Proceedings of the 2012 ICME
International Conference on Complex Medical Engineering
July 1 - 4, Kobe, Japan

Relationship between Sense of Agency and Task Performance in Target Search Task

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***Abstract*—Human cognitive and psychological characteristics should be considered for design of user interfaces. In this study, the relationship between the sense of agency and the task performance was examined through an experiment. The experimental task was target-searching by controlling a joystick. In the experiment, temporal delay of visual feedback was set to indirectly control the participants' sense of agency. The experimental results demonstrated that there is a negative correlation between the degree of sense of agency and the reaction time. Based on the result, we concluded that the sense of agency plays a key role for the improvement of the cognitive performance.**

***Index Terms*—sense of agency, reaction time**

I. Introduction

Various intelligent systems have been developed with the rapid improvement in computer technologies. Automation is good enough for stand-alone type machinery or computer systems. In the systems, which are interacting with humans, on the other hand, automation has been changed the cognitive demands and responsibilities of the humans [1], [2]. Therefore, user interfaces of such systems must be appropriately designed.

Among various issues in designing user interfaces, especially in teleoperation, effects of time delay in the control loop have been of great importance over the years [3], and there have been so many studies tackling the issue [4]–[8]. It is important for the interfaces to be designed based on human cognitive and psychological characteristics.

In the fields of cognitive psychology and neuropsychiatry, there are many researches conducted on the sense of agency, the sense that 'I' am the one who is causing or generating an action [9], [10].

Some studies have been suggested that the inferior parietal cortex has a crucial role in judging whether an action is caused or generated by oneself or by others [11]–[13]. Generally, there are two types of models in human brains; a forward model and an inverse model. The forward model uses an efferent copy of the motor command to predict sensory consequences of the movement. The inverse model outputs a required motor command from a desired motion trajectory. Based on the forward model, the comparator model has been proposed [14]–[17].

In the comparator model, the motor command is transmitted to the muscles through the parietal cortex, and an efference copy of the command is simultaneously sent to a forward model. The forward model is composed of two parts, a forward dynamic model and a forward output model. The forward dynamic model makes a prediction of the consequences of motor commands. The forward output model predicts the sensory feedback and it is compared with the actual sensory feedback. Based on the comparison, a sensory discrepancy is calculated and a judgment on whether the movement is self-generated is made according to the discrepancy. In other words, the large difference between predicted sensory consequences and the actual ones leads to attribution of the movement to others, and the small difference causes self-attribution (Fig. 1).

In this study, we form a hypothesis that an operator's sense of agency has a positive effect on her cognitive performance. The objective of this study is to clarify the relationship between the sense of agency and task performance in a human-computer interface with temporal delay between human input and it's feedback and to verify the hypothesis.

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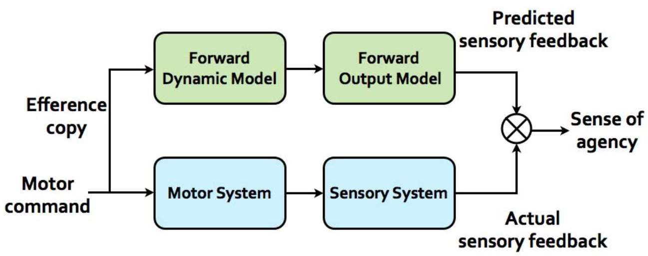

Fig. 1. Comparator model proposed by Blakemore *et al.* [17]

II. Method

A. Participants

In the experiment, 21 healthy volunteers (aged 20–28 years, mean=22.5; 12 men, 9 women) were participated. The experiment was approved by the ethics committee of Graduate School of Engineering, the University of Tokyo, and informed consent was obtained from all the participants before the experiment.

B. Apparatus

The experiment was conducted in a silent, dark room. Visual stimuli were created and the experiments were conducted using Visual C++ and OpenGL on a Windows PC. The stimuli were displayed on a 24-inch computer screen. Participants were required to seat in front of the screen and hold a joystick (Cyborg eve Force, Saitek) with their right hand (Fig. 2). The joystick was equipped with a trigger to input user commands.

C. Procedure

In the experiment, the participants searched a target (red circle with radius 4 mm) in an area of searchlight (yellow circle with radius 40 mm) (Fig. 3). The target was randomly located and was invisible unless it was within the area of searchlight. The participants were required to pull the trigger with their index fingers as soon as they detect the target. The movement speed of the searchlight was 60 mm/s. Figure 4 shows the experimental procedure.

In the experiment, it is necessary to change the degree of the sense of agency. In essentials, however, the participants' sense of agency cannot be directly controlled by the experimenter. According to the past studies [18], [19], temporal delay between control and feedback can decrease an operator's sense of agency. Therefore, we set temporal delay between the joystick input and the motion of searchlight. In this experiment, there are five temporal delay conditions (0, 100, 300, 500, or 700 ms) to change the degree of the sense

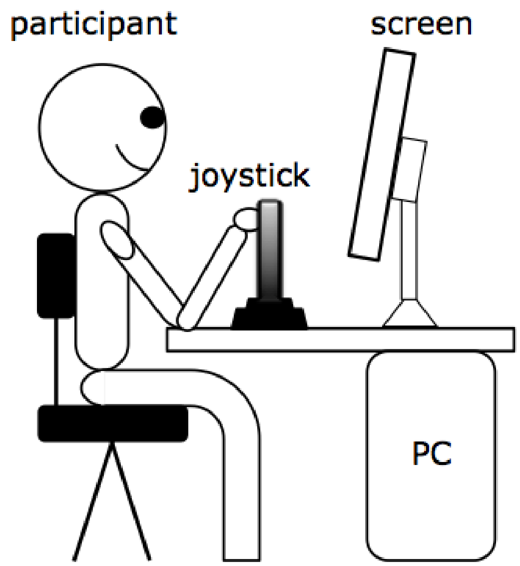

Fig. 2. Illustration of the experimental apparatus

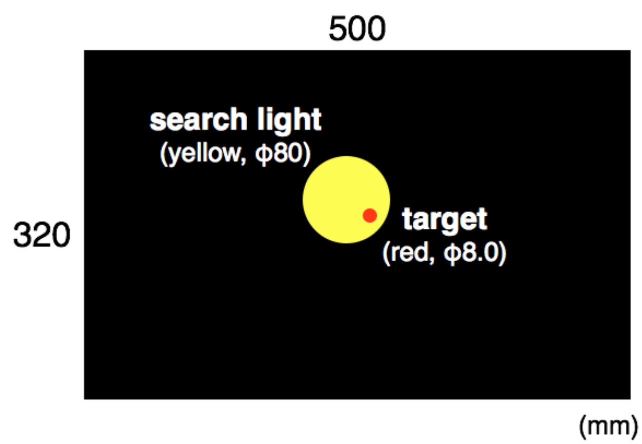

Fig. 3. Appearance of the computer screen. A searchlight is a yellow circle with radius 40 mm and a target is a red circle with radius 4 mm. Participants of the experiments search the target anywhere in a searching area (320 mm $\times$ 500 mm) using the searchlight.

of agency. The participants was not informed the existence of the temporal delays.

As mentioned in the previous section, the comparator model explains the mechanism of the sense of agency. With the comparator model, the idea of this experiment can be explained as follows:

The motor command is transmitted to the motor system to operate a joystick, and an efference copy of the command is simultaneously sent to a forward dynamic model. As the searchlight moves after a certain delay, the sensory system receives delayed visual feedback. In the forward model, on

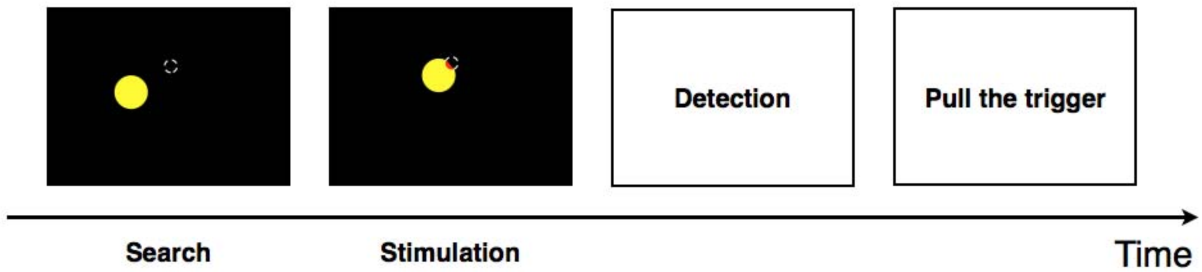

Fig. 4. Procedure of an experimental trial. Time interval between moments of stimulation (an area of searchlight overlaps the position of target) and response (a participant pulls the trigger) is measured.

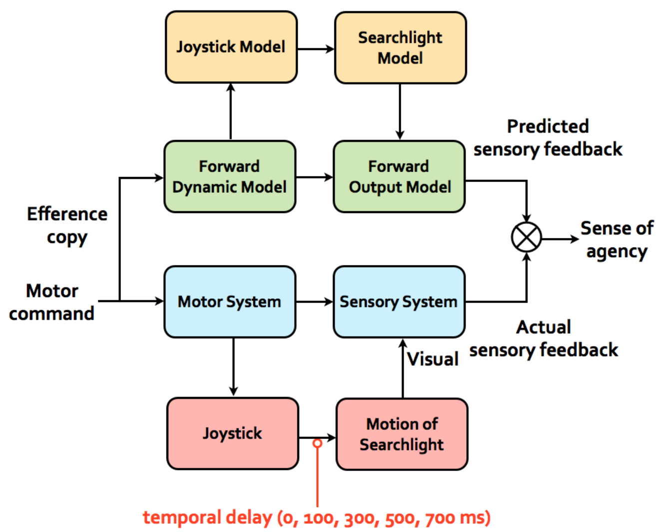

Fig. 5. Setting temporal delay in the experiment

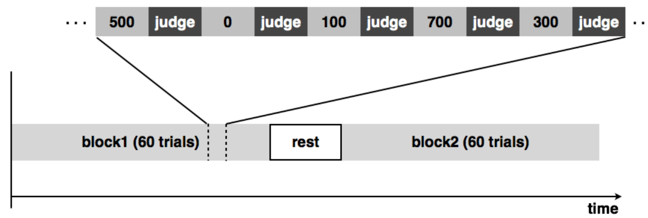

Fig. 6. Procedure of the experiment

the other hand, a joystick model and a searchlight model predict their motion and the forward output model predicts the sensory feedback. In this case, there will be a certain discrepancy between predicted visual feedback and the actual one (Fig. 5). Thus, we expected that the degree of the sense of agency could be indirectly controlled by modulating the temporal delay.

Before the experiment, participants practiced enough to control the searchlight using the joystick. The experiment consists of 2 blocks. In each block, 60 trials (5 conditions $\times$ 12 times) were conducted in random order. Thus, a total of 120 trials were conducted for each participant. The participants took a break between the blocks (Fig. 6). In the experiment, reaction time, which is a time interval between the moments of stimulation (the target appeared in the area of searchlight) and response (the participants pulled the trigger of the joystick), was measured. The participants were required to judge whether they felt that they moved the searchlight or not just after each trial.

III. Results

Figure 7 shows a relationship between sensory feedback delay and the sense of agency. The horizontal axis shows the length of temporal delay between the joystick inputs and the motions of searchlight. The vertical axis is the ratio of trials in which participants judged the motion of the searchlight as self-generated. Each box shows the 50th percentile as well as 25th and 75th. The average "YES ratios" of each length of feedback delay (0, 100, 300, 500, and 700 ms) are 0.994 ($SD = 1.46 \times 10^{-2}$), 0.968 ($SD = 3.38 \times 10^{-2}$), 0.749 ($SD = 0.207$), 0.450 ($SD = 0.251$), and 0.286 ($SD = 0.216$), respectively.

As a whole, there is a tendency for the ratio to decrease as the delay increases. The result was analyzed using a Wilcoxon signed rank test with Holms correction. According to the test, there are significant differences between every two conditions ($p < 0.01$). The result can support the comparator model. That is, the large temporal delay causes the large discrepancy between predicted sensory feedback and the actual ones, and this leads attribution of the movement to others.

Based on the result, the sense of agency could be indirectly controlled by the sensory feedback delay in this experiment.

Figure 8 shows a box plot of the reaction time to the sensory feedback delay. Each box shows the 50th percentile as well as 25th and 75th. The average reaction times of

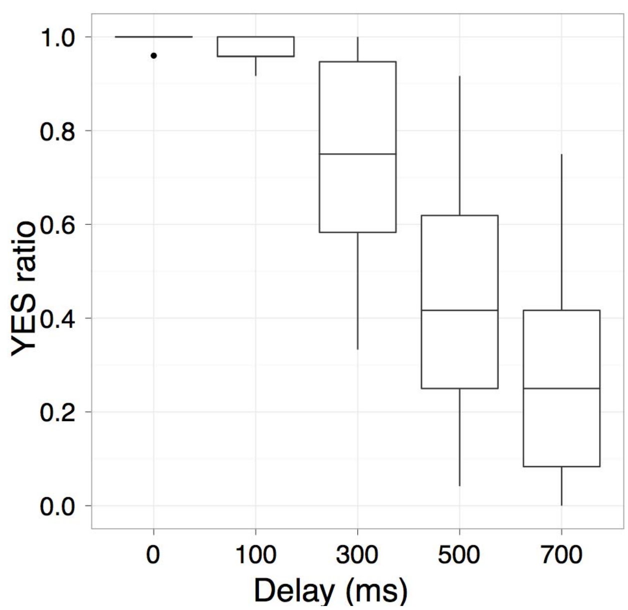

Fig. 7. Relationship between the length of temporal delay and the degree of the sense of agency

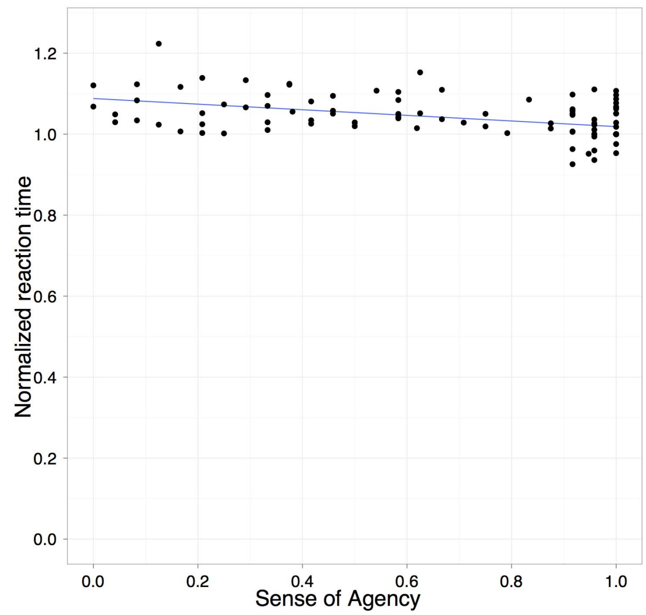

Fig. 9. Relationship between the degree of the sense of agency and normalized reaction time

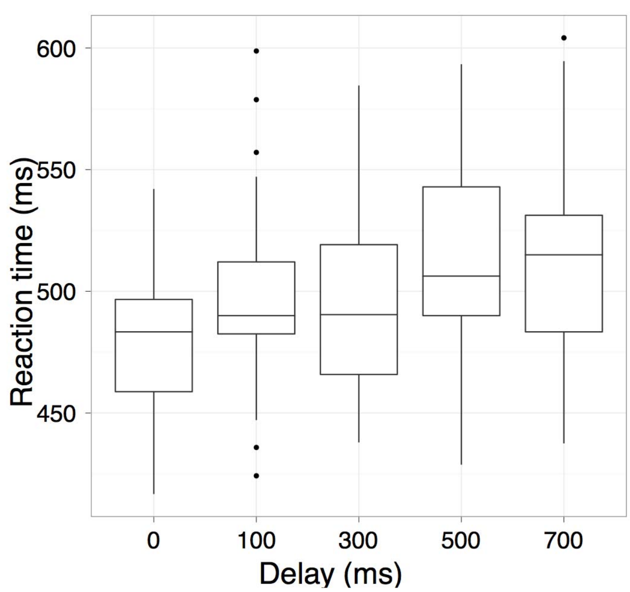

Fig. 8. Relationship between the length of temporal delay and reaction time

each length of feedback delay (0, 100, 300, 500, and 700 ms) are 481.57 ($SD = 33.04$), 498.51 ($SD = 42.63$), 500.28 ($SD = 39.19$), 511.53 ($SD = 42.47$), and 512.92 ($SD = 44.38$), respectively.

There is a tendency for the reaction time to increase as the delay increases. For every combinations of conditions, a paired t-test with Holms correction was conducted. According to the test, there were significant differences between no-delay condition (delay = 0 ms) and other conditions (delay = 100, 300, 500, and 700 ms) ($p < 0.05$). However, the differences of the other combinations were not significant ($p > 0.05$).

IV. Discussion

In order to analyze a relationship between the sense of agency and cognitive performance, the reaction time was normalized. In the normalization process, the mean reaction time of each participant at the no-delay condition was set to 1.0, and the mean reaction time at other conditions were divided by that at the no-delay condition. The normalization enabled us to put together the results of participants.

A relationship between the degree of the sense of agency and the normalized reaction time is shown in Fig. 9. Here, the degree of the sense of agency means the "YES ratio" for each temporal delay condition of each participant.

There is a tendency for the normalized reaction time to decrease as the degree of the sense of agency increases. There is a negative correlation ($r = -0.46$) between the degree of the sense of agency and the reaction time. In this study, the reaction time is the evaluation index to measure the human cognitive performance. Therefore the experimental result suggests that the stronger the sense of agency is, the higher the cognitive performance will be.

In the experiment, the sense of agency was indirectly controlled by changing the length of sensory feedback delay. Considering the comparator model, however, the indirect control did not only change the degree of sense of agency, but also enlarge discrepancy of the comparison between predicted and actual sensory consequences. That is, controlling feedback delays might cause a change of predictability. Therefore, in future, we should investigate the relationship between predictability and the cognitive performance.

In human-machine interaction, situation awareness is critical to good decision making and performance of humans [20]. Situation awareness is defined as the perception of elements in the environment with in a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future [21]. From the viewpoint of situation awareness, a feeling that 'I' control a machine is very important. The experimental result of this study can be a strong evidence to back up this claim.

V. Conclusion

In this study, we examined the relationship between the sense of agency and task performance in a human-computer interface with temporal delay between human input and it's visual feedback. The experimental results showed that there is a correlation between the sense of agency and the task performance. Based on the result, it can be concluded that the sense of agency plays an important role for improvement of human cognitive performances.

References

[1] L. Bainbridge, "Ironies of Automation," Automatica, Vol.19, No.6, pp.775–779, 1983.

[2] D. D. Woods, "Decomposing Automation: Apparent Simplicity, Real Complexity," R. Parasuraman and M. Mouloua (Eds.), Automation and Human Performance: Theory and Applications, Erlbaum, pp.3–17, 1996.

[3] T. B. Sheridan, "Space Teleoperation Through Time Delay: Review and Prognosis," IEEE Transactions on Robotics and Automation, Vol.9, No.5, pp. 592–606, 1993.

[4] A. K. Bejczy, W. S. Kim, and S. C. Venema, "The Phantom Robot: Predictive Displays for Teleoperation with Time Delay," Proceedings of the IEEE International Conference on Robotics and Automation, pp.546–551, 1990.

[5] D. A. Lawrence, "Stability and Transparency in Bilateral Teleoperation," IEEE Transactions on Robotics and Automation, Vol.9, No.5, pp.624–637, 1993.

[6] T. Fong and C. Thorpe, "Vehicle Teleoperation Interfaces," Autonomous Robots, Vol.11, pp.9–18, 2001.

[7] P. Arcara and C. Melchiorri, "Control Schemes for Teleoperation with Time Delay: A Comparative Study," Robotics and Autonomous Systems, Vol.38, pp.49–62, 2002.

[8] A. Shahdi and S. Sirouspour, "Adaptive/Robust Control for Time-Delay Teleoperation," IEEE Transactions on Robotics, Vol.25, No.1, pp.196–205, 2009.

[9] S. Gallagher, "Philosophical Conceptions of The Self: Implications for Cognitive Science," Trends in Cognitive Sciences, Vol.4, No.1, pp.14–21, 2000.

[10] P. Haggard, "Conscious Intention and Motor Cognition," Trends in Cognitive Sciences, Vol.9, No.6, pp.290–295, 2005.

[11] C. Farrer and C. D. Frith, "Experiencing Oneself vs Another Person as Being The Cause of An Action: The Neural Correlates of The Experience of Agency," NeuroImage, Vol.15, pp.596–603, 2002.

[12] C. Farrer, N. Franck, N. Georgieff, C. D. Frith, J. Decety, and M. Jeannerod, "Modulating The Experience of Agency: A Positron Emission Tomography Study," NeuroImage, Vol.18, pp.324–333, 2003.

[13] P. Ruby and J. Decety, "Effect of Subjective Perspective Taking During Simulation of Action: A PET Investigation of Agency," Nature Neuroscience, Vol.4, No.5, pp.546–550, 2001.

[14] R. C. Miall, D. J. Weir, D. M. Wolpert, and J. F. Stein, "Is The Cerebellum A Smith Predictor?," J. of Motor Behavior,Vol.25, No.3, pp.203–216, 1993.

[15] D. M. Wolpert, R. C. Miall, and M. Kawato, "Internal Models in The Cerebellum," Trends in Cognitive Sciences, Vol.2, No.9, pp.338–347, 1998.

[16] H. Imamizu, S. Miyauchi, T. Tamada, Y. Sasaki, R. Takino, B. Pütz, T. Yoshioka, and M. Kawato, "Human Cerebellar Activity Reflecting An Acquired Internal Model of A New Tool," Nature, Vol.403, pp.192–196, 2000.

[17] S. -J. Blakemore, D. A. Oakley, and C. D. Frith, "Delusions of Alien Control in The Normal Brain," Neuropsychologia, Vol.41, pp.1058–1067, 2003.

[18] A. Sato and A. Yasuda, "Illusion of Sense of Self-Agency: Discrepancy Between The Predicted and Actual Sensory Consequences of Actions Modulates The Sense of Self-Agency, But Not The Sense of Self-Ownership," Cognition, Vol.94, pp.241–255, 2005.

[19] T. Asai and Y. Tanno, "The Relationship Between The Sense of Self-Agency and Schizotypal Personality Traits," J. of Motor Behavior, Vol.39, No.3, pp.162–168, 2007.

[20] R. Parasuraman, T. B. Sheridan, and C. D. Wickens, "Situation Awareness, Mental Workload, and Trust in Automation: Viable, Empirically Supported Cognitive Engineering Constructs," J. of Cognitive Engineering and Decision Making, Vol.2, No.2, pp.140–160, 2008.

[21] M. R. Endsley, "Automation and Situation Awareness," R. Parasuraman and M. Mouloua (Eds.), Automation and Human Performance: Theory and Applications, Erlbaum, pp.163–181, 1996.