# NEURAL MECHANISMS ON SELF-OTHER DISCRIMINATION BASED ON VISUAL AND PROPRIOCEPTIVE FEEDBACKS

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#### Abstract

How we discriminate self from others is crucial for social cognitive psychology, as well as for real-world technological applications, such as interactive robots. We consider that cooccurrence of proprioceptive and visual feedbacks is important in this process. The parietal cortex in the human brain has often been considered to be the region where proprioceptive and visual information of one's own body are integrated. In this study, we conducted neuroimaging experiments to investigate parietal role in self-other discrimination. Further, based on the obtained results, we proposed a neural model for self-other discrimination. In the experiments, we examined the parietal cortical activity during a visual-proprioceptive synchrony judgment task in which visual feedback of passively moving one's hand was delayed (86-319 ms, at 33 ms intervals). The subject judged whether there was a delay between visual and proprioceptive feedbacks or not. The parietal cortical activity was measured by a 48-channel near-infrared spectroscopy (NIRS) apparatus. The threshold of delay for the synchrony judgment (50% point) was about 190 ms. Neuroimaging results demonstrate that the activity in the parietal cortex was modulated by the delay between visual and proprioceptive feedbacks of passively moving one's own hand and was consistent with subjective judgment. We then proposed a model for self-other discrimination, where visual and proprioceptive feedbacks are integrated into the self-body representation in the parietal cortex based on the temporal consistency between these feedbacks.

#### Keywords: Neural mechanism, Neuroimaging, Self-other discrimination.

#### Presenting Author's biography

Sotaro Shimada. My current research interest focused mainly on the neural mechanisms of social cognition. I use neuroimaging techniques to investigate brain activity related to social cognition. Topics of my interest include self-other discrimination, imitation, multi-sensory integration, self-consciousness, theory of mind and communication. I am also specialized in computational modeling, especially in machine learning. Now I apply computational modeling techniques to human higher cognitive functions to understand its mechanisms more precisely.



## 1 Introduction

How can you recognize an image of an arm as your own arm? One hypothesis on this ability is through the co-occurrence of multiple sensory feedbacks, especially visual and proprioceptive feedbacks from self-body. Since proprioceptive feedback is peculiar to oneself, the visual property that coincides with proprioceptive feedback is most likely to result in perception of one's own body.

Rubber hand illusion [1] supports this hypothesis. When the subject watches a rubber hand that is touched by the experimenter, while the subject's invisible own hand is synchronously touched with the rubber hand, she/he soon feels like the rubber hand is her/his own hand. This illusion disappears when the subject's hand was touched asynchronously with the rubber hand. This indicates that synchrony between visual and proprioceptive feedbacks is crucial for self-body recognition.

It has been suggested that the parietal lobe in human brain is the region where proprioceptive and visual information of one's own body is integrated [7]. This study investigated whether activity in the parietal lobe is sensitive to the synchrony between visual and proprioceptive feedbacks. In the experiment, visual feedback of the subjects' own passively moving hand was delayed, and the subjects were required to judge whether or not there was a delay between the proprioceptive and visual feedbacks. Parietal cortical activity was measured using a 48channel near-infrared spectroscopy (NIRS) apparatus. We anticipate that parietal activity would be modulated by the length of the delay between visual and proprioceptive feedbacks.

We further propose a neural model for selfother discrimination based on the experiment described above. Since self-other discrimination is essential for social interaction, our model could be useful for better understanding of human social psychology, as well as for development of human-machine interaction technologies, such as interactive robotics.

## 2 Neuroimaging Experiment

### 2.1 Methods

Twelve subjects participated in the experiment. The subjects were asked to sit at a table on which a turntable with an electric motor (custom-made) was horizontally placed (Fig. 1). They were then asked to put their right hand palm down on the turntable and inhibit any voluntary movements during the experiment. The subjects' right hands were filmed vertically by a CCD camera (DXC-LS1, SONY, Tokyo, Japan) and projected onto screen located а approximately 2 m away. The apparatus was controlled by a computer program.



Fig. 1 Experimental Settings

Visual feedback delay was introduced using a hardware device (EDS3310, ELETEX, Osaka, Japan) connected between the CCD camera and projector. Eight delay conditions ranging from 85 to 318 ms with 33.3 ms intervals were used. The task was to judge whether the hand image projected on the screen was exactly synchronized with their hand movement. In each trial, the hand image appeared for 6 sec, followed by a 14-sec rest period. The order of the delay conditions was random. Sixteen trials constituted one session and four sessions were conducted in total with 2-minute intersession breaks. Therefore, each subject executed 8 trials for each condition, a total of 64 trials.

#### 2.2 Neuroimaging method

A 48-channel near-infrared spectroscopy unit operating at 780, 805, and 830 nm wavelengths (OMM-1080S, Shimadzu, Kyoto, Japan) was used to measure temporal changes in oxy-Hb, deoxy-Hb, and total-Hb concentrations. Sixteen optodes were placed on the parietal region in a lattice pattern to form 24 channels for each hemisphere, including C3 (C4) of the 10/20 system in the anterior portion (9 x 9 cm square area, Fig. 2).



emitter detector 1 - 48: channel

Fig. 2 Location of channels for NIRS measurement

#### 2.3 Results

The subjects were required to judge whether the movements they saw on the screen were synchronized with their own movements or delayed. Fig. 3 shows the synchrony judgment rate as a function of the delay. The subjects tended to judge the image as not synchronized with their hand movements as the length of the delay was increased. The threshold (50 % point) for the delay was approximately 190 ms.

Because of the individual differences in sensitivity to delay detection, the conditions were categorized into three types: where (1) synchrony between the proprioceptive and visual feedbacks was detected (75-100%), (2) asynchrony was detected (0-25%), and (3) synchrony judgment was considerably difficult (25-75%, intermediate).



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NIRS measurements revealed that parietal activity was modulated by the length of the delay (Fig. 4). Synchrony-detecting channels were located in superior/middle parietal areas, while asynchrony-detecting channels were found in the inferior parietal area. The synchrony-detecting channels (ch-34 in Fig. 2) showed strong activation in the synchrony condition, but were not activated in the other two conditions. By contrast, the asynchrony-detecting channels (ch-14 in Fig. 2) exhibited elevated activation, as the length of the delay was larger, and this tendency was more obvious in the right hemisphere.

#### **3** A Model for Self-other Discrimination

In the experiment, we investigated the effect of temporal consistency between visual and proprioceptive feedbacks on the neural activity and subjective judgment. The results showed that the subjects reported temporal discrepancy more frequently as the length of the delay between these feedbacks becomes larger. The threshold length of the delay was approximately 190 msec. The superior portion of parietal cortex was activated when the subject feel synchrony between visual and proprioceptive feedbacks, whereas the inferior portion of parietal cortex was activated when the subject feel asynchrony between those.



Fig. 4 Activity in the parietal cortex during synchrony detection task

Our results are consistent with some previous studies. A patient with a left superior parietal lesion was not able to maintain an internal representation of her right arm and hand when her eyes were closed, but this was immediately re-established after she opened her eyes [7]. This evidence suggests that the superior parietal lobe is a critical component of the neural network that generates and/or maintains body images of contralateral limbs.

Right hemisphere dominance in self-other distinction has been well demonstrated [2]. Ruby and Decety (2001) showed that imaging a movement from a third-person perspective, compared to a first-person perspective, activated the right inferior parietal lobe [6]. Farrer et al. (2003) reported graded activation in the right angular gyrus when spatial distortion of a self-generated movement was gradually enlarged [4]. Leube et al. (2003) reported that the right tempoloparietal junction (TPJ) was activated with temporal distortion of one's own hand movement [5]. Our study is in line with these results in that right inferior parietal region is activated when perceiving non-self-generated body movement, as the channels located on the right inferior portion showed fairly strong activations in the asynchrony condition.

Recently, it has been revealed that a brain region in the occipital lobe called extrastriate body area (EBA) selectively activated for visually presented body stimuli (photo pictures, images, or line drawings of body parts or whole body) [3]. Interestingly, EBA does not activate for non-body stimuli (scissors, houses, etc.). These results suggest that EBA is sensitive for whether the presented stimuli were body parts or not.



Fig. 5 A Schematic Model for Self-other Discrimination

Based on the neural evidence, including our results, we proposed a model for self-body recognition (Fig. 5). First, visual body stimuli are inputted to the visual area in the occipital lobe, and identified as body parts in EBA. On the other hand, proprioceptive body information processed is in the somatosensory area in the parietal cortex. Second, these visual and proprioceptive information are forwarded to the parietal association regions. The temporal consistency between these information is judged using threshold window of approximately 200 msec. Finally, visual body stimuli that coincided with the proprioceptive feedbacks are stored as the self-body image in the superior parietal cortex. Similarly, visual body stimuli that conflicted with proprioception are perceived as other's body in the inferior parietal cortex. Self-body image in the superior parietal cortex can also be used to anticipate the next (future) state of the self-body (Fig. 5).

## 4 Implementation Issues

We proposed a schematic model of neural mechanism for self-other discrimination capability in humans. Although computational implementation of this model will be fully addressed in the future research, we briefly suggest possible implementations here.

Our model is based on the temporal consistency between proprioceptive and visual input. Rather than assuming a perfectly matched associative map between those inputs. we prefer a detection mechanism whether the onset of motional changes of these inputs are temporally coincided or not. Suppose that only one body part, say a right arm, is currently of interest. Proprioceptive motional changes can be detected when angle or torque of elbow-joint changed. Similarly, visual motional is changes can be detected by calculating, for example, optical flow of the visual field. Note that the important feature here is the onsets of these motional changes, not kinematics, trajectory, or other physical properties of movement. Therefore, all we have to do is judge whether motional change field coincides with in visual the proprioceptive motional change. If it is the case, the object detected in the visual field is perceived as self-body, otherwise it is perceived as someone else's body parts.

Comparing the timings between visual and proprioceptive motional changes would be more precisely depicted by a neural network model as shown in Fig. 6. A proprioceptive motional change detected by proprioceptive motional change detector (MCD) is inputted to intermediate neuron. This signal is hold for a certain duration (approximately 200 ms). A visual motional change detected by visual MCD is also inputted to this neuron, as well as to the other's-body detection neuron. If the additive value inputted to the intermediate neuron exceeds the threshold, the output signal is forwarded to the self-body detection neuron, which results in detection of self Simultaneously, this body. signal is forwarded as inhibitory input to the other'sbody detection neuron to suppress its activation. Conversely, if the inputs to the intermediate neuron do not exceed the threshold, other's-body detection neuron keeps being activated.

This self-body recognition mechanism fits well with our neuroimaging results shown in Fig. 4. Superior parietal lobe where self-body representation is stored was activated only when visual and proprioceptive feedbacks were temporally consistent. On the other hand, inferior parietal lobe where other's body was represented showed modulated activation; the lowest activation in the synchrony condition and the highest activation in the asynchrony condition. The intermediate activation was observed in the intermediate condition, that can be explained by our model. That is, visual bodily input first activates other's-body detection neuron, but this activity was later suppressed via the intermediate multi-sensory neuron as the activation of the neuron occurs somewhat after the visual MCD input.





## 5 Conclusion

We proposed a schematic model of neural mechanism for self-other discrimination capability in humans, based on our neuroimaging experiment. Future research will address computational implementation of this model. Since self-other discrimination is essential in human social intelligence, our model would contribute to social psychology, as well as development of real-world manmachine interfaces, including interactive robotics.

## 6 References

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