Biological Psychology 133 (2018) 54–62

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Inter-brain synchrony and cooperation context in interactive decision making

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ARTICLE INFO

Keywords:
Interactive decision making
Cooperation
Inter-brain synchrony
EEG
Hyperscanning

ABSTRACT

People engaged in interactive decision making rely on prior decision behaviors by other persons to make new choices and they exhibit inter-brain synchrony between each other. The functional meanings of such inter-brain synchrony, however, remains obscure. In the present study, dyads (15 pairs, all female) played the Prisoner's Dilemma game while their brain activities were recorded simultaneously by electroencephalography (EEG)-based hyperscanning technique. We manipulated the context of the game with higher versus lower cooperation index (HCI vs. LCI) and to each participant, we depicted the interaction as involving either another human partner or a machine (H-H vs. H-M). The results showed a higher cooperation rate and larger theta/alpha-band inter-brain synchrony in condition H-H than in H-M. In the condition H-H, there were larger centrofrontal theta-band and centroparietal alpha-band inter-brain synchrony in tasks set for high cooperation (HCI vs. LCI). Enhanced inter-brain synchrony covaried with increased cooperative choices observed between LCI and HCI. Furthermore, a subjective measure of perceived cooperativeness mediated the relationship between game context and inter-brain synchrony. These findings provide evidence for a role of cooperation on inter-brain synchrony during interactive decision making, and suggest distinct underlying neural processes recruited by cooperation contexts to enable high-level social cognitive processing in decision making.

1. Introduction

Interactive decision making, defined as the dynamic process of identifying and choosing alternatives in interacting tasks, is one of the most ubiquitous activities in human beings (Klijn & Koppenjan, 2000; Wang & Benbasat, 2009). Such an activity involves theory of mind, social cognition, and goal-directed behaviors (Yun, Chung, & Jeong, 2008). In interactive decision making, the choices of one person depend on the antecedent decision behaviors of the other. For example, in the game of Prisoner's Dilemma (Rapoport & Chammah, 1965), players tend to cooperate when their partners have cooperated in the previous iteration, but refuse to cooperate if their partners have defected (Sachs, Mueller, Wilcox, & Bull, 2004). In this study, we explore how dyads engaged in interactive decision making make choices which are conducive to their social relationships and to what extent their brain activities are synchronized.

The rational choice theory posits that interacting individuals make choices that favor themselves (Balliet et al., 2011; Rand & Nowak, 2013; Schacter, Gilbert, & Wegner, 2011). The decision-making process is affected by knowledge of contextual changes, such as the costs and benefits related to decisions (Dreber, Rand, Fudenberg, & Nowak, 2008; Engelmann & Hein, 2013; Vlaev, Chater, Stewart, & Brown, 2011; Vlaev and Chater, 2006, 2007). If a cooperative decision brings a greater benefit, or a defective decision brings a greater cost, the temptation to cooperate will be large; whereas, there is a higher temptation to make a defective decision when the benefit of cooperation behavior decreases (Dreber et al., 2008; Chater, 2006, 2007;). The effect of contextual changes on decision making was evidenced when two persons were performing the Prisoner's Dilemma game (e.g., Vlaev et al., 2011), judging various prospects (e.g., Stewart, Chater, Stott, & Reimers, 2003), and making intransitive choices (e.g., Kalenscher et al., 2010). Moreover, evidence from neuroeconomic experiments has demonstrated that contextual modulators affecting the decision-making process (e.g., cooperation index scale, risk-benefit ratio) can influence coincident brain activities between players. Such coincident neural responses were found in the orbitofrontal cortex (Elliott, Agnew, & Deakin, 2008; Grabenhorst & Rolls, 2009; Kalenscher et al., 2010; Plassmann, O'Doherty, Shiv, & Rangel, 2008).

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https://doi.org/10.1016/j.biopsycho.2017.12.005
Received 24 May 2017; Received in revised form 21 December 2017; Accepted 21 December 2017
Available online 29 December 2017

Recently, some studies using hyperscanning techniques found that during interactive decision making, there was inter-brain synchrony (Astolfi et al., 2010; Astolfi et al., 2015; De Vico Fallani et al., 2010). Hyperscanning is an approach to simultaneously record brain activities in at least two persons (Koike, Tanabe, & Sadato, 2015; Montague et al., 2002). It can be applied to a number of neuroimaging techniques, for instance electroencephalography (EEG). Previous studies using EEG-based hyperscanning technique found that when individuals played the Prisoner's Dilemma game, there were synchronous cortical activities between interacting dyads (Astolfi et al., 2010). Individuals' decision to cooperate or defect could be predicted from changes of connectivity pattern in the hyper-brain network (intra- and inter-brain synchronization) (De Vico Fallani et al., 2010). Similarly, participants playing the Third Party Punishment game, a novel paradigm used to explore emotional sharing and altruistic punishment (Baumgartner, Götte, Gügler, & Fehr, 2012; Fehr & Fischbacher, 2004), showed alpha-band inter-brain synchrony in a fronto-parietal network (Astolfi et al., 2015). Recently, Jahng et al. (2017) used EEG-based hyperscanning to investigate the neural dynamics of two players when cooperating during the Prisoner's Dilemma game. They found the inter-brain synchrony between the right temporoparietal and frontal areas during mutual cooperation. These findings echoed earlier fMRI-based hyperscanning studies in interactive decision making, which revealed brain-to-brain correlations between two persons (King-Casas et al., 2005; Krueger et al., 2007).

Two hypotheses have been proposed to explain the emergence of inter-brain synchrony in interactive decision making: the cooperative interaction hypothesis vs. the similar task hypothesis. A line of imaging evidence has demonstrated that neural activities of two individuals are more synchronized when they perform cooperative interactions, such as singing (Osaka et al., 2015), counting (Mu, Guo, & Han, 2016), key-pressing (Cheng, Li, & Hu, 2015; Cui, Bryant, & Reiss, 2012; Pan, Cheng, Zhang, Li, & Hu, 2017), group communication (Jiang et al., 2012; Nozawa, Sasaki, Sakaki, Yokoyama, & Kawashima, 2016), game playing (Liu et al., 2016), and guitar playing (Lindenberger, Li, Gruber, & Müller, 2009; Müller, Sänger, & Lindenberger, 2013; Sänger, Müller, & Lindenberger, 2012,2013). These findings suggest that inter-brain synchrony may be derived from coherent interpersonal interaction and thus represents a tendency to cooperate with each other (cooperative interaction hypothesis). However, another line of evidence has shown that inter-brain synchrony could be induced by some non-cooperation or non-interaction activities, for example movie watching (Nummenmaa et al., 2012), music listening (Abrams et al., 2013), and human-machine coordination of speech rhythm (Kawasaki, Yamada, Ushiku, Miyauchi, & Yamaguchi, 2013). Participants in these studies performed the same task in an independent way, where interactions scarcely existed. The inter-brain synchrony therefore may just reflect the functional similarity of common tasks (similar task hypothesis).

This study aims to examine the potential function of contextual change in decision making and its associated inter-brain synchrony. Dyads were recruited to perform the Prisoner's Dilemma game. We manipulated the context for cooperation, namely the cooperation index (CI). The cooperation index is a characteristic of profits distribution and can be used to quantify the degree of cooperativeness in the Prisoner's Dilemma game (Rapoport & Chammah, 1965; Vlaev et al., 2011). Games played in the context of higher cooperation index (HCI) carry a higher benefit from cooperative choices (and relatedly, lower benefits from defection), while contexts with lower cooperation index (LCI) carry a lower benefit from cooperation (and relatedly, a higher benefit from defection). Similar to findings from previous studies (Vlaev & Chater, 2006, 2007,2011), we expected that the context with HCI vs. LCI would lead to greater cooperation within dyads.

We recorded brain activity through EEG combined with the hyperscanning technique (Babiloni & Astolfi, 2014; Dumas et al., 2010). To examine the functional meanings of inter-brain synchrony, we specifically set up two conditions, i.e., human–human (hereafter referred to as H-H) and human-machine (H-M). In the H-H condition, dyads were instructed to play the game with their partners repeatedly, whereas in the H-M condition, they were instructed to play the game with a computer (in reality the computer was still their partner). Under the cooperative interaction hypothesis, we expected that inter-brain synchrony (*i*) would be higher in the H-H condition than in the H-M condition due to the interaction demand, and (*ii*) that it would be higher in the context of HCI than with LCI due to the greater temptation to cooperate associated with the former. Alternatively, based on the similar task hypothesis, we expected that inter-brain synchrony would not differ between conditions H-H and H-M, due to the similar environment and task perceived by each person in the two conditions.

2. Methods

2.1. Participants

Thirty undergraduates (fifteen female–female pairs) with a mean age of 22.7 ± 3.4 years (*M* ± *SD*) participated in the study. They were unacquainted with each other before the experiment. All participants were right-handed and had normal or corrected-to-normal vision. None of them reported a history of psychiatric or neurological disease. Written informed consent was obtained from each participant in accordance with the declaration of Helsinki. The procedure was approved by the University Committee on Human Research Protection, East China Normal University. Participants were paid for their participation.

2.2. Task

The task used in the present EEG-based hyperscanning study was the Prisoner's Dilemma game (c.f., Astolfi et al., 2009, 2010, 2011; Babiloni, Astolfi, Cincotti, Mattia, Tocci, Tarantino & De Vico Fallani). In this game, a player chooses either to cooperate (C) with or to defect (D) from the other player. Accordingly, there are four possible circumstances: both players cooperate (CC), the first player cooperates whereas the second defects (CD), the first one defects whereas the second cooperates (DC), both players defect (DD). In each circumstance, the participant may incur gains or losses. As with most Prisoner's Dilemma studies (Bone, Wallace, Bshary, & Raihani, 2015; Christensen, Shiyanov, Estepp, & Schlager, 2014), the player in the current study would possibly gain higher by choosing to defect rather than cooperate. But if both players choose to defect, they lose more than if they choose to cooperate.

2.3. Experimental factors

We manipulated two within-participant variables. The first one was the Payoff Context in terms of cooperation index (CI, Rapoport & Chammah, 1965). The cooperation index is calculated by the formula: $CI = (C - D)/(T - S)$. Here, C, D, T, and S are the gains or losses one player can obtain in four circumstances of CC, DD, DC, and CD, respectively. Consistent with previous studies (Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Wang, Suri, & Watts, 2012), we adopted a payoff matrix for HCI as:

$$P = \begin{pmatrix} P^{CC} & P^{CD} \\ P^{DC} & P^{DD} \end{pmatrix} = \begin{pmatrix} 5 & 0 \\ 6 & 1 \end{pmatrix}, \tag{1}$$

which cooperation index CI was 0.67 = (5 − 1)/(6 − 0); and a payoff matrix for LCI as:

$$P = \begin{pmatrix} P^{CC} & P^{CD} \\ P^{DC} & P^{DD} \end{pmatrix} = \begin{pmatrix} 4 & -1 \\ 7 & 1 \end{pmatrix}, \tag{2}$$

which cooperation index CI was 0.38 = (4 − 1)/[7 − (−1)]. The above payoffs were received by the first player in the four circumstances. For the other player in the dyad, the matrices were transposed.