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Using NIRS to Investigate Social Relationship in Empathic Process

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1. Introduction

We perform appropriate social actions in the various scenes of everyday life. For example, we speculate about other people's intentions and feelings in order to understand them, or inhibit negative emotions such as anger toward them. Furthermore, we engage in altruistic behaviors out of consideration and empathy for unrelated others. Even for a person who we do not like, we can also be sensitive to his or her feelings and take the most suitable action that seems altruistic at the time. When we behave in such a prosocial way, how do we recognize ourself and others, regulate our emotions, and make decisions?

In this chapter, we first give an outline of the social neuroscience studies on empathy and perspective-taking that use brain imaging techniques. Next, we review a near-infrared spectroscopy (NIRS) study reported by Nomura, Ogawa, and Nomura (2010), and finally we explain how we can use NIRS to investigate psychological and social neuroscience issues.

1.1 Social cognition and social brain

The mental ability underlying prosocial behaviors involving interaction with others is called *social cognition*, and the neural network involved in the functions of social cognition is called *social brain* (Brothers, 1990). Although brain imaging and lesion studies have always been related to psychology, over the past two decades the social brain studies have demonstrated the neural mechanisms underlying social cognition, including self-other recognition, emotion, recognition of facial expression, detection of intentionality and eye-direction, imitation of action, and theory of mind; these studies have been conducted in such fields as cognitive neuroscience, comparative cognitive science, social psychology, and developmental psychology (e.g., Decety & Cacioppo, 2011). Social cognitive neuroscience is a relatively new field studying social cognition from the standpoint of cognitive neuroscience (Cacioppo & Bernston, 1992; Ochsner & Lieberman, 2001).

In this chapter, we focus on empathy to others as a theme of social cognition. After we review recent studies on empathy by the approach of social cognitive neuroscience (mainly using functional magnetic resonance imaging (fMRI)), we introduce a NIRS study in which we investigated perspective taking associated with social relationships in the empathic process. First, however, we briefly explain the principle of NIRS measurement.

1.2 Measurement of human brain activity by NIRS

In the field of brain science, fMRI and positron emission tomography (PET) have mainly been used to measure human brain activity since the 1990s. Coupled with the development of cognitive neuroscience, brain imaging techniques using NIRS have spread rapidly since the early 2000s.

When neural activity occurs in the human brain, regional cerebral blood flow increases in specific brain regions associated with the performance of a particular task. Therefore, hemoglobin concentration of blood increases in the regions. Capturing the change of hemoglobin concentrations enables us to identify the active regions in the brain. NIRS noninvasively monitors the hemodynamic change mediated by the change in hemoglobin concentration (advantages and disadvantages of NIRS in comparison with other devices are described in Section 3).

The NIRS device emits a near-infrared light from the surface of the head through optical fiber and detects the scattered and reflected light in the brain. The light of the near-infrared range, from 700 to 1,000 nm, has relatively high permeability in living tissue. The measurement uses the different absorbance characteristics between oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb). Because the light path's length from the emitting position to the detecting position cannot be measured, absolute concentration changes of hemoglobin in the brain tissue cannot be determined. The relative concentration changes in oxy-Hb, deoxy-Hb, and total-Hb are calculated by using three wavelengths in the current NIRS devices according to the modified Beer-Lambert law (e.g., Hoshi & Tamura, 1993; Villinger & Chance, 1997).

Previous studies using brain imaging techniques of multi-channel NIRS clarified the neural mechanisms involved in various cognitive functions, such as motion perception of the human body (Shimada, Hiraki, Matsuda, & Oda, 2004), language processing (Herrmann, Ehlis, & Fallgatter, 2003; Noguchi, Takeuchi, & Sakai, 2000), emotion (Suzuki, Gyoba, & Sakuta, 2005), Stroop effect (Schroeter, Zysset, Kruggel, & Yves von Cramon, 2003), and Go-Nogo task (Herrmann, Plichta, Ehlis, & Fallgatter, 2005).

1.3 Neuroscience perspectives on empathy

1.3.1 Functional components of empathy

"Empathy" is understanding another person's internal state, including their thoughts and feelings, imaging the viewpoint of the other, and responding with compassion to the other's distress (e.g., Decety & Ickes, 2009; Preston & de Waal, 2002). The psychological construct of empathy that motivates prosocial behaviors is regulated by both a basic emotional contagion system (affective components) and a more advanced cognitive perspective taking system (cognitive components).

Emotion contagion occurs by the influence of others' emotions automatically without self-awareness (Hatfield, Rapson, & Le, 2009). On the other hand, cognitive perspective taking is the ability to understand the other's thoughts and feelings by imaging his or her viewpoint. In order to understand the other intentionally and consciously, cognitive empathy may modulate and control emotions depending on executive resources (i.e., higher cognitive functions including working memory, attention control, and memory retrieval).

Decety (2006) proposed a neuroscientific model corresponding to the conceptual model of empathy. This model consists of four major functional components: shared representation between the self and the other, mental flexibility to take the other's perspective, self-awareness, and emotion regulation. It is assumed that these four components dynamically interact to produce empathy.

The four components are related to brain functions according to Decety's model. Shared representation is related to fronto-parietal networks based on the shared circuits between perception-action, and self-awareness is related to the inferior parietal lobule and the anterior insula on the right side. Mental flexibility is related to the prefrontal cortex. Emotion regulation is involved in the interaction between prefrontal and anterior cingulated systems and subcortical emotion-generation systems.

1.3.2 Empathy and ventrolateral prefrontal cortex

According to the model of empathy (Decety, 2006) described above, it is hypothesized that the interaction between bottom-up processing and top-down processing produces empathy. Bottom-up processing begins by an input of perceived data (information from the outside world) and interprets the perceived data under the influence of the physical characteristics of the stimuli. When we meet an other person, we are resonant to the movements and emotions of that person by the perceptual input automatically and unconsciously. In other words, emotions are contagious, and this processing proceeds in a bottom-up fashion automatically. On the other hand, top-down processing is influenced by the context of the present situation and by knowledge from past experience that individuals use as stimuli. Consequently, in order to understand others from the viewpoint of the others, intentional and conscious mental efforts are required. These cognitive empathic processes modulate emotion regulation and perspective taking, depending on the executive functions for higher controlled processing of working memory, attention control, and memory retrieval.

Such higher cognitive-controlled functions are involved in the prefrontal cortex, including the ventrolateral prefrontal cortex (VLPFC). The right VLPFC is well known as a critical region for general inhibition and for regulating affective responses. The VLPFC also modulates the activity of the amygdala, which plays a key role in emotional appraisal and is related to detections of fear expression and eye-direction (Adolphs, Tranel, Damasio, & Damasio, 1994, 1995; Wicker, Michel, Henaff, & Decety, 1998). Therefore, the VLPFC is a critical area for the processing of emotional regulation via cortical-subcortical pathways (Batson, Early, & Salvarini, 1997).

1.3.3 "Pain network" which feels the pain of others

Previous studies on perspective taking have been reported in the brain imaging studies that deal with empathy for the physical pain of others (Decety & Grezes, 2006; Singer, Seymour, O'Doherty, Kaube, Dolan, & Frith 2004; Singer, Seymour, O'Doherty, Stephan, Dolan, & Frith, 2006). These studies found the existence of a "*pain network*" including the anterior cingulate cortex (ACC) and insula, which are involved in understanding the pain of others like one's own pain.

Singer et al. (2004) used fMRI to compare brain activities between two conditions: when participants felt pain in oneself, and when participants observed that their beloved partner, who came to the laboratory with them, felt pain. In addition, the subjective empathic abilities of the participants were measured by questionnaires. The results show that the activated brain areas in common between the self condition (i.e., the participants themselves feel a pain) and the other condition (i.e., the participants observe their partners feeling a pain) were the bilateral anterior insula (AI), rostral anterior cingulate cortex (ACC), brainstem, and cerebellum. The activation levels of AI and ACC were significantly correlated positively with the empathic ability of individuals. These findings indicate that AI and ACC form the neural basis of understanding the emotions of one's own and others' pain and that the areas are related to emotion processing to evoke the empathic response to the pain of others.

Furthermore, Singer et al. (2006) reported evidence that the empathic response to the pain of others is affected by the social relationship with the other. Namely, a person shows strong empathy for the pain of a favorite person, whereas a person does not show empathy for the pain of non-favorite persons. More interestingly, the results indicate that males appear to feel pleasure in the pain of the non-favorite others.

In the experimental paradigm presented by Singer et al. (2006), participants played the Prisoner's Dilemma game in order to form a good or a bad impression of the opponent players (confederates) before measuring the brain activity by fMRI. In the game, one of two opponents made a cooperative and fair play toward the participants, whereas the other opponent made an uncooperative and unfair play. As a result, the participants came to like the fair opponent but came to dislike the unfair opponent. After the game, the brain activity was measured while the participants were observing the opponent receive a pain to the hand by electrical stimulation.

The results showed that activation in the pain network encompassing the AI and ACC was observed for fair opponents in both male and female participants. However, this activation was significantly reduced in males for pain given to the unfair opponents. At the same time, it was reported that the activity of the nucleus accumbens, known as a reward-related area, increased depending on the degree that the participant strongly desired revenge. This means that for males, the pain felt by the opponents who show unfair behavior brings them satisfaction in their revenge.

Nevertheless, even if they are disliked or unknown others, we can give them a helping hand when we encounter a situation in which the disliked or unknown other feels pain or distress, and we feel the need to help them from an ethical viewpoint. In order to clarify the neural mechanisms underlying such prosocial behaviors that suppress our own feelings, we must examine how the individual difference in perspective-taking ability influences not only the social relationships with the others but also influences the ability to evaluate the emotional states based on the social relationship.

Previous studies have demonstrated that emotion regulation processing is involved in the right VLPFC in relation to regulating or suppressing negative emotions caused by pain (Lieberman, Eisenberger, Crockett, Tom, Pfeifer, & Way, 2007; Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). In addition, it has also been reported that both self- and other-perspective taking are related to the activation of the pain network (Jackson, Brunet, Meltzoff, & Decety, 2006), and the activation of these areas increases depending on the degree of subjective empathic abilities as measured by questionnaires (Singer et al., 2004, 2006). Therefore, Nomura et al. (2010) focused on the mechanism of perspective taking in the empathic process and investigated the individual differences in perspective taking and the neural responses evoked by the inhibition of emotions; this was done by analyzing the activation of VLPFC.

2. A NIRS study on perspective taking associated with social relationships by Nomura et al. (2010)

2.1 Purpose

Following the paradigm of Singer et al. (2006), after playing the Prisoner's Dilemma game to form a good or a bad impression of the opponents, the participants observed the opponents' facial expressions (happy, neutral, and angry) and evaluated the valence of each facial expression on a 7-point scale ranging from "pleasantness" to "unpleasantness." The participants observed the facial expressions under two perspective-taking conditions: self-perspective vs. other-perspective. The brain activity was measured by using NIRS while the participants were evaluating the facial expressions. The participants were divided into two groups according to the points of the Interpersonal Reactivity Index (IRI) that they completed after all experiments. The IRI measures the components of empathy, from which we took particular note of perspective taking (e.g., 'I sometimes try to understand my friends better by imagining how things look from their perspective.').

The prediction was that a higher unpleasant emotion would be produced in the self-perspective condition rather than in the other-perspective condition during observation of an unfair opponent, since negative emotions should arise automatically when the participants observe the facial expression of the unfair opponent. On the other hand, in the other-perspective condition with the unfair opponent, the participants should rate the facial expression from the viewpoint of the unfair opponent while inhibiting the negative emotions for the disliked opponent, especially for a happy expression. Therefore, it was expected that the activation would increase in the right VLPFC in the other-perspective condition.

Moreover, the right VLPFC might play an important role for individuals who have a high ability of perspective taking. The right VLPFC would likely have a greater impact on taking the other-perspective, since top-down control from the prefrontal cortex functions very well for individuals with a high ability of perspective taking than for individuals with a low ability of perspective taking.

2.2 Method

2.2.1 Participants

Thirty-seven healthy volunteers (18 females; mean age ± SD: 19.5 ± 3.4) were divided into two groups according to the perspective taking scale of a Japanese version of the IRI (Davis, 1983): 19 participants with a high perspective-taking ability (mean score 24.79 ± 1.76) and 18 participants with a low perspective-taking ability (mean score 18.83 ± 1.89).

2.2.2 Stimuli

Pictures of happy and anger facial expressions were made by a morphing technique, based on digitized grayscale images of 6 Japanese faces (3 men and 3 women) showing a neutral facial expression. Participants in a pilot study rated each facial expression on a 5-level scale (0 = not at all to 4 = very intense) in terms of happiness and anger. The mean rating for the valence of the selected stimuli was 2.32 ± 0.73 for anger and 2.57 ± 0.89 for happiness. Furthermore, the intensity of each facial expression was rated and the rating scores for the intensity of all selected facial stimuli showing anger and happiness were 3.40 ± 0.92 and 3.15 ± 0.86, respectively.

2.2.3 Procedure

First, as an orienting task, the relationship between the participants and six opponent players (two fair, two unfair, and two neutral players) was manipulated through a sequential Prisoner's Dilemma game controlled by a computer program. In each trial, the participants decided whether they cooperate with the opponent or not. If both the participant and the opponent decide to cooperate, they each earn 10 points; if both defect, neither earns any points. If the participant cooperates and the opponent defects, the participants loses 40 points and the opponent earns 40 points, and vice versa. The cooperation rates throughout all trials for the fair opponent, the neutral opponent, and the unfair opponent were set in 80%, 50%, and 20%, respectively.

The opponent's facial expressions were presented on a PC screen after the participants decided their selection. When both the participant and the opponent cooperated, the opponent's expression became happy; when both defected, the opponent's expression became angry. When the participant cooperated and the opponent defected, the opponent's expression became happy, whereas when the participant defected and the opponent cooperated, the opponent's expression became angry. After playing with each opponent, the participants evaluated the opponent on a 7-point scale ranging from "cooperative" to "uncooperative" and "like" to "dislike."

After the orienting task, the participants performed a perspective-taking task with the NIRS device. A block design consisting of 12 blocks was used. The participants observed the facial expressions of the opponents under the two conditions of self-perspective and other's perspective. After a fixation point, the other's facial expression was shown for one second. The participants evaluated the valence of the facial expression on a 7-point scale from "pleasantness" to "unpleasantness" within two seconds.

2.2.4 NIRS data acquisition

A dual-channel NIRS unit (NIRO-200; Hamamatsu Photonics K.K., Hamamatsu, Japan) was used to measure the temporal changes in oxy-Hb, deoxy-Hb, and total hemoglobin during the perspective taking task. Near-infrared light at three wavelengths (775, 850, and 910 nm) was used as the light source. The distance between the emitter and the detector was set to 4 or 5 cm. The sampling rate was 1 Hz.

The hemoglobin concentrations were calculated by subtraction from the baseline concentrations. Two probe holders were placed on the left and right sides of the forehead corresponding to the ventral area of the prefrontal cortex. These positions were localized between Fp1 and F7 (left) and between Fp2 and F8 (right), according to the international 10–20 system.

2.3 Results and discussion

First, the orienting task confirmed that the operation of the social relationship between the participants and the opponents succeeded. The rating scores of “cooperativeness” showed that cooperative others were rated as more cooperative than uncooperative others and neutral others, while uncooperative others were rated as more uncooperative than cooperative others and neutral others. In the rating scores of “likeness,” it was confirmed that the cooperative others were liked, whereas the uncooperative others were disliked.

2.3.1 Behavioral data

Figure 1 shows behavioral data of the pleasantness points in the perspective taking task. For the pleasantness points, a 2 × 3 × 3 (perspective taking, social relationship, and facial expression) analysis of variance (ANOVA) showed main effects of the three factors. The analysis also showed a significant 3-way interaction. The results showed that taking the other’s perspective yielded no differences between high and low abilities of perspective taking. This indicated that the ability of perspective taking was not reflected in the behavioral data.

Further analyses of the interaction indicated that for the cooperative others in both the self- and other-perspective taking, the mean score in the happy condition was higher than that in the neutral and anger conditions, and the mean score in the neutral condition was higher than that in the anger condition (all $p < .05$). However, for the uncooperative others, these differences between facial expressions were only significant in the other-perspective taking. Note that in the self-perspective taking condition to uncooperative others, there was no difference among the rating scores of the three facial expressions.

Fig. 1. Behavioral evaluation of the validity of the mean value of each condition on a 7-point scale ranging from “pleasantness” to “unpleasantness.” Adapted from Nomura et al. (2010).

2.3.2 NIRS data

Figure 2 shows the mean concentration change of the oxy-Hb in the right VLPFC. For the NIRS data, a 2 × 2 × 3 × 2 (perspective taking ability, perspective taking, social relationship, and hemisphere) ANOVA showed a significant 4-way interaction. No main effect was found in any of the factors. In the unfair condition, the oxy-Hb concentrations significantly increased in the right VLPFC while taking the other's perspective as compared to the self-perspective (Figure 3). Accordingly, taking the other's perspective while perceiving the facial expressions of an unfair opponent significantly activated the right VLPFC only when the participants have high perspective-taking ability.

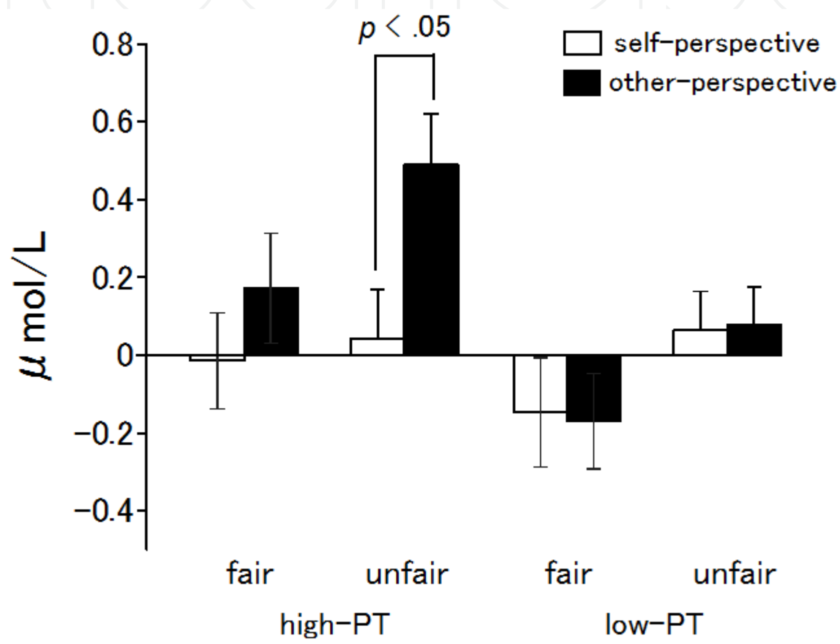

Fig. 2. Mean concentration changes in oxy-Hb during hemodynamic response in the right VLPFC. Adapted from Nomura et al. (2010).

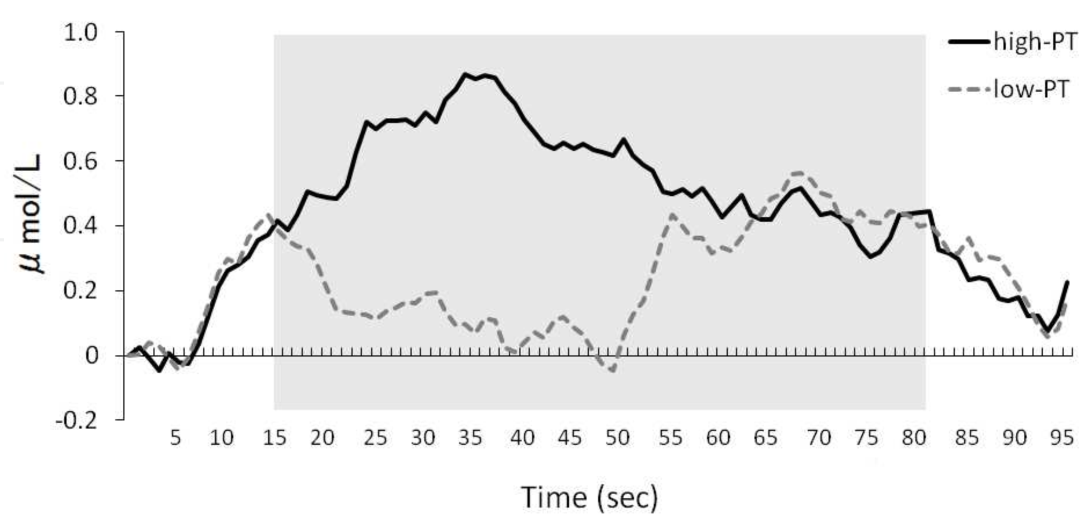

Fig. 3. Averaged oxy-Hb concentration time changes in the right VLPFC hemodynamic response. Gray zone indicates task interval times and white zone indicates rest interval times in the unfair and other's perspective condition. Adapted from Nomura et al. (2010).

3. Conclusions and future directions

3.1 Neural mechanisms of empathic process and social relationships

As described above, in line with individual differences in the ability of empathic processing, Nomura et al. (2010) revealed that for a person who has a high ability of perspective taking, the right VLPFC activates to take the other-perspective of the unfair other. Previous studies have presented evidence that the right VLPFC can modulate the activity of the amygdala even when emotional responses in the amygdala are implicitly evoked by emotional signals independent of the current conscious cognitive processing (Hariri, Bookheimer, & Mazziotta, 2000; Nomura, Ohira, Haneda, Iidaka, Sadato, Okada, & Yonekura, 2004).

According to these findings, the results reported by Nomura et al. (2010) suggest that the amygdala activation in the participants with high perspective-taking ability is suppressed while taking the perspective of an unfair person, and this leads to a decrease in their subjective negative emotions. The suppression of negative emotion is formed by the cognitive appraisal of the social behaviors of others by top-down processing. It was found that because participants with a higher perspective-taking ability evaluate the valence of emotions from the others' perspective when observing a happy facial expression by disliked others, they possibly use top-down intentional processing to effectively suppress the negative emotion evoked automatically by bottom-up processing. In contrast, participants with a lower perspective-taking ability could not suppress the negative emotion when they took the perspective of the disliked other. This reflects the decreased activation in the right VLPFC. In this way, the sensitivity to stimuli to evoke emotions varies according to the individual difference of the empathic ability, and this would produce different brain activities associated with the suppression of negative emotions. Further studies using fMRI and PET are needed to assess the neural basis related to the empathic process, including the activity of the amygdala.

3.2 Application and prospects of NIRS

We finally describe the advantages and disadvantages of brain imaging techniques using NIRS. Although fMRI and PET also measure the local bloodstream of the brain, each of these NIRS devices has its own advantages and disadvantages and is chosen depending on the purpose of research.

The disadvantage of NIRS in comparison with other imaging techniques is that the spatial resolution is lower. In addition, NIRS cannot measure deep parts of the brain such as the amygdala, brainstem, and cerebellum because brain tissues can only be measured approximately 3 cm from the surface of the head. Furthermore, it is difficult to identify the detailed anatomical position associated with brain function. The brain regions cannot be identified precisely from the scalp, and it becomes necessary to measure three-dimensional MR images in order to confirm the positions between the probes and brain regions. However, the positions of the probes can be determined according to the international 10-20 system for electroencephalogram recording, and at present, a number of studies using NIRS adopt this system.

On the other hand, NIRS has some strong advantages. First, it is highly non-invasive and thus safe. The burden on participants is relatively low, since they are not injected with radioisotopes into the blood-stream and do not need to be restricted in a noisy device like fMRI and PET. Accordingly, it is possible to examine brain activity during performance tasks with natural body movement (cf. Morioka, in this book), as well as the brain activity of infants and children (cf. Ozawa; Kaneko, Yoshikawa, Ito, Nomura, & Okada, in this book). The second advantage is that the temporal resolution of NIRS is higher than those of fMRI and PET. The third is that a NIRS device has high portability with its relatively compact size and does not need special laboratory equipment. In addition, it offers easy operation. As a result of these advantages, NIRS techniques are contributing to the progress of evaluations such as the embodiment and development of infants and children, which were difficult to examine by fMRI or PET in the early cognitive neuroscience.

In this chapter, we discussed the neural basis underlying the empathic process based on the approach of social cognitive neuroscience. As explained above, given the limitations of NIRS, i.e., the lower spatial resolution and the inability to measure the deeper parts of the brain, it is difficult for this technology to contribute to brain function imaging studies on its own. In the future, we will need to construct a model of neural mechanisms underlying social cognition, adopting the evidence obtained from imaging techniques using fMRI or PET in a complementary manner. Furthermore, psychological and brain neuroimaging studies with concurrent biochemical and pharmacological measurement of both neurotransmitter functions, in particular those investigating the effect of gene polymorphisms, appear to be useful for clarifying the relationship between social brain functions and personality traits.

NIRS can also be used with devices measuring eye movement and skin electricity activity at the same time. The use of these combinations with NIRS will enable us to investigate issues such as detection of intentionality and eye-direction, as well as emotion. Furthermore, it will be relatively easy to measure the brain activity of two persons cooperatively performing a task at the same time. Consequently, we can anticipate the application of NIRS to interpersonal relationships and cooperative behavior. Further research on social cognitive neuroscience will be expected to provide new evidence for the neural mechanisms underlying cognitive functions, including emotions, empathy and joint attention under a bidirectional situation.

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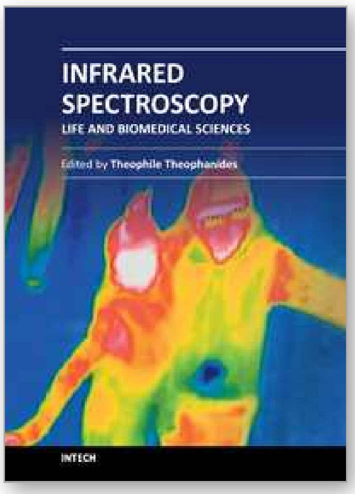

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