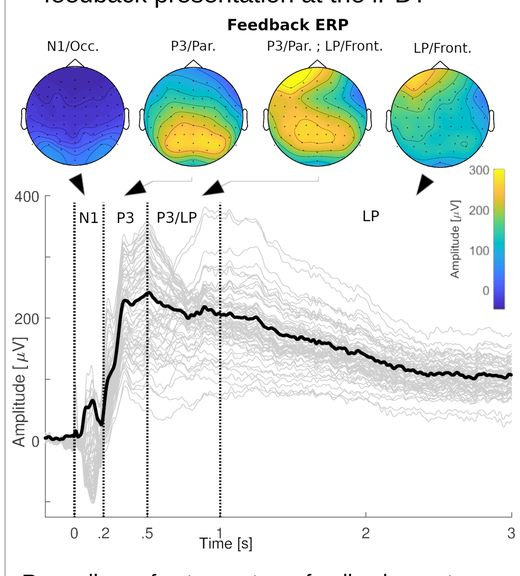
→ Spatial filtering techniques[7] were used to extract components related to feedback processing. Event-related potential and spectrotemporal analysis methods were further employed to identify which are modulated by co-player choice.

→ From these components, relevant waveform and spectrotemporal cluster feedback data were partitioned by player's choice at the following round, analyzed with a minimum of 10 trials per partition.

→ Two-way RM ANOVA (player, co-player) were applied to feedback ERPs. Nonparametric analyses were applied to relevant contrasts in spectrotemporal data. Tests for differences by subsequent choice were performed (Wilcoxon rank sum or paired *t*-tests), depending on normality of underlying distributions assessed with the Shapiro-Wilk GOF test.

Results

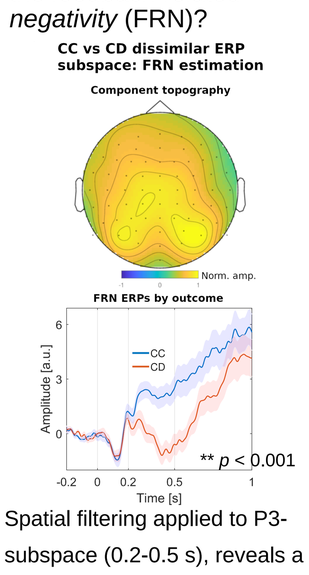
What event-related potentials follow feedback presentation at the iPD?



Regardless of outcome type, feedback onset triggers a N1 to P3 to late potential ERP sequence, over occipital to parietal to left frontal scalp regions, over the 0-0.2, 0.2-1, and 0.5-3 s time intervals respectively.

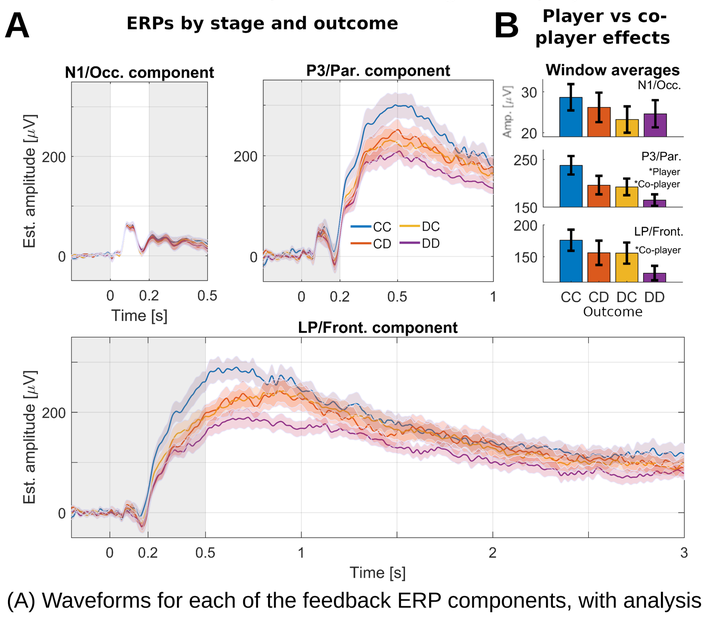
P3/par. & LP/front. components partially overlap.

How do results relate to the *feedback-related negativity* (FRN)?



Spatial filtering applied to P3-subspace (0.2-0.5 s), reveals a component maximizing the separation[7] between CC mutual coop. and CD 'sucker's payoff'. Topography may be associated with FRN[8]. Bands indicate ± 1 SEM.

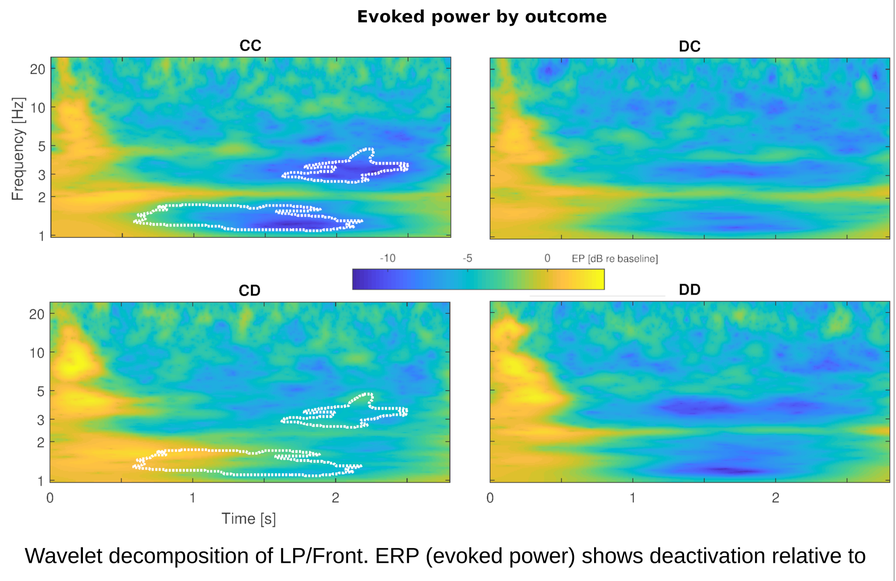
How is each ERP component encoding for co-player choice?



(A) Waveforms for each of the feedback ERP components, with analysis time intervals shown in white.

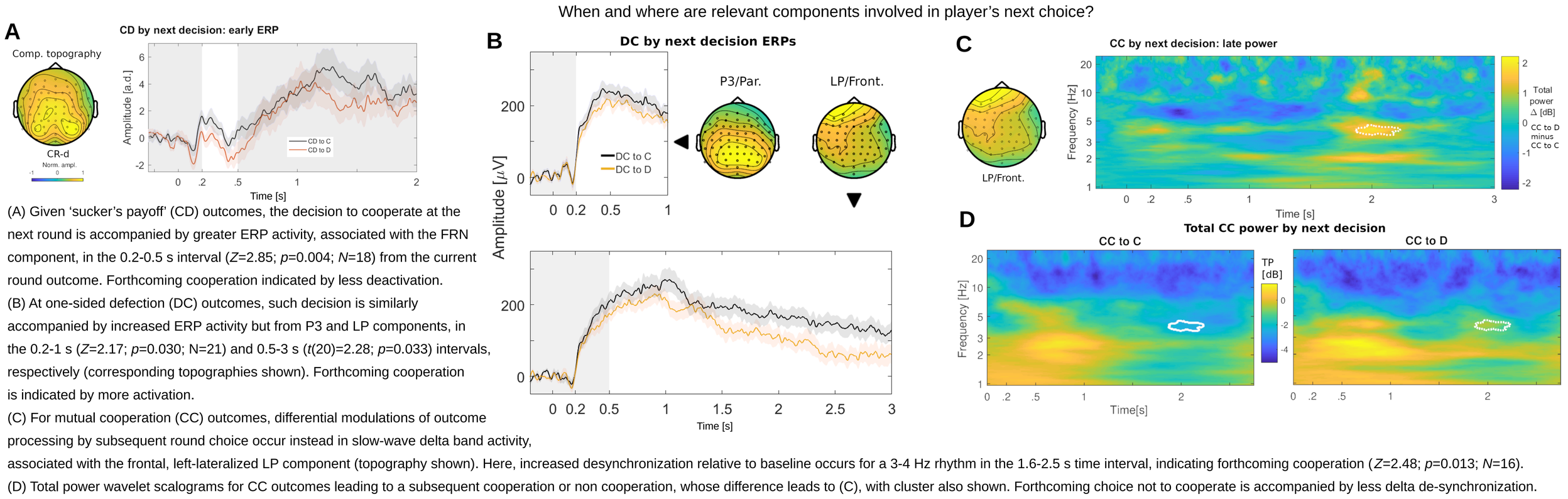
(B) Summary of feedback component ERP magnitudes, averaged over their respective intervals. P3/Par. and LP/Front. both show an effect by co-player choice (p=0.002 and p=0.04 respectively). In addition, P3/Par. shows an effect of player choice (p=0.005), with no interaction.

Where/when in spectrotemporal activity may co-player choice be encoded?



Wavelet decomposition of LP/Front. ERP (evoked power) shows deactivation relative to baseline levels, in the delta range (1-4 Hz) post transient onset, for most outcomes. Non-parametric analyses[9] of relevant contrasts, CC vs CD, and DC ('one-sided defection') vs DD ('mutual defection'), show significant clusters of differential spectrotemporal activatio, between CC and CD, in low-delta (~1.4 Hz; p=0.002) and a high-delta (~3.2 Hz; p=0.034) regions, extending 0.6-2.5 s overall. Cluster boundaries shown.

When and where are relevant components involved in player's next choice?



(A) Given 'sucker's payoff' (CD) outcomes, the decision to cooperate at the next round is accompanied by greater ERP activity, associated with the FRN component, in the 0.2-0.5 s interval (Z=2.85; p=0.004; N=18) from the current round outcome. Forthcoming cooperation indicated by less deactivation.

(B) At one-sided defection (DC) outcomes, such decision is similarly accompanied by increased ERP activity but from P3 and LP components, in the 0.2-1 s (Z=2.17; p=0.030; N=21) and 0.5-3 s (t(20)=2.28; p=0.033) intervals, respectively (corresponding topographies shown). Forthcoming cooperation is indicated by more activation.

(C) For mutual cooperation (CC) outcomes, differential modulations of outcome processing by subsequent round choice occur instead in slow-wave delta band activity, associated with the frontal, left-lateralized LP component (topography shown). Here, increased desynchronization relative to baseline occurs for a 3-4 Hz rhythm in the 1.6-2.5 s time interval, indicating forthcoming cooperation (Z=2.48; p=0.013; N=16).

(D) Total power wavelet scalograms for CC outcomes leading to a subsequent cooperation or non cooperation, whose difference leads to (C), with cluster also shown. Forthcoming choice not to cooperate is accompanied by less delta de-synchronization.

Discussion

→ The FRN, P3 and delta-band lateralized frontal activity are key EEG indices of feedback processing at the iterated prisoner's dilemma.

→ Earliest modulations per subsequent choice are contingent on current outcome: associations are found for FRN with 'sucker's payoff', P3 and a late frontal potential with unilateral defection, and delta-band desynchronizations therein with mutual cooperation.

→ FRN is interpreted as a prediction error signal (reinforcement learning)[10] which might indicate expected reward or salience of a given 'betrayal' event

→ Frontoparietal networks are on the other hand involved in theory of mind[11], which might be involved in framing an analogous prediction error but in co-player terms[12].

→ Frontal EEG assymetries are indices of approach/avoidance behavior[13], while wakeful delta rhythms may be involved in homeostatic regulation[14]. Suppression is consistent with inhibition of defense mechanisms, possibly conditioned on the representation of conditions for further engagement.

Conclusion

The feedback stage of the iterated prisoner's dilemma entails an early window where to gauge intent to cooperate. Involvement of predictive coding mechanisms[15] in triggering the ensuing decisional process, at distinct timescales and over different relevant networks, is suggested.

Acknowledgments

This work was supported by the *Proyectos de Investigación y Desarrollo*, and the *Programa de Movilidad e Intercambios Académicos*, by the Comisión Sectorial de Investigación Científica (UdelaR, Uruguay). We are also thankful for support from the *Fondo Santiago Achúgar Díaz* in coordination with the Programa de Desarrollo de las Ciencias Básicas (Uruguay).

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