

A Preliminary Study on Neural Basis of Collaboration as Mediated by the Level of Reasoning

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Abstract. In this study, we investigated the neural correlates of collaboration and the relationship between collaboration and the reasoning level (low; zeroth-order or high; first-order) of other person. Fourteen volunteers played a collaborative matrix game with a computerized agent and predicted the agent's behavior in the functional magnetic resonance imaging (fMRI) scan session. From the results, the collaboration game evoked neuronal activations within both the left and right insula. Also, in the collaboration game, insula activation was greater in the higher-order reasoning condition than the low-level reasoning condition of the agent. The insula area is known to be related with sense of agency, autonomic arousal, and motivation. The collaborative game may cause participants to be motivated and deeply involved in the emotional experience, such as achieving a common goal with other person. In this context, the increased activation within insula seemed to be associated with participants' motivational and emotional states while collaborating with other person.

Keywords: Functional magnetic resonance imaging, theory of mind, collaboration, reasoning order, insula, matrix game.

1 Introduction

Theory of mind (ToM) has been defined as the ability to understand desires, intentions, or beliefs of others [1] and its underlying neural mechanism have been studied for decades. Regions including medial prefrontal gyrus, posterior cingulate cortex, temporoparietal junction, and amygdala have been mainly reported as the ToM network [2, 3].

In particular, researchers have been focused on neural basis of cooperative behavior [4, 5, 6]. For example, Decety and colleagues (2004) investigated brain regions underlying collaboration and found medial frontal activation in collaboration condition. Also, brain regions related to reward processing were also found in collaborative

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setting. For instance, Krill and Platek (2012) reported the activation in caudate and putamen, suggesting rewarding nature of collaboration.

On the other hand, some researchers have developed hierarchical model of ToM to explain depth of thoughts, or reasoning order [7, 8]. Reasoning order tells how a person can recursively predict the other person's behavior. Within this hierarchical model, a zeroth-order reasoner only considers his desires and beliefs to make a decision, without considering other person's desires or beliefs. A reasoner, who uses high level of reasoning, can infer other person's thoughts and make a decision based on the inference in a social context. Previous neuroimaging literatures have found that higher level of reasoning positively correlated with medial prefrontal or dorsal prefrontal cortex activation [9, 10], and these regions reflected successful mentalizing of other's behavior.

To our knowledge, however, there was no study investigating the relationship between collaboration and the reasoning order. This functional magnetic resonance imaging (fMRI) study aimed at investigation of the neural correlates of collaboration with a counterpart who had low or high level of reasoning.

2 Methods

2.1 Participants

Fourteen healthy right-handed students volunteered to participate in this study (8 males, age=23.6±3.7 year). They had no history of neurological and mental disorders such as depression, anxiety disorder, or borderline disorder. Once participants fully understood the experimental procedure, they gave written informed consent. Prior to fMRI experiment, all participants visited the laboratory and were trained to be familiar with the matrix game. The study procedure was approved by the Institutional Review Board of Korea University.

2.2 Experimental Paradigm

Each participant performed a 2×2 collaborative matrix game (modified from [7]) with either a myopic (zeroth-order) or a predictive (first-order) computer agent as an opponent. As shown in Fig. 1, the game matrix consisted of 4 cells labeled as A, B, C, and D, and each cell contained respective payoffs (between \$1 and \$4) for the participant (left) and the computer agent (right). The two players took turn and made a 'move' or a 'stay' decision by pressing buttons. The participant always started first at cell A. The game could be ended anywhere (A, B, C, or D) according to decisions made by the players. For example, if the participant decided to stay at cell A, the game ended at cell A and the computer agent was deprived of its chance to move at B. On the other hand, when the participant moved to cell B and the opponent moved to cell C, the game would be ended at cell C or cell D. The movement from C to D was determined based on the participant's advantage. The game was ended at cell D only when the participant's outcome was greater in cell D than cell C.

In a game, the participant was asked to win the payoffs as much as possible according to one of two instructions: 1) control condition: maximize own payoff regardless

of the opponent's payoff; 2) collaboration condition: maximize the summed payoff of the self and the opponent. The participants were required to predict the opponent's move, which was either of a 'move' or a 'stay' decision at cell B. The participants were told that they were going to play with a myopic (zeroth-order) or a predictive (first-order) opponent. A zeroth-order opponent makes a decision only based on his own payoffs at cell B and C. Meanwhile, a first-order opponent decides to move or stay with regards to his payoffs and the other player (the participant)'s payoffs at cell B, C, and D. The opponent's reasoning order was consistent during an fMRI scan, and the participants played games with zeroth-order opponent in one fMRI scan and first-order opponent in the other fMRI run. They were told that an order of opponent strategy would be randomly mixed across fMRI scans. To motivate participants to actively collaborate with the opponent, the participants were told that they would be playing with the human player which would be one of our study members. In fact, a computerized agent implemented with the zeroth- and first order reasoning was deployed during the game with pseudo-randomly generated response time.

In each of two fMRI scan runs, the participants performed 20 trials consisted of 10 pairs of matrix games. In each pair of matrix game, a single matrix game was used for both control condition and collaboration condition. During the fMRI experiment, participants went through a training run (about 4-6 min) and two task runs (about 12-15 min as shown in Fig. 1). Again, an opponent's reasoning order was counterbalanced across the participants to prevent a potential confounding effect.

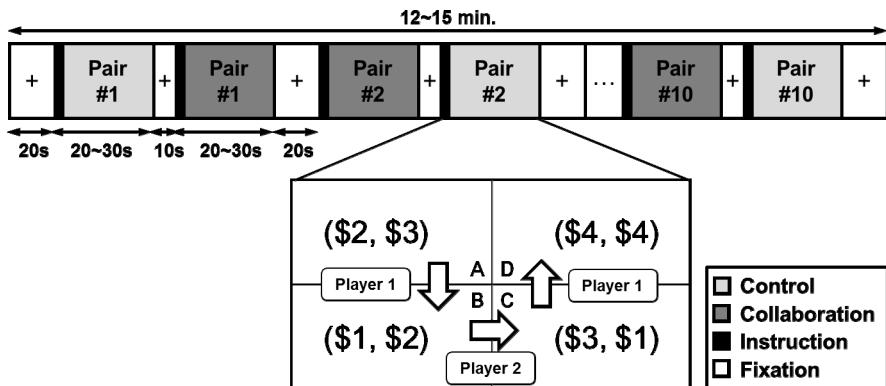


Fig. 1. Experimental protocol. Player 1: participant; Player 2: computerized opponent

2.3 fMRI Data Acquisition

The participant's response time (RT) and accuracy were recorded during fMRI scanning. After the fMRI scan runs, participants were asked how strong they believed that they were collaborating with a human opponent (perceived feeling of interaction; 1: least, 5: most), and how difficult the game was (1: easiest, 5: most difficult).

The fMRI experiment was conducted in a 3-T MR scanner with 12-channel head coil (Tim Trio, Siemens, Erlangen, Germany). The gradient-echo T₂* weighted echo planar imaging (EPI) was applied to measure neuronal activity based on blood-oxygenation

level-dependent (BOLD) mechanism (TR/TE=2000/30 ms, 35 slices parallel to the participant's bi-commissural plane, slice thickness=4 mm, in-plane voxel size=3×3 mm², matrix size=64×64, flip angle=90°, field of view=240 mm).

2.4 Data Analysis

Preprocessing. SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK) was used for preprocessing of the obtained EPI data. In detail, a slice timing excluding the first 5 dummy volumes and head motions were corrected. The corrected EPI volumes were spatially normalized to the standard Montreal Neurological Institute (MNI) space and resampled with a 3 mm isotropic voxel size. Then, an 8 mm isotropic full-width at half-maximum Gaussian kernel was applied for spatial smoothing.

Statistical Analysis. The preprocessed data of each participant were analyzed using a general linear model in an individual level. Four different regressors were designed following the onset timing and durations for each of the prediction of the zeroth-/first-order opponent's move in control condition, prediction of the zeroth- /first-order opponent's move in collaboration condition. Then, a group-level analysis was conducted using the contrast of neuronal activations across individuals/participants via one sample *t*-test to compare game types (*i.e.*, collaboration vs. control), or opponent's reasoning orders (*i.e.*, first-order vs. zeroth-order).

3 Results

3.1 Behavioral Response

All participants performed the tasks successfully (accuracy=94.6±6.1%) and most of them reported that the task difficulty was moderate (overall difficulty=2.9±0.7). Also, participants reported that they felt active collaboration with the opponent (perceived feeling of interaction=3.9±1.0). In terms of response time, participants responded faster in zeroth-order condition (295.3±169.4 ms) than first-order condition (363.8±201.9 ms), and the effect was marginal ($p=0.055$).

3.2 Estimated Spatial Patterns Using fMRI Data

Fig. 2 shows the neural correlates of collaboration compared to control condition during the game. In zeroth-order condition, the left anterior insula was shown greater activations during the collaboration condition than the control condition. There was no brain region that showed greater neuronal activations from the control condition than the collaboration condition with the zeroth-order opponent. Table 1 shows the detailed information.

The left insula activation was also found while participants were collaborating with first-order opponent, whereas the middle temporal gyrus was shown greater activations in the control condition while playing with the first order opponent.

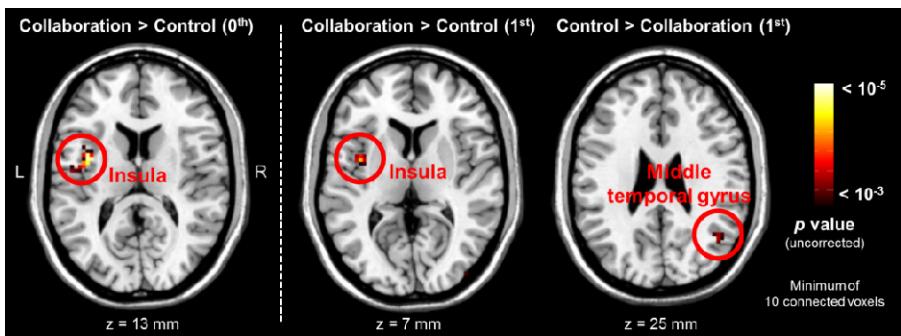


Fig. 2. Activated regions when collaborating with an opponent

Table 1. Activated regions in a collaboration (CB) and control (CN) condition

Condition	Region	L/R	MNI (mm)	t score	Cluster size
<i>Zeroth-order</i>					
CB > CN	Insula	L	-39, -1, 13	6.32	33
<i>First-order</i>					
CB > CN	Insula	L	-39, -1, 7	5.55	25
	Middle occipital gyrus	R	27, -94, 1	4.98	12
	Fusiform gyrus	R	45, -55, -26	4.37	11
CN > CB	Middle temporal gyrus	R	45, -61, 25	4.49	10

Fig. 3 shows the interaction between collaboration and opponent's reasoning order. A collaboration with first-order than zeroth-order opponent resulted in a greater activation in bilateral insula, and right precentral gyrus. However, the opposite contrast (*i.e.*, zeroth-order > first-order) did not reach a statistical significance. Table 2 shows the detailed information.

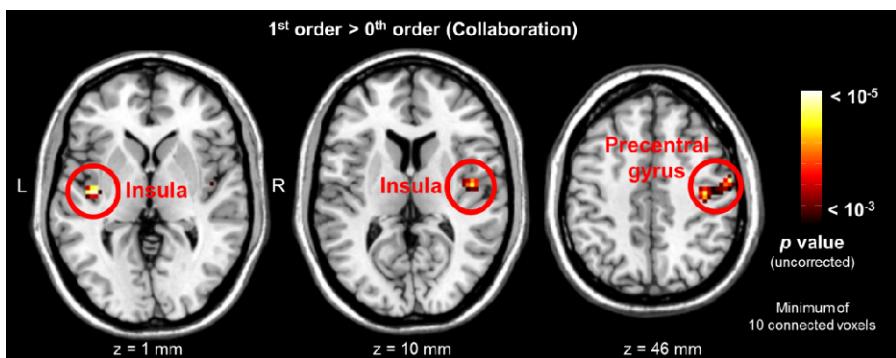


Fig. 3. Activated regions when collaborating with the opponent

Table 2. Activated brain regions depending on a reasoning order of opponent

Condition	Region	L/R	MNI (mm)	t score	Cluster size
<i>Collaboration</i>					
First > Zeroth	Insula	L	-42, -13, 1	4.41	30
	Precentral gyrus	R	57, -7, 46	4.13	138
	Insula	R	45, -10, 10	4.11	44
<i>Control</i>					
Zeroth > First	Lingual gyrus	R	30, -67, -8	4.66	19
First > Zeroth	Middle temporal gyrus	R	45, 14, -38	4.08	11

4 Discussion

In this study, we reported the neural basis of collaboration and its interaction with reasoning order. When participants were collaborating with a counterpart, the brain activations were found in the insula areas with much greater statistical significance in the high reasoning order (first-order) condition.

Prior studies have suggested that insula played an important role in social interactions [4, 11] and motivational process [12]. When an individual attributes the result of an action to the self, the activation within insula is increased and this activation may represent high level of sense of agency. This high-level of sense of agency strongly correlates with high motivational states and self-determined decision [12]. Thus, we may suppose that the activation within the insula reflects participant's engagement in the game that requires a social interaction. The positive effect of social interaction such as collaboration and competition on motivation has been widely known [13]. Based on the fact that participants reported increased level of engagement during the collaboration game than the control game, the collaborative game might require more motivational demand compared to the control game.

An anterior part of insula has known to be related to autonomic arousal, which is closely tied with emotional experience [14]. Indeed, the collaborative game with a counterpart was more likely to evoke participants' arousal, compared to control condition. This is because participants were asked to carefully consider the opponent's reasoning order in a collaboration condition. Furthermore, in order to collaborate with an opponent in a higher reasoning level (*i.e.*, first-order), participants had to be more attentive to the task to complete the task successfully. In this context, greater anterior insula activation may imply that participants were more attentive during the task to successfully reach the goal together.

In future study, we would try to remove non-neuronal artifacts including motion related as well as physiological artifacts to refine the neuronal components in the measured BOLD signals. We would also employ data-driven analytic methods such as principal component analysis and independent component analysis techniques followed by a connectivity analysis between brain regions. It would also be very interesting future study in the context of the ToM how the neuronal mechanism related to other types of social interaction such as competition are interpreted in relation to the collaboration.

5 Conclusion

In this study, we tried to figure out the neuronal mechanism underlying collaboration with other individual and found neuronal activations within bilateral insula areas. The level of insula activations was increased when deploying higher order reasoning collaborating with the opponent. This may suggest that collaborating with other people may recruit a great extent of motivational process in the insula area and future investigations to collect further evidences and utilities are warranted.

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