Analysis of the Sense of Agency using a Tactile Device *

Masataka Murabayashi [1], Yusuke Ikemoto [1], Mihoko Otake [1], Takaki Maeda [2], Motoichiro Kato [2], and Hajime Asama [1]

[1] Research into Artifacts, Center for Engineering (RACE), The University of Tokyo, Chiba, Japan

[2] Department of Neuropsychiatry, School of Medicine, Keio University, Tokyo, Japan

masataka@race.u-tokyo.ac.jp

Abstract Human cognitive mechanisms have been studied for designing user-friendly interfaces. One important issue is the attribution of one's own actions to the intention of self or others. Patients with schizophrenia are known to sometimes attribute their own actions to the intentions of others and, when they feel they are acting with voluntary behavior, might perceive themselves as causing events which they do not in fact control. For this study, we design an exhaustive experiment about self-attribution of tactile, optical and tactile-optical mixed cognition. We then performed the experiment using normal subjects. Results showed that the forward model is appropriate to the model for self-other attribution of tactile-optical mixed cognition. Moreover, it gave the suggestion that a normal person's forward model for sensory mixed feedback, which includes tactile and optical stimuli, is referred to two forward models for tactile and optical cognition.

1 Introduction

In recent years, the quality of user interfaces has been important because machines have been used in many situations and have required more easy-to-use mechanical designs. Especially with regard to human interfaces, human-machine interfaces have attracted attention and have begun to be designed based on human cognitive and psychological characteristics. "Sense of Agency" is one such human characteristic. It is a useful clue to produce a more user-friendly human interface to clarify the system of a "Sense of Agency".

Sense of Agency is "the sense that I am the cause or author of the thought or movement when I really do so". Normal subjects have a Sense of Agency, but some schizophrenic people with disturbances of ego attribute actions which are their own to other people or, by contrast, attribute actions which are produced by others to themselves. Hypotheses for explaining the Sense of Agency have been suggested in recent studies such as the

*This work was partially supported by a Grant-in-Aid for Scientific Research on Priority Areas "Emergence of Adaptive Motor Function through Interaction between Body, Brain and Environment" from the Japanese Ministry of Education, Culture, Sports, Science and Technology.

forward model (Figure 1)(S.-J.Blakemore et al. (2003)) or the Who System (Jeannerod et al. (2003)).

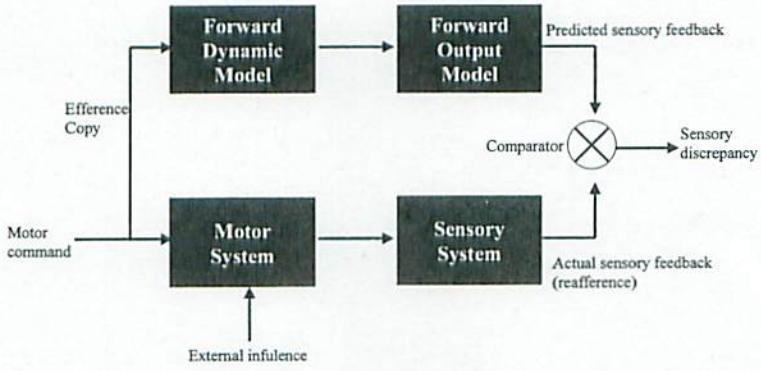

Figure 1. Forward model of motor command (S.-J.Blakemore et al. (2003))

In this experiment, we assume that the forward model is a model of Self-Other attribution. We examine this assumption by investigating how often normal subjects attribute to themselves tactile, optical, and tactile-optical mixed stimuli that are earlier or later than standard stimuli. This result suggests a difference between each single-sense stimulus. The forward model for mixed stimuli is made of those for single-sense stimuli.

2 Self-Other Attribution

2.1 What Is "Self-Other Attribution"?

Self-awareness of brain science has flourished in recent years. Self-Other Attribution is studied in the Sense of Agency of a research paradigm. The Sense of Agency is an experiment that shows himself or herself as the agent when a person thinks or acts. Self-Other Attribution is defined as a trend toward self-attribution or other-attribution when someone's body moves: they discern the agent of the movement.

2.2 Relation between Sense of Agency and Brain

The function of Self-Other Attribution occurs in the brain. Farrer et al. monitored activation in the brain by fMRI (C.Farrer and C.D.Frith (2002)). In the experiment, subjects used a joystick to drive a circled object along a T-shaped path and attributed the actions appearing on the screen to themselves or others. The result shows that being aware of causing an action was associated with activation in the anterior insula, but awareness of not causing the action and attributing it to another person was associated with activation in the inferior parietal cortex. Other similar experiments indicated that the inferior right parietal cortex was activated more when subjects did not self-attribute an action; the right posterior cortex was activated more when subjects did (C.Farrer et al. (2003)).

2.3 Forward Model

Internal models are working in their brains when people promote an action. We recall the model of exterior environment in the internal model, one of central nervous systems. Two types of internal model exist: a forward model and an inverse model. The forward model receives an efference copy of the motor command as input and output predicted by sensory consequences of a movement. By contrast, the inverse model provides motor commands to achieve the goal.

2.4 Self-Other Attribution with Forward Model

This paragraph explains a forward model of motor control. An efference copy is inputted to a forward dynamic model as soon as motor commands are provided and enter a motor system. A forward dynamic model predicts the consequences of motor commands. These are compared to the desired state. The forward output model makes a prediction of the sensory consequences of movement. Finally, the predicted consequences and actual consequences are compared and the action is distinguished to what is produced by self or other produced signals. Consequences are canceled and signals are attributed to self when the discrepancy of this comparison is slight (S.-J.Blakemore et al. (2003)). This also explains a normal subject who laughs when others tickle him but does not laugh when he tickles himself.

However, subjects who were able to attribute an action correctly made two types of misattribution of an action in some experimental systems: experimenters made them attribute an exterior-produced action to themselves(over-attribution) and experimenters made them attribute an self-produced action to others (under-attribution). The joystick experiment is an example of the former experiment.

This misattribution by normal subjects is explained like this. Over-attribution happens when the actions are produced by others so that their consequences are matched to the predicted consequences of actions produced by their forward models. Little or no difference pertains between actual sensory feedback and predicted sensory feedback. They attribute the feedback to themselves. By contrast, subjects under-contribute when self-produced actions are influenced by external factors and their consequences are not matched to prediction of consequences. Sensory discrepancy between actual sensory consequences and corollary discharge make them attribute their own actions to others that do not produce them actually.

Normal people can usually attribute an action to themselves or others rightly. They are unable to do so only if they participate in these experiments as subjects. However, some people lose a Sense of Agency and cannot judge who is an agent of an action. They are schizophrenia patients with delusion of control.

3 Relation between Sense of Agency and Schizophrenia

Schizophrenia is a problem with various symptoms in the nervous system such as the brain and described in terms of positive and negative symptoms. It is thought that a positive symptom of schizophrenia is disturbance of ego in existing psychiatric medicine. For example, thought broadcasting, which is included by Schneider's first-rank symp-

toms, makes patients with it feel that his very thought comes through the world without intermediation. According to patients, it is the feeling of "Thought is not only mine and other people get engaged in it. Moreover, all people in the world know it". We can regard disturbance of ego such as 'thought broadcasting' and 'feelings or actions experienced as made by external agents' as a disability of Self-Other Attribution within the framework of Sense of Agency. Feelings or actions experienced as made by external agents are thought to be a misattribution to themselves or other people when patients think or perform some actions. We believe that it is important to investigate misattribution of schizophrenia to elucidate the mechanism of Sense of Agency because schizophrenia is closely linked to the Sense of Agency. Recently, patients participated in experiments for Sense of Agency actually. For example, in the experiment by Frank et al., subjects were told to move a joystick. Movement of the joystick is presented on a monitor, but it is randomly affected by angular deviation or temporal delay (Franck et al. (2001)). Not only normal subjects but schizophrenia patients participated in these experiments. The results show that the latter subjects are less aware of the connection between an action and its consequences than the former subjects.

Moreover, the parietal lobe, which has somatosensory area, is regarded as a part of the brain that is very much related to the Sense of Agency from a medical standpoint. For example, it is reported that the parietal lobe of some people who can not attribute an action rightly is small. Experiments with patients who performed 'actions experienced as made by external agents' showed that their right inferior parietal lobe and angular gyrus were activated too much when they experienced delusion of control (Spence et al. (1997)), and the right inferior parietal lobe was also over-activated when they performed no task (Franck et al. (2002)).

In this study, subjects participate in the task for which they attribute presented tactile feedback to themselves or others. Therefore, it is important to research Sense of Agency with particular emphasis on tactile sense because, in the parietal lobe, somatosensory areas signal from tactile receptors and signal to the parietal association area, where various sensory information is integrated.

4 Experiment

4.1 Definition of Terms in this Experiment

For this study, we present various timing stimuli to subjects and define two terms: 'the standard (of Sense of Agency)' and 'the bias (of Sense of Agency)' . The standard means "A standard timing when subjects attribute an action to self or others". The bias means "How much timing difference a subject has for Sense of Agency for an action".

4.2 Application

Subjects are given an easy task. They are told to push the Enter key on the keyboard as soon as a "Push!!" signal is displayed on a monitor and a stimulus is indicated as a feedback of their key or by others (Figure 2). Subjects attribute their actions to themselves or others after a given stimulus. If they feel a sense of self-agency, they push the key of "Self". If they attribute to others, they push the key of "Others".

This workflow by which subjects push an Enter key, thereby making an attribution to themselves or others is defined as a stage.

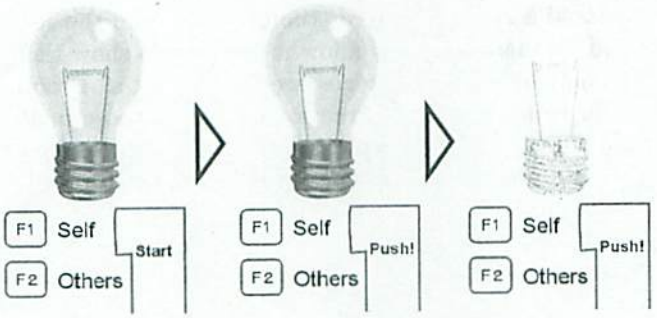

Figure 2. Workflow in the application

Stimuli of three types are presented to subjects: tactile (type 1), optical (type 2), and mixed (type 3), which comprises these two sense stimuli (Table 1). Vibration as a tactile stimulus is activated using a controller (XBOX360; Microsoft Corp.). In each stage, a time lag pertains between pushing the Enter key and the presented stimuli. Time lags are of 11 types (0 ms, 40 ms, 80 ms, 120 ms, 160 ms, 200 ms, 240 ms, 280 ms, 320 ms, 360 ms, and 400 ms). Stimuli with respective time lags are presented randomly four times in an experiment of each type: 44 stimuli in each stimuli type of experiment. These 44 stages are defined as the 'Test Time'. Before these main experiments, we show a 200-ms-delayed stimulus as a standard feedback. It encourages us to investigate the Sense of Agency not only for time-delayed stimuli but also for earlier feedback. Three kinds of Test Time are used: that in which only optical stimuli are presented, only tactile stimuli are presented, and only mixed stimuli are presented.

Table 1. Three kinds of actions as feedback

	Actions
Type 1	Vibration
Type 2	Flash
Type 1	Vibration and Flash

4.3 Method

In all, 12 normal subjects participated in this experiment for an investigation of their Sense of Agency (Experiment 1) and ability of perception (Experiment 2). In Experiment 1, subjects were asked "Who produced this stimuli, Self or Other?" after each stage. In Experiment 2, subjects were asked "Is there a difference between a standard feedback and this feedback" after each stage.

Experiment 1: Research of Sense of Agency Subjects performed Practice 1, Practice 2, and Test Time of each type of stimuli in order. We taught them "standard stimulus" in Practice 1 and "presence of the experimenter as other subject" in Practice 2. First, subjects indicated a 200-ms-delayed stimuli 10 times in the situation where all the stimuli are produced by them and they know it in order to show them the consequences of self-produced stimulus. These 10 stages are designated as Practice 1. Subjects are told to participate in Practice 2 after Practice 1. The purpose of Practice 2 is making subjects cherish the illusion that the experimenter also produces feedback with them. In Practice 2, subjects are presented five types of delay stage (0 ms, 120 ms, 200 ms, 280 ms, and 400 ms) randomly and one type of the quick stage. The quick stage is certainly attributed to others because it is presented before subjects push down the Enter key (as soon as "Push!!" is displayed). Moreover, the experimenter pretends to participate using a dummy computer and states that presented stimuli are produced by him in some tasks of Practice 2 (Figure 3). These improvements make subjects think that their computer and the experimenter's computer are linked and the experimenter also performs key-pushing although stimuli are delayed randomly and that the experimenter's computer is not actually working. Subjects perform each stage twice in Practice 2 . Finally, subjects participate in Test Time. Subjects are told that the situation of Test Time is identical to that of Practice 2, and answer the agent who makes feedback after each task.

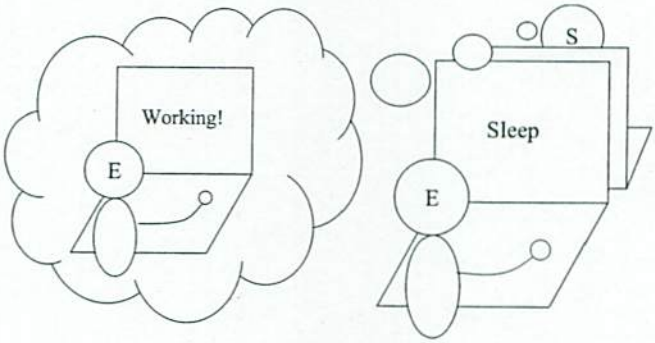

Figure 3. E and S respectively denote the experimenter and the subject. Subject S takes part in the experiment and believes that E also does. However, in fact, E does not and the two computers are not mutually synchronized.

For this experiment, subjects wear headphones to prevent any influence by sound (e.g., sound produced by pushing keys on a keyboard or by a vibrating controller). In Practice 2 and the Test Time of each sensory feedback, a partition is installed between a subject and the experimenter.

Experiment 2: Research of Ability of Perception Each subject participates in Practice 1 and Test Time in order in Experiment 2. Subjects are told that all stimuli are made by subjects in Experiment 2. They judge that there is a difference about timing between a stimulus in Test Time or in Practice 1. The subjects' ability of perception is

studied to show that it is different from the Sense of Agency.

5 Result

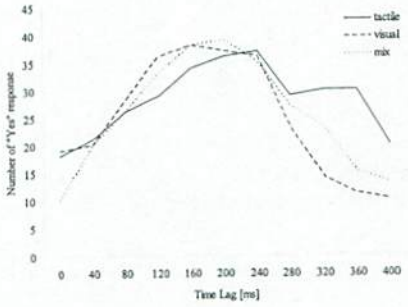

Figure 4. Sense of Agency

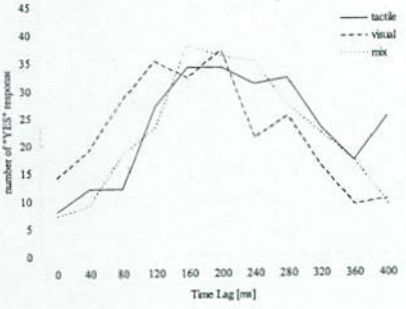

Figure 5. Ability of Perception

Figure 4 and Figure 5 show results for the Sense of Agency and an ability of perception. In Table 2, the mean and a standard deviation of the data in Figure 4 and Figure 5 are shown. First, it is suggested that the Sense of Agency is not equal to an ability of perception. Table 2 shows that the value of standard deviation of the Sense of Agency is higher than that of an ability of perception related to tactile feedback and mixed feedback.

Table 2. Means [ms] and S.D. [ms] in each type about Sense of Agency (upper line) and the capability of perception (lower line)

	Type 1	Type 2	Type 3
Average	207.8	177.7	195.8
	216.7	188.2	207.6
S.D.	115.0	103.6	104.0
	108.2	103.8	101.3

Results indicate that self-other attribution for mixed feedback is explained by a forward model because the greater the number of "SELF" responses decrease, the greater the difference between feedback timing and the average become. Moreover, this study shows that each forward model is different because feedback which are delayed more than 240 ms tend to be more over-attributed; feedback which are delayed from 80 ms to 200 ms tend to be more under-attributed in the experiment for tactile feedback than in experiments for the other senses.

Next, we describe the bias and the standard. The means of these data which express the standard of Sense of Agency in this experiment show that the mean of mixed feedback is almost equal to an average rate of the means tactile feedback and of optical feedback.

The standard deviation which expresses the bias of the Sense of Agency indicates that the bias of mixed feedback is almost equal to that of optical feedback but is not similar to that of tactile feedback, as shown in Figure 4. Therefore, It is suggested that the standard of the mixed forward model is influenced by an average of each standard of two other forward models and that the bias of the mixed forward model is influenced by a smaller value of two biases, in this case by the bias of a forward model for optical feedback.

6 Conclusion

For this study, we discuss the propriety of adopting the Forward Model to the model of Self-Other Attribution for mixed feedback. Results indicate that 1) Self-Other Attribution of each sense is different because the bias and the standard of Sense of Agency differ among the three kinds of senses, and 2) the bias and the standard of mixed feedback is decided as the way to compare those of tactile feedback with those of optical feedback. We will improve the Forward Model to explain the system of losing the Sense of Agency by having schizophrenia patients perform this key-pushing task.

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ROMANSY 17

ROBOT DESIGN, DYNAMICS, AND CONTROL

PROCEEDINGS OF THE SEVENTEENTH CISM-IFToMM SYMPOSIUM

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