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Role of the right inferior frontal gyrus in turn-based cooperation and competition: A near-infrared spectroscopy study

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ABSTRACT

Interpersonal interaction can be classified into two types: concurrent and turn-based interaction, requiring synchronized body-movement and complementary behaviors across persons, respectively. To examine the neural mechanism of turn-based interaction, we simultaneously measured paired participants activations in their bilateral inferior frontal gyrus (IFG) and the bilateral inferior parietal lobule (IPL) in a turn-taking game using near-infrared spectroscopy (NIRS). Pairs of participants were assigned to either one of two roles (game builder and the partner) in the game. The builder's task was to make a copy of a target disk-pattern by placing disks on a monitor, while the partner's task was to aid the builder in his/her goal (cooperation condition) or to obstruct it (competition condition). The builder always took the initial move and the partner followed. The NIRS data demonstrated an interaction of role (builder vs. partner) by task-type (cooperation vs. competition) in the right IFG. The builder in the cooperation condition showed higher activation than the cooperator, but the same builder in the competition condition showed lower activation than in the cooperation condition. The activations in the competitor–builder pairs showed positive correlation between their right IFG, but the activations in the cooperator–builder pairs did not. These results suggest that the builder's activation in the right IFG is reduced/increased in the context of interacting with a cooperative/competitive partner. Also, the competitor may actively trace the builder's disk manipulation, leading to deeper mind-set synchronization in the competition condition, while the cooperator may passively follow the builder's move, leading to shallower mind-set synchronization in the cooperation condition.

1. Introduction

Successful interpersonal interaction requires a shared understanding of related information in a particular context (Wittgenstein, 1958). Human beings are social by nature, i.e., our minds and behaviors are mostly affected by other persons (Baumeister & Leary, 1995). Neuroscience is no exception and indifferent to those trends toward the social nature of human brains (Cozolino, 2006). However, the majority of research in social neuroscience has primarily focused on the neural mechanism of an individual's behavioral process in a single-brain paradigm, in which an individual participant interacts with a computer (Polosan et al., 2011) or with a pseudo person (Halko, Hlushchuk, Hari, & Schürmann, 2009). Although single-brain studies are highly appropriate to explore primary sensory functions (Hari & Kujala, 2009), a complete understanding of the cognitive processes underlying human behavior cannot be achieved without examining the dynamic interactions among individuals (Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012). Therefore, growing research has shifted toward a "second-person neuroscience" (Schilbach et al., 2013). In the same vein, the purpose of the present study was to examine the neural substrates of interpersonal interaction in a real human–human situation.

Interpersonal interaction is defined as an individual's "simultaneous or sequential actions that affect the immediate and future outcomes of the other individuals involved in the situation" (Johnson & Johnson, 2005). Accordingly, interpersonal interaction can be categorized into two types: concurrent interaction and turn-based interaction. The concurrent interaction involves continuous moment-to-moment exchange of information among persons forming body-movement synchronization. Although the behavioral synchrony is important for group performance such as music ensembles, it alone is not enough to understand the turn-based interaction. The turn-based interaction normally requires shared representation of actions and intentions across people for

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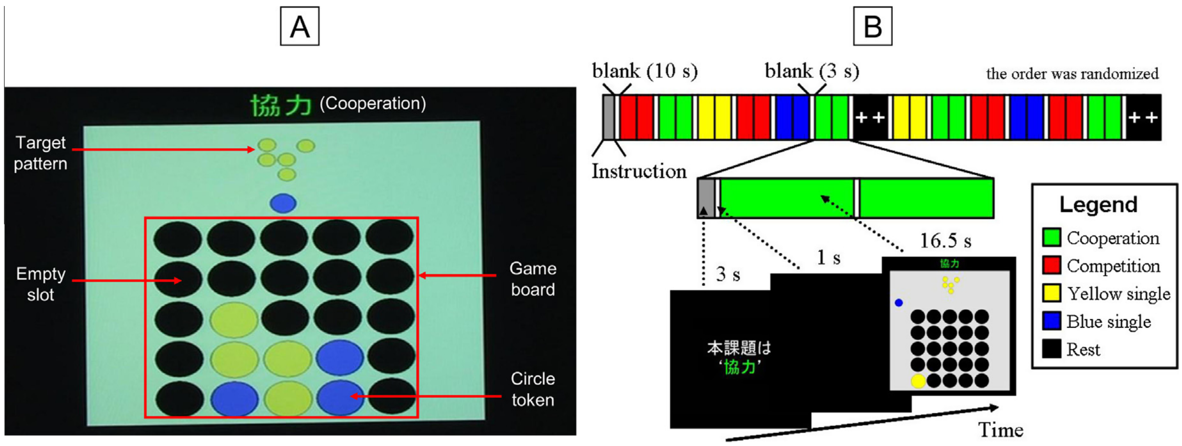

Fig. 1. (A) A clip from a game in the cooperation condition (the indicative rows and letters were not displayed in the experimental games). (B) Experimental procedure in one session (revised from Decety et al. (2004)).

complementary or contrary behaviors (Hari, Himberg, Nummenmaa, Hämäläinen, & Parkkonen, 2013).

Recently, an increasing number of studies in second-person neuroscience have attempted to acquire the cerebral data from two or more subjects simultaneously (termed as hyperscanning by Montague et al. (2002)) during interpersonal interactions (Babiloni & Astolfi, 2014; Konvalinka & Roepstorff, 2012). However, most of them have mainly focused on body-movement synchronization involved in concurrent interactions using various tasks such as key-press task (Cui, Bryant, & Reiss, 2012; Funane et al., 2011), finger-movement task (Holper, Scholkmann, & Wolf, 2012; Naeem, Prasad, Watson, & Kelso, 2012; Yun, Watanabe, & Shimojo, 2012), and music-playing task (Babiloni et al., 2012). Little is known about the neural mechanism of turn-based interaction due to the complex dynamics of interactive situations (Ménoret et al., 2014).

Cooperation and competition are two basic modes of interpersonal interaction (Decety, Jackson, Sommerville, Chaminade, & Meltzoff, 2004). That is, depending on the interaction modes (cooperation vs. competition) individuals may either facilitate the goal achievement of others or obstruct others' goal achievement. Cui et al. (2012) have measured pairs of participants' prefrontal activations during concurrent cooperation and competition using near-infrared spectroscopy (NIRS). The task of the paired participants was to press two keys either simultaneously to show synchronized action in the cooperation condition or as fast as possible to win over their partner in the competition condition. The participant pairs showed increased inter-brain synchronization in their right superior frontal cortices during cooperation (but not during competition), due to the requirements of modeling the behaviors of others in the cooperative interactions.

In another EEG hyperscanning study, to examine the neural correlates underlying the body-movement synchrony, Yun et al. (2012) simultaneously measured pairs of participants' brain activity in a finger-movement task using two sets of EEG. During a cooperative training, one participant as a leader was asked to randomly move a finger in a 20 × 20 cm square, while the other participant followed the leader's finger movement. After the training, the participant pairs showed increased synchronization in both their finger movement (i.e., body-movement synchronization) and their frontoparietal activation, suggesting that the frontoparietal network (including the inferior frontal gyrus, IFG) may be the "neurophysiological substrates of inter-brain synchronization" linked with the behavioral synchrony during cooperative interaction.

Taken together, the inter-brain synchronization in the frontoparietal regions may be important for concurrent cooperation, but not for concurrent competition. Concerning the turn-based cooperation and competition, Decety et al. (2004) have measured single participants' brain activation when they played a two-person turn-taking game with an experimenter outside the scanner room using fMRI. Fig. 1A shows an example scene of the game. The single participant and an experimenter were assigned to either one of two roles (game builder and the partner) in the game. The builder's task was consistently to make a copy of yellow[1] target-pattern by placing yellow disks on a monitor, while the partner's task was to aid in the builder's task (cooperation condition) or to obstruct it (competition condition) by placing blue disks. The builder always took the initial move and the partner followed. During the experiment, the participant played as a builder in half of the games and as a partner in the other half. The data obtained from both roles revealed that cooperation is associated with the right orbitofrontal cortex, and competition is associated with the medial prefrontal cortex and the right inferior parietal lobule (IPL). Decety et al. (2004) concluded that cooperation provides a reward or benefit to interacting people, while competition requires additional resources of mentalizing and self–other distinction to predict an opponent's actions and intentions.

Although Decety et al. (2004) have demonstrated the neural correlates of turn-based cooperation and competition, there are still two points needed to be addressed. First, the builder and the partner's active efforts to achieve their respective goals may be affected by behavior of their partner (Deutsch, 1949; Johnson & Johnson, 2005), leading to distinctive activations. Second, interpersonal interaction involves mutual exchange of information across persons, which cannot be assessed by only measuring single brains (Hasson et al., 2012). That is, without examining the interacting two brains simultaneously, it is hard to fully understand the neural mechanism underlying interpersonal interactions (Hari & Kujala, 2009). Therefore, it is important to explore the inter-brain relationship between the builder–partner pairs in the same two-person turn-taking game.

Previous studies have demonstrated that both cooperative and competitive interactions necessitate requirement of an empathic view and self–other monitoring to trace the other person's action, and in turn to adjust one's own action (Decety & Sommerville, 2003). In particular, the requirement is greater in competition when people have divergent goals (De Cremer & Stouten, 2003; Decety et al., 2004). It is well acknowledged that the IFG and the IPL, belonging to the mirror neuron system, play a critical role in social

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.