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From Physical Brain to Social Brain

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1. Introduction

In our highly complex human society, social intelligence is essential for interacting with other agents (Frith et al.; 2004). One of the key elements of social intelligence is the ability to assess *social compatibility (distance)* between oneself and others, e.g. judging whether someone could be a friend or enemy, while also selecting proper behavioural options in our social interaction (Bogardus, 1959; Akerlof, 1997), as it influences our socioeconomic behaviours (Hoffman et al.; 1996; Charness & Gneezy, 2003; Jones & Rachlin, 2006). Across cultures, the nature of interpersonal relationships are often thought of, described and acted out in terms of physical space (e.g. "close friends" or "distant relatives") (Ossowski, 1963; Bottero & Prandy, 2003). In our daily life, social distances are also acted out in our natural behaviours, such as our tendency to regulate "personal space" based on the degree of social connection with others (Hall, 1966; Hayduk, 1983). Moreover, it has been widely observed that there is a tendency for people to cognitively map social distances onto physical space, giving rise to psychological tools such as sandplay therapy and sociograms. However previous neuroscience studies tend to show that social intelligence has strong ties with the emotion-related brain area and the reward-related brain area (Goleman, 2006). Is the connection between spatial concepts and social concepts in linguistics and psychology only a convenient metaphor or based on deep biological roots in the brain?

One intriguing possibility is that the connection between the mental representations of social relationships and those of physical space is based on common neural substrates in the brain (Ramachandran and Hubbard, 2001). In particular, since the parietal cortex is known to be involved in the self-referential operations that convert the spatial information of external objects into self-centred (i.e. egocentric) coordinates for action behaviour (Roland et al.; 1980; Rapcsak et al.; 1995; Neggers et al.; 2006; Naito et al.; 2008), the common origin hypothesis predicts that the parietal cortex should also be engaged in social distance judgments, when a self-referential process is required (Vogeley & Fink, 2003). If the parietal cortex indeed performs analogous operations in social space, such a self-referential mapping of social distance would be an efficient manner of organizing complex social information to guide interactions with others.

2. Social relationships represented in physical space

2.1 A doll-arranging task

We have originally created a new experiment to reveal whether people symbolically organize social relationships on a 'distance' scale when estimating social compatibility with other agents. We call this experiment "a doll-arrangement task" where participants spatially arranged 6-cm-high dolls including a self-doll and other dolls on a 30 × 30-cm stage (Fig. 1). The doll-arranging task was a virtually modified version of the social measurement that was done to measure spatial distance between persons, allowing researchers to carefully observe human natural social behaviours (Hall, 1966; Hayduk, 1983). This task was designed to be easily conducted in an experimental room. By measuring physical distances between a self-doll and other dolls, we may know if people represent social relationships on a 'distance' scale when estimating social compatibility with other agents.

2.2 Free behavior in a doll-arranging task

We conducted a doll-arrangement task on fifteen participants (12 male and 3 female; ages 20–32 years). The participants spatially arranged dolls on a stage (Fig. 1A). Each participant was first asked to place a white doll (representing self) and a black doll (representing an incompatible person) wherever they liked on the stage. Next, he/she randomly picked one doll at a time out of 12 dolls (each had a facial picture of an unfamiliar person), and if he/she felt that he/she would be compatible with the person in real life, he/she had to place it anywhere on the stage. A total of 12 dolls were tested. Even though each participant was allowed to place the compatible dolls anywhere on the stage (Indeed, some participants simply sorted the dolls in a row fashion), the averaged distance between the self and compatible dolls across participants was significantly (physically) shorter than that between the self and incompatible dolls (paired t-test, $t = 4.2$, $df = 14$, $p < 0.001$; Fig. 1B). These suggest that people can choose compatible persons solely based on their facial appearance, and clearly demonstrate that people tend to spontaneously arrange representations of socially compatible individuals near themselves even without explicit instructions to do so. Thus, it is likely that people represent social relationships on a 'distance' scale when estimating social compatibility with other agents.
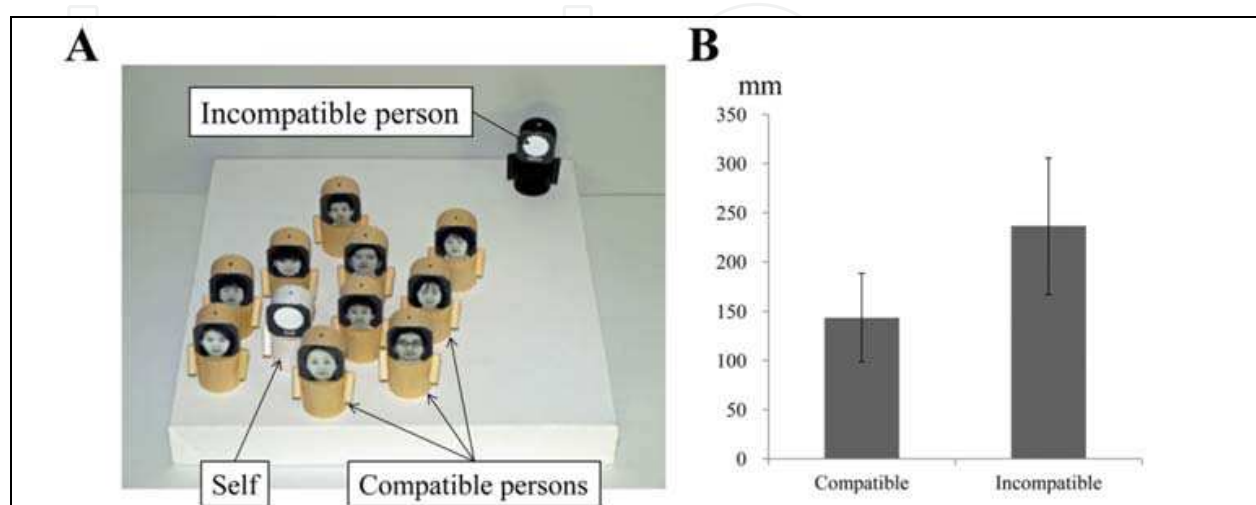

Fig. 1. Results of a doll-arrangement task.

3. A feature in 'distance' evaluation

3.1 Social distance (SD) and Physical distance (PD) task

We conducted a psychophysical experiment to examine whether these two aspects of 'distance' representation have a common feature. Twenty-four healthy volunteers (ages 19–34 years) performed sets of tasks. First, we prepared a physical distance (PD) task and a social distance (SD) task. In the PD task, a display presented two inanimate objects whose relative physical positions could be inferred by texture and lighting cues, and participants indicated which object they judged to be closer to themselves (Fig. 2A). We prepared four different texture panels, and displayed two of those textures in each trial. The two panels were rendered along a virtual line on the monitor (Figure 2A top); this line was tilted at three different angles (15°, 30° and 45°) to the participants' frontoparallel plane. In half the trials, the right panel was closer, and in the other half, the left. In the presentation of the stimuli, the angle of tilt (3), direction of tilt (2) and combination of textures in pairs (12) were counterbalanced. Thus, the task comprised 72 trials. In the SD task, the display presented pictures of two faces, and participants indicated which individual they felt they would be more compatible with and would interact and cooperate with better in real life (Fig. 2B). We used, with permission, facial pictures from a publicly available facial picture database produced by Softopia Japan (Gifu, Japan). The database consists of facial (neutral) pictures of Japanese males and females (ages 15–64 years). We used this database because Japanese faces would be more familiar to the participants, though the individual in the picture was unfamiliar. For the present study, we selected pictures of 36 males and 36 females ranging from 20 to 35 years of age (roughly the same generation as that of the participants). Pictures were paired off in order of age, within the same gender. Each trial stimulus comprised one of these 36 pairs, and each pair was used twice to counterbalance the left-right positions, making a total of 72 trials. The facial pictures were chosen because the facial appearance of a person is known to give us the first impression of the person and if the person is attractive to us we often feel social compatibility to that person, increasing the motivation to build a sustainable relationship (Zebrowitz, 1997).
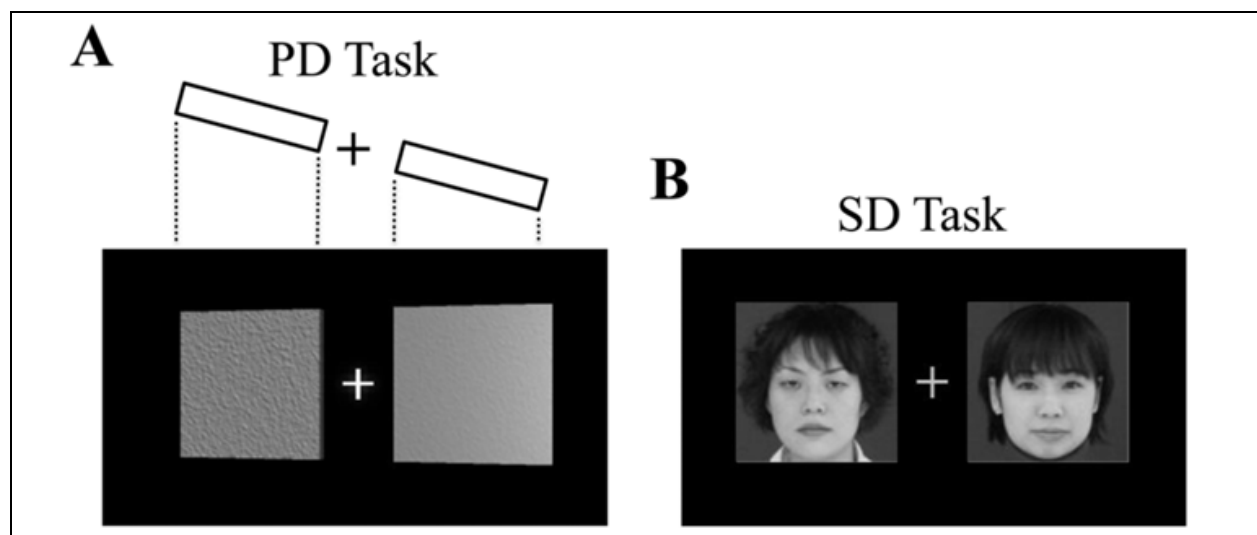

Fig. 2. Examples of stimuli used in the PD and SD tasks

For each task, stimuli were displayed for 3 s per trial, and participants were instructed to press a button as soon as they made a decision. They were also instructed to fixate on a cross

displayed at the centre of the screen in order to minimize possible eye movements. Special care was taken so that the locations and sizes of paired stimuli on the monitor were identical across the PD and SD tasks.

3.2 Psychophysical feature in SD and PD tasks

In order to verify a feature in 'social distance' evaluation, the SD task was conducted with an additional rating task after each trial. The participants were also requested to provide a rating (1–5) in the SD trials for how different each pair of faces was in terms of the social compatibility to the participant. As social compatibility seems to be represented on a 'distance' scale (see above), this provided a measure of subjective social distances analogous to the objectively defined distances used in generating the PD stimuli. The reaction times (RTs) in the PD task were sorted into three categories according to the angle of tilt used to generate the stimulus (15°, 30° and 45°), and the RTs in the SD task were sorted into four categories (1, 2, 3 and over 4) based on the ratings provide in the tasks performed outside the fMRI scanner (see below). The mean RT for each category in each task was calculated for each participant.

We found that the reaction time (RT) became significantly longer as the differences in 'distances' decreased, and that this relationship was consistent across both the SD and PD tasks. That is, when pairs of faces were rated as being similar in social distance, the RTs increased ($F(3, 69) = 74.2$, $p < 0.001$, single-factor ANOVA; Fig. 3B). The same trend was seen in the PD task: when the two physical objects were about the same distance from the participant, the RTs increased ($F(2, 46) = 32.0$, $p < 0.001$; Fig. 3A). The graded RTs in the SD task imply that when people evaluate social compatibility with a person and compare these about two persons, abstract magnitudes of their social 'distances' could be compared, as in the case when people compare physical distances from themselves to two objects in the PD task.
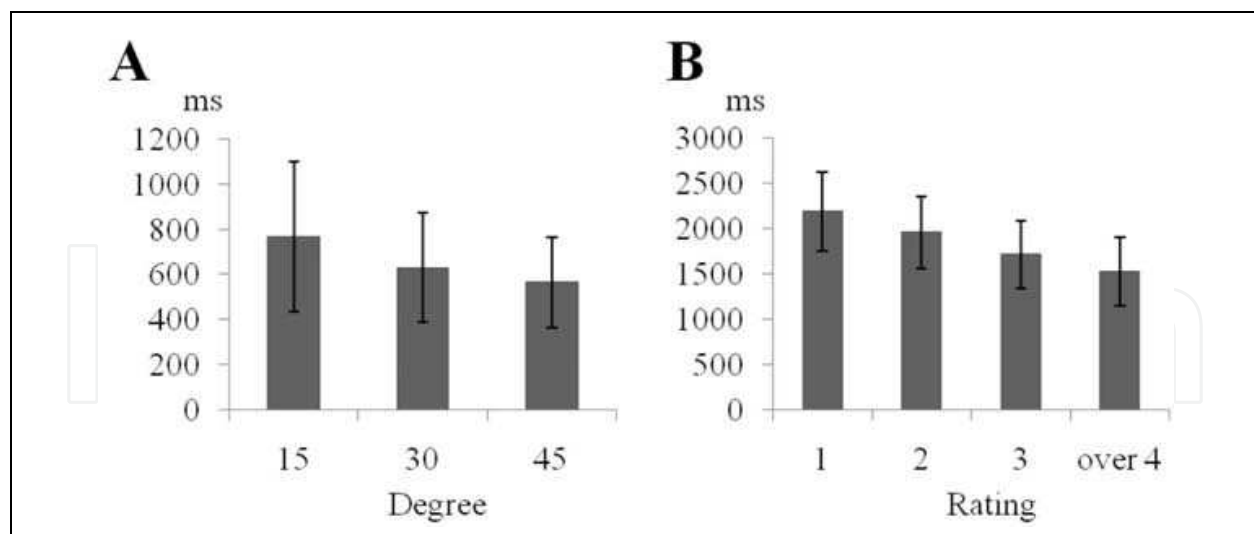

Fig. 3. The results of average RT in the PD and SD tasks

4. Neural correlates of social and physical distance

4.1 Brain activity related to 'distance' analysis

Using a functional magnetic resonance imaging (fMRI), we investigated whether similar brain activity emerges in the evaluation of both physical and social distance, and degree of

the brain activation reflects demands of neuronal computation for evaluating abstract 'distance' during the SD task. Twenty-four healthy volunteers who were same individuals in psychophysical experiment participated in the fMRI experiment (details of methods; see Yamakawa et al. 2008).

In order to depict brain areas related to both the PD and SD tasks, we prepared two control conditions (PC and SC, respectively). In these control conditions, participants simply pressed a button in response to the displayed objects or faces that are the same in the PD and SD tasks. Thus, by directly comparing brain activity during the tasks with that during their corresponding control conditions, we may depict activations purely related to the tasks that cannot be accounted by factors of simple visual and motor processing.

4.2 Neural correlates of evaluation of 'egocentric space'

We defined a linear contrast in the general linear model(Friston et al.; 1999) to identify activity that was exclusively related to the PD task by directly comparing it with activity obtained in the control task (PD vs. PC). By this procedure, we could depict brain areas that play essential roles in the PD task and are distinct from those simply related to visual processing and motor response. The same procedure was used to identify activity exclusively related to the SD task (SD vs. SC).

The fMRI analysis revealed that the only brain activity that was significantly associated with the PD task was in the superior aspects of the posterior parietal cortices. This bilateral activation included the intraparietal regions [PD vs. PC, $p < 0.05$ corrected; left and right peak coordinates, (–16, –64, 58) and (22, –68, 52); Fig. 4]. This is consistent with previous notion that posterior parietal cortex is involved in self-referential coding of external objects that is often used for upcoming motor behaviors (Connolly et al.; 2003; Medendorp 2005). The parietal lobule is often activated when people make self-referential spatial judgement of an external object, whereas the lobule becomes silent when people judge allocentric spatial
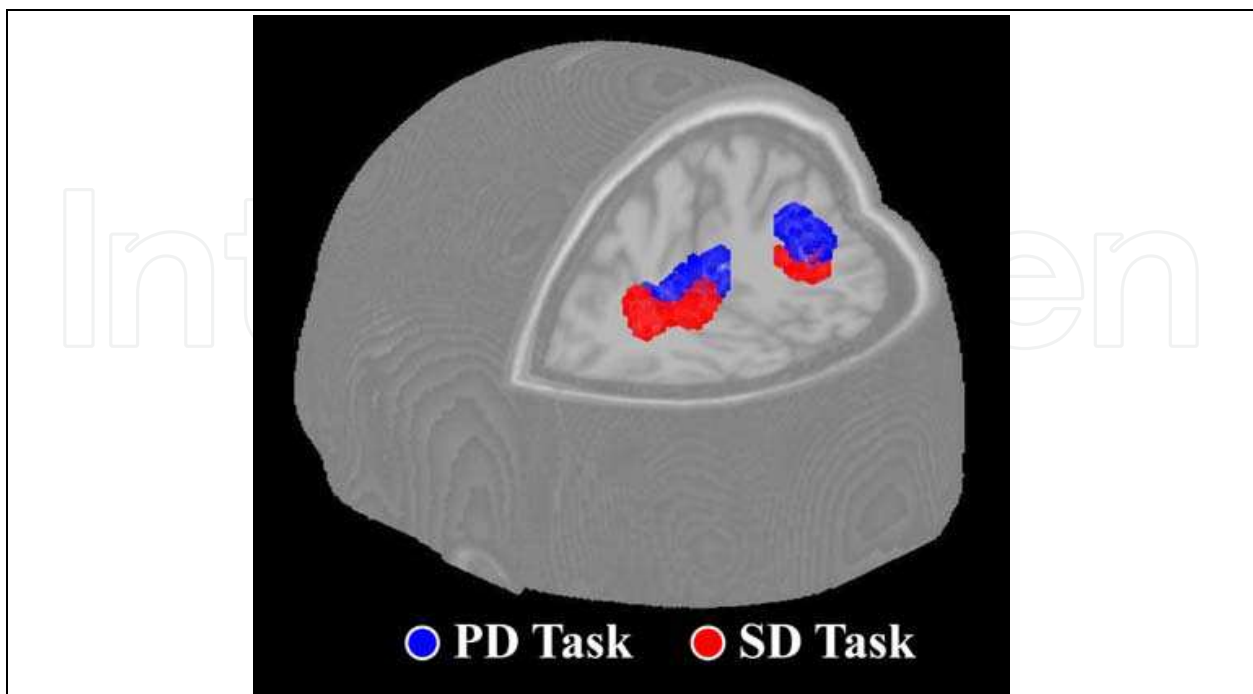

Fig. 4. Brain activations during PD and SD

location of an object (Neggers et al.; 2006). Furthermore, a patient with lesion in the parietal lobule shows impairment in relating her body to external objects (Milner & Goodale, 1995; Rapcsak et al. 1995). All these findings indicate the importance of superior aspect of posterior parietal cortex in humans in a function of self-referential (egocentric) spatial processing of external world such as the estimation of egocentric distances.

Notably, significant bilateral parietal activation was also found during the SD task (SD vs. SC, $p < 0.05$ corrected; peak coordinates, (–38, –56, 46) and (30, –54, 38); Fig. 4A), and these regions overlapped with those of the PD task (47 voxels), in a slightly ventro-lateral portion [peaks of overlapping sections, (–22, –66, 54) and (22, –70, 52)]. As expected, the SD task also activated a network of brain areas consistent with the requirements of visual face processing and general social cognition for the task: the bilateral visual cortices, extending into the fusiform gyri; bilateral medial frontal cortices; inferior frontal cortices; insular cortices; and left basal ganglia and amygdala (Fig. 6A).

4.3 Correlation analysis of 'social distance'

A more stringent method to isolate areas relevant to 'distance'during the SD task is to search for brain areas whose activities scale with the task demands. Subjective ratings of differences in social distance are a putative measure of the task demands (see above). We confirmed that the behaviours inside and outside the scanner were consistent when we analyzed the data obtained by the fMRI experiment. We also performed a correlation analysis across participants to see if there was a consistent trend in which participants who required longer RTs inside the scanner also required longer RTs outside the scanner. As results, the RTs for the SD task also became significantly longer as the differences in 'distances' decreased inside scanner ($F(3, 69) = 11.3$, $p < 0.001$). The average RT which participants required in the SD task were significantly correlated inside and outside the scanner ($df = 22$, $r = 0.69$, $p < 0.001$), indicating the consistency of the SD task demands for participants both inside and outside the scanner.

As their validity was confirmed by the consistency and systematicity of the behavioural data, we then performed parametric modulation analysis across all the brain areas activated by the SD task(SD vs. SC; Fig. 5A) to find voxels whose activation correlated with the demands as measured by the social distance ratings. First, we individually calculated the mean rating for each fMRI blocks. Then, we performed parametric modulation analysis between the ratings and effect size in the block. Effect size was obtained by comparing activity during the block with activity.

The correlation analysis revealed that, within the brain areas active during SD task, only the left intraparietal cortex showed a significant correlation [peak coordinates, (–24, –60, 44); Fig. 5A]. The activity in this region was negatively correlated with the social distance rating, i.e. trials in which the two faces were rated as having similar social distances resulted in greater activation of the left parietal cortex (Fig. 5B). The SD task required the participants to evaluate social compatibility with a person based on his/her facial appearance. As demonstrated in the doll-arranging task, when people evaluate the social compatibility, they tend to think of the compatibility as a 'distance' that can be converted into physical distance from the self-representing doll that brought their egocentric viewpoints (Fig. 1B). Thus, it is assumed that the participants also performed self-referential (egocentric) processing of an abstract magnitude of 'distance' from a person in the SD task, as indicated by the graded RT in this task (Fig. 3B). Then, we found activations during the SD task in the intraparietal

regions that are also active during the self-referential assessment of physical distance (PD) (Fig. 4), and the activity reflected the demands (i.e.; the differences in social distances between self and two persons) of SD task (Fig. 5A, B). These results suggest that the activations should be related to core process of the SD task.
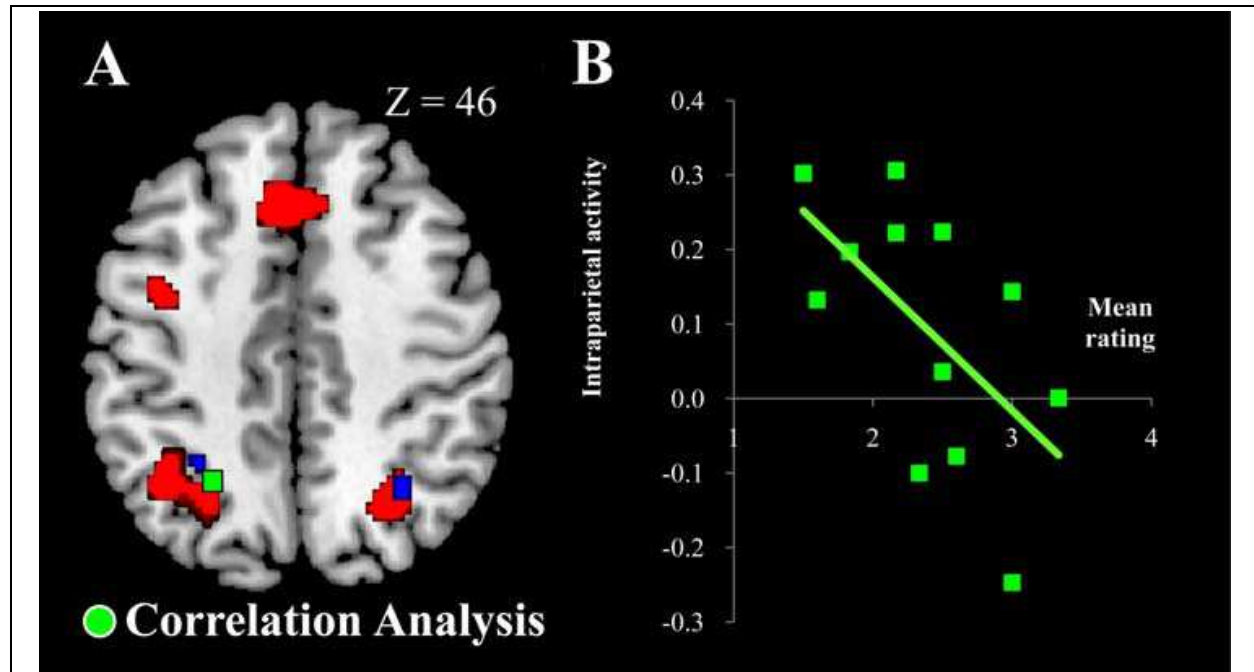

Fig. 5. Brain activations (A), and a representative result from correlation analysis (B)

5. Neural correlates of 'Social distance' and 'Social feature'

5.1 Brain activity related to 'social distance evaluation' and 'social feature judgment'
We investigated if the parietal activation in the SD task is exclusively associated with neuronal computation for evaluating abstract 'distance' from other agents in the egocentric framework. In order to isolate the elements of the SD task related to egocentric social distance, we prepared another task, i.e. a social feature (SF) task. In the SF task, the participants were presented with the same pairs of faces but were asked which would be more 'socially popular' or 'get along with people in general'. This task replicated elements of the SD task, such as the evaluation of facial features or empathetic processing, but lacked the element of self-referential distance. Thus, it is likely that the SD task and the SF task both require common neuronal process related to the analysis of one's facial features and empathetic processing, but only the former activates the parietal cortex imposed a role of self-referential (egocentric) processing of evaluation of social distance.

5.2 Distributed and overlapping representations between SD task and SF task
We compared the activation pattern during the SD task to that during the SF task. Overlapping activation for SD and SF was found in the bilateral visual cortices and fusiform gyri and in the bilateral medial frontal and right inferior frontal cortices [(SD + SF) vs. SC; see Fig. 6]. This suggests a number of areas which might underlie the cognitive functions shared between SD and SF, and some which are unique to SD. In particular, the activation of the parietal cortex appears to be unique to SD. No significant parietal activation was found

in the SF task (SF vs. SC), suggesting that the common factors between SD and SF, including eye movements and attentional factors, did not contribute to the parietal activation observed only in the SD task. A direct comparison between SD and SF revealed that SD caused greater activation in the left intraparietal cortex ($p = 0.001$ uncorrected). These differences exist despite the fact that the stimuli for SD and SF were the same and that both RTs, each of which was significantly longer than that of the PD task, indicated similar difficulty levels [SF, 1597 ± 332 ms; SD, 1768 ± 367 ms; PD, 771 ± 197 ms]. Thus, it seems that self-referential (egocentric) evaluation of social compatibility with a person engages the intraparietal regions that are associated with the self-referential assessment of physical distance.
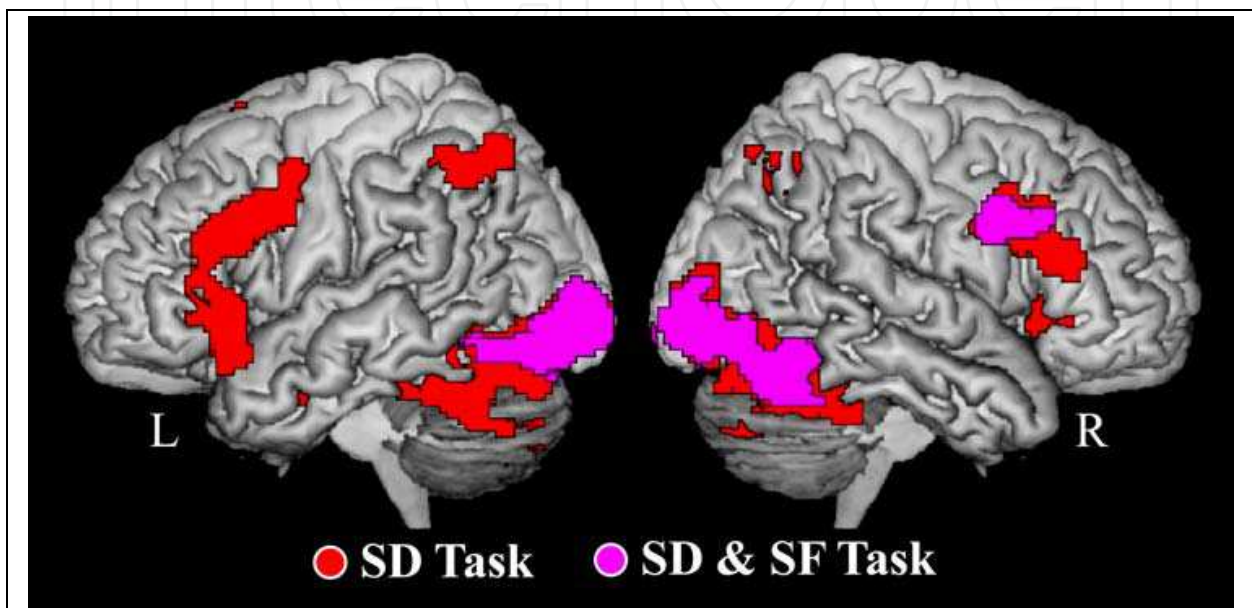

Fig. 6. Brain activations during SD and SF tasks

5.3 Psychophysiological interaction analysis in the SD and SF tasks

Finally, we examined the functional connectivity of the parietal region as a measure of its relevance to the social task. If the activity in the parietal cortex actually mediates the task of assessing social distance based on the face stimuli, then we may expect that it communicates with areas where task-relevant information is processed, such as the fusiform gyrus, which is known to process facial features (e.g. Kanwisher et al.; 1997; Haxby et al.; 2001). While both the SD and SF tasks elicited fusiform gyrus activity, that activity should influence the parietal activity only in the SD task, perhaps via the anatomical connection from the intraparietal cortex to a wide range of cerebral cortices, including the fusiform gyrus, within the same hemisphere (Cavada & Goldman-Rakic, 1989; Rushworth et al.; 2006). We examined such conditional coupling using psychophysiological interaction analysis (Friston et al.; 1997), investigating whether the activity in the parietal cortex receives stronger contextual influences from the fusiform gyrus under the SD task compared to those under the SF task.

Although, the bilateral fusiform gyrus was active in both the SD and the SF tasks, since only the left intraparietal cortex was significantly correlated with the social distance ratings in the previous analysis, we focused on the data obtained from the left hemisphere for this analysis. In each participant, we extracted the time series data from a 5-mm-radius sphere

around the peak (–40, –54, –26) of the left fusiform gyrus activity in common between the SD and SF tasks [(SD + SF) vs. SC]. Based on this data, a PPI regressor was computed. We constructed a linear regression model (general linear model) using the PPI regressor as well as the SD and SF regressors used in the first analysis (boxcar × hemodynamic response). Hence, this analysis was specific to the context-dependent influence of each region that occurred over and above the effects of the two tasks.

This analysis revealed enhanced coupling in the SD task between a fusiform region (–40, –54, –26) and an intraparietal region (–40, –62, 42; Fig. 7A, B) within the left hemisphere. Again, this left intraparietal region matched the region active in the SD task (p < 0.05, after small volume correction). This supported the context-dependent involvement of intraparietal cortex. Namely, both the SD and SF tasks engaged the fusiform gyrus that plays an essential role in the facial processing, but functional coupling of activities between the fusiform gyrus and the parietal cortex in the left hemisphere was specifically enhanced in the SD task. This suggests that when the brain has to evaluate social compatibility with a person based on his/her facial appearance, the information processed in the facial processing area needs further computation for the evaluation of social distance.
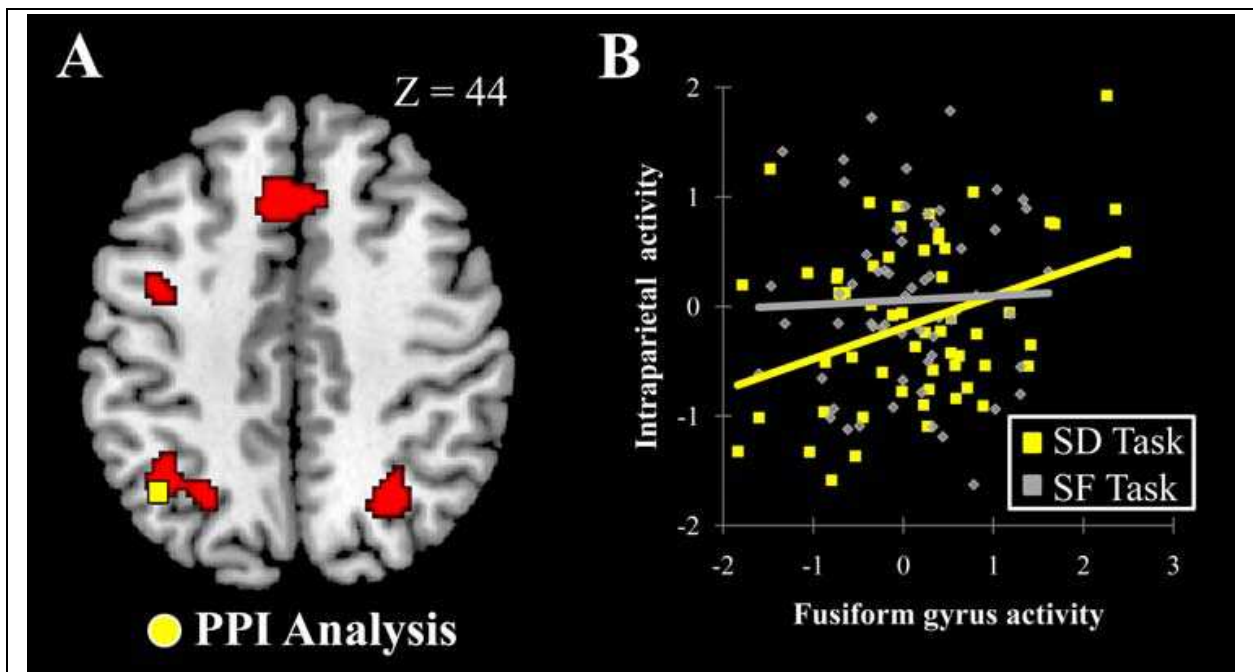

Fig. 7. Brain activations (A), and a representative result from PPI analysis (B)

Neuronal comunication between the ventral portion of the parietal cortex in the human dorsal visual pathway (Milner & Goodale 1992) and the fusiform region in the SD task allows the brain to analyze the distance based on the information of facial features normally analyzed in the human ventral visual pathway.

6. Conclusion

Our results demonstrate that neuronal activity in the human parietal cortex, which is involved in the spatial processing of self-referential physical distance, seems to be associated with the evaluation of social distance between self and others. Thus, our neuroimaging finding raises a possibility that the human parietal cortex may have social-cognitive function

in spatial terms that is analogous to its intrinsic properties of spatial function. It means that our ability to judge human relationship in spatial terms may have its evolutionary root in the ontologically older neural substrates for spatial processing. In addition, converting a function of particular brain region related to an ontologically older processing of physical world into the processing for social world could be a basic and general strategy of the brain. The present study may provide an example of this extending function in human social cognition.

In past studies on the neural underpinning of social cognition, much focus has been given to emotional (Baron-Cohen and Belmonte 2005; Frith and Frith, 2006) and reward-related brain regions (Izuma et al.; 2008; Zink et al.; 2008). Our present findings extend the cortical network of social cognition to the parietal cortex by suggesting that the parietal cortex subserves analytic functions in evaluating social relationships (c.f. Chiao et al.; 2008). In order to share a brain function between analyses of physical and social worlds, social quantity should be represented as abstract magnitude of it. Human parietal cortex appears also to be specialized for this purpose because the parietal cortex participates in the processing of magnitudes of temporal discrepancy and of numerical differences (Walsh, 2003; Hubbard et al.; 2005; Piazza et al.; 2007). Growing evidence in non-human primate supports the involvement of the parietal cortex in the social evaluation. Neurons in the intraparietal sulcus exhibit activities that appear to represent values regarding other agents such as female, subordinate and dominant moneys (Klein et al. 2008). Moreover, neuronal activities in the intraparietal sulcus are modulated in a context-dependent manner under a circumstance where 'social' hierarchy exists (Fujii et al. 2007). While neurons in the intraparietal sulcus are classically implicated in the spatial processing of depth (Sakata et al, 1997), those primitive 'social' functions seem to be supported by neurons in the parietal cortex. However, the most striking difference between our human observation and the monkey studies might be that humans can evaluate social distance from other agents based solely on their unfamiliar facial pictures by mentally simulating future outcomes from the cooperation with the agents.

In summary, we found activity in the parietal cortex in connection with a task involving self-referential judgments of social distance. The location of this parietal activity overlapped with areas activated during judgment of spatial distance, suggesting a shared cognitive mechanism, perhaps one of distances in the abstract. This may help explain the linguistic, psychological and behavioural connections between the concepts of the physical and social spaces. Taken together, it seems that parietal cortex may have evolved beyond its original purpose of analyzing physical space, to work as a multi-purpose module for computing abstract distances. Such a co-opting of spatial processing for the purposes of social cognition would seem useful in an evolutionary context, given the scale, complexity and abstractness of relationship networks in human societies. Thus, human beings would have come to evolve and adapt from the brain in physical world to the brain in social world.

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