

Positive Effect of Slight Delay for Operational Performance

1st Ryota Akimoto
2nd Masatoshi Miyaji
Nagoya Inst. of Tech., Japan

3rd Kenji Funahashi
Nagoya Inst. of Tech., Japan
kenji@nitech.ac.jp

4th Koji Tanida
Kindai Univ., Japan
tanida@mech.kindai.ac.jp

5th Shinji Mizuno
Aichi Inst. of Tech., Japan
s_mizuno@aitech.ac.jp

Abstract—Experienced tool manipulators often describe that they can move a tool in the way they intend like a part of the body. Based on the findings from experiments about delay, we hypothesized that appropriate delay in a control system would help us to understand the characteristics of tools and would improve operational performance. It was suggested that appropriate delay improved operational performance for a little difficult operation.

Index Terms—sense of self ownership, slight delay, operational performance

I. INTRODUCTION

In the field of cognitive science, research on self awareness has been performed, and Gallagher has proposed the psychological concepts of the sense of self agency and self ownership [1]. The sense of self agency is the sense that they are the cause or author of the movement, and the sense of self ownership is the sense that they are the subject of the movement. The research [2] has shown that the sense of self agency is stronger when the delay and noise between the operation and the object motion is smaller. Waltemate et al. showed that motor performance, the sense of self agency and the sense of self ownership decline with a certain amount of latency for a subject's body action in VR environment [3]. Tochioka et al. showed that the sense of self ownership was just decreased monotonically in the situation where the latency of a subject's hand motion was long, that was realized and experimented in AR environment [4]. We had expected that same results were obtained for tool operation, and experimented them in VR environment. Although the sense of self agency and the sense of self ownership had a similar tendency for the researches described above, it was suggested that slight delay improved tool operation performance unexpectedly. By the way, Mazda which is Japanese automobile manufacturer has reported that slight delay is important element apparently—*When you start to move the accelerator pedal, the time until the tension of the neck muscle starts is constant at 0.2 to 0.3 seconds. It is the first necessary condition that acceleration is generated in accordance with the "timing of the stance" to realize a reasonable and natural reaction* (end of section 2.2 in [5]). Farrer also had an experiment about the change of the sense of self agency when adding delay for displaying the response on a screen after pressing a button [6]. In this experiment, it was found that increasing the delay resulted in subjects' responses varying from full control, to partial control and to

no-control. A person who is skilled in the manipulation of a tool may feel the tool as if it were their own hand or foot. The phrase "I can move a tool like a part of the body in the way I intend" is sometimes used not only for i.e. a tennis racket that appearance and how to use are similar to a part of a body and its action (compare the following car example), but also for i.e. a car that is not similar [7], [8].

In this study, we focus on this sense that a person feels a tool as an integral part of themselves, and they feel it as if it were a part of the body. In order for a person who is not skilled in tool manipulation to feel this sense and to use tools better, it is necessary to recognize tools appropriately and not to be pushed around. Based on the findings of Farrer's experiment, it can be expected that a small delay is effective for proper recognition for the other stuff. In the experiment, we examined the effect of the delay between input operation and output response for the tool manipulation. The operation was a moving object task as continuous movement by reach extender, it meant grabber, which was more difficult than simple button pressing task. Kasahara i.e. showed that spatial-temporal deformation of a virtual body actually changed the sense of body as well as physical movement [9]. We also examined the effect of the difficulty to operate for the sense. The difficulty was expressed as a length of a reach extender. It was suggested that appropriate delay improved operational performance for a little difficult operation. However, in the case of very easy and difficult tasks, the positive effect of the delay was not noticeable. This was expected to provide insights for development of interface also for VR system that enables even person who is not skilled in manipulation to effectively acquire the sense of self ownership for tool operation.

II. EXPERIMENTAL SYSTEM

We consider an experiment that a subject moves an object by a tool in a VR environment. A reach extender is used as a tool, and a subject moves a ball as an object from one table to another (Fig. 1 (a)). Two tables are also prepared in a VR space. The movement of the reach extender is linked to the stylus of force feed back and 6DOF pointing device PHANTOM Omni (Fig. 1 (b)). The virtual reach extender movement is delayed for PHANTOM to delay it for the motion of the subject's hand. A cardboard is placed to prevent the subject from seeing at PHANTOM.

The motion of a tool and an object can be divided into two types: one is steady state, such as constant speed linear motion, constant acceleration rotational motion and stopped state, and another is transient state. In this experiment, we focus on the delay in the transient state, because the delay in the steady state may not be easily recognized. Therefore, we choose the task that is started clearly and proceeded in short period. In order to measure operation time, the object is fixed before start. We draw a “lid” on the object to represent visually that it is fixed (Fig. 1 (c)). The PHANTOM stylus is also prevented to limit the reach extender. A three second countdown is displayed to announce the start of the move operation. After the countdown, a subject can move the object. The delay can be changed also to zero but it actually includes PHANTOM communication and drawing time. It is supposed that shaft length of the reach extender is 25mm, and the total length between tip of jaws and trigger of handle is 60mm because of movable range of PHANTOM, and the VR scene is displayed on a 22 in. screen at about 3.4 times the size (Fig. 2), it means the total length seems about 200mm. If the position of the tables is always the same, the subject may become accustomed to the operation. So the position of the tables is changed in parallel and symmetrical randomly, but this distance is always constant, because the fairness of the task cannot be maintained if the distance between them changes. Horizontal distance between the center of tables is 110mm, vertical distance between the top of tables is 50mm, and absolute distance is 120mm, that seems about 400mm.

III. EXPERIMENT 1

A. Exploratory experiment

We had expected that same results were obtained for tool operation, and experimented them in VR environment first. The subjects were 20 undergraduate and graduate students in their 20s. Consent to participate in the experiment was obtained from all subjects. Before the experiment, we provided the subjects with a few minutes of practice to familiarize themselves with the experimental system and PHANTOM, and to experience the following standard actions 1 to 4 in order for them to understand the task to move an object by using the reach extender.

Action 1: Manipulate an actual object (sponge ball) directly by hand (Fig. 3 (a)).

Action 2: Manipulate an actual object (sponge) directly by an actual reach extender (Fig. 3 (b)).

Action 3: Manipulate a virtual object with no delay by a virtual reach extender.

Action 4: Manipulate a virtual object with the maximum delay in this experiment.

This action 1 meant direct operation by their own hand without any tool. Action 2 was the operation with a reach extender as a tool in real world. It assumed that the action 3 was equivalent to action 2. And the subjects had an experience about delay with action 4. We also explained that these behaviors were used as a measure of the responses to the

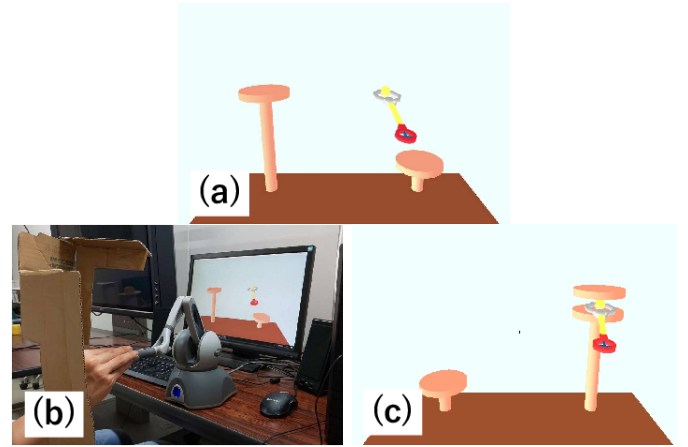


Fig. 1. Appearance of experiment.

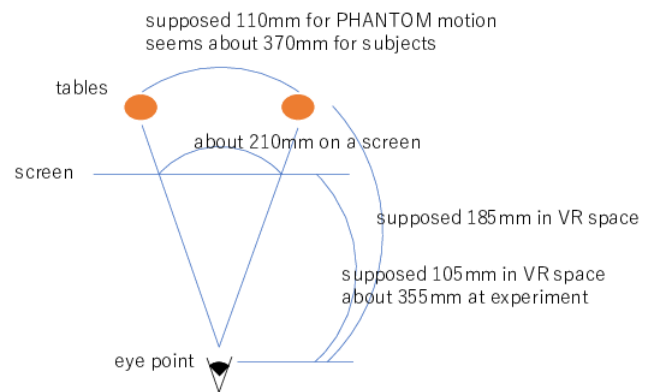


Fig. 2. Top view of positional relationship.



Fig. 3. Appearance of standard action.

post experimental questionnaire. In our experiments, the delay was 0[ms] (although about 5[ms] was included as PHANTOM communication and drawing time, but we treated this as no delay) to 450[ms], with 10 steps of 50[ms]. Subjects performed 10 movement tasks (5 round trips) in a trial. In experiment 1, we assigned five delay patterns for each subject as five trials (50 tasks) in random order from 10 patterns. After experiencing the standard actions, the experiment was carried out as follows. The evaluation was based on the subject's responses to a questionnaire about the sense of operation and the time spent to move from one table to another.

Step 1: The delay and the table positions were set initially.

Step 2: Operated the PHANTOM to grab an object on the table by the virtual reach extender.

Step 3: Performed the task 10 times (5 round trips).

3-1: Waited for 3 seconds in the countdown.

3-2: Moved the object to another table quickly and smoothly as possible.

Step 4: For each trial, answered the following questionnaire about their sensations during operation.

Question 1: Were you able to move the reach extender with your own intentions (the sense of self agency)?

Question 2: Did you feel the reach extender as if it were your own hand (the sense of self ownership)?

Questions 1 and 2 were rated on a scale of 0 to 9. We asked the subjects to evaluate each trial as follows: the action 1 by their own hands was 10 (greater than 9), the action 2 and 3 by the real and virtual reach extenders were 5, and the action 4 with the maximum delay was 0.

B. Result of experiment 1

The results were broadly similar to those of previous studies in terms of the sense of self agency and the sense of self ownership. The evaluation value about sensation during operation became smaller as the delay decreased overall in the experiment 1 (Fig. 4). Although the value of the sense of self agency in the range of 0-150[ms] became smaller as the delay increased, the value of the sense of self ownership was almost constant in the same range. A Wilcoxon rank sum test was conducted on the sensory evaluation at 0 and 150[ms]. There was a significant difference between 0 and 150[ms] at the 5% level for the sensory evaluation of the sense of self agency, whereas there was no significant difference for the sensory evaluation of the sense of self ownership. This suggested the existence of the sense of self ownership between 0 and 150[ms] delay. However, the transitions in sensory evaluations of both were similar overall. A two way test of variance was conducted between the both results and the amount of the delay. There was no significant difference between two sensory evaluations, and no interaction. The value of the Fig. 4 (b) at 0[ms] was above 5, it meant that some subjects felt that the sensation was more similar to the sensation of manipulating an object directly by hand than without the delay.

The average operation time increased as the delay increased overall in the experiment 1 (Fig. 5). However, the average operation time at 100[ms] was shorter than the time at 0[ms]. It was analyzed whether there was a significant difference between the average operation time with a delay of 0 and 100[ms]. There was significant difference at the 5% level. This suggested that appropriate delay in the control system improved the operational performance. Furthermore, there was no significant difference between 50 and 100[ms], and there was significant difference between 100 and 150[ms] at the 1% level. These suggested surprisingly that the appropriate delay improved the operational performance was about 50 to 100[ms]. Now it was examined whether experience and fatigue affect on the operation time. A two way test of variance was conducted for the first, sixth, and tenth total permutations of the task and the amount of the delay. There were no significant

differences in operation time by task order in each trial, and there was not interaction between the task order and delay. This suggested that experience and fatigue did not affect on the operation time.

IV. EXPERIMENT 2

A. Revalidation experiment

Appropriate delay in the control system might improve the operational performance in experiment 1. We tried to examine it again with other subjects, and the same experimental system and the same procedure. The subjects were 30 undergraduate and graduate students in their 20s. Consent to participate in the experiment was obtained from all subjects. For each trial, they answered the following questionnaire about their sensations during operation instead of the Step 4 in section III-A:

Step 4': For each trial, answered the following questionnaire about their sensations during operation.

Question: Did you feel as if the other were intervening in the manipulation of the reach extender (the sense of the presence of the other)?

Question was rated as follows: cooperative interference was positive point (maximum 5), obstructive interference was negative point (minimum -5), and no interference felt was zero point. Note that we told them before this experiment that it might work with not only obstructive delay but also cooperative support, even though cooperative operational support was not provided actually. The minimum effective delay in the experiment system was 16[ms] due to the modification of the drawing process, and 8 trials were allotted per a subject.

B. Result of experiment 2

Unfortunately, the average operation time in the experiment 2 (Fig. 6) was not improved as clearly as in experiment 1. By the way, the subjects really felt the other as cooperator between 0 and 200[ms] without any actual support, and felt the other as obstacle for delay longer than 250[ms] (Fig. 7), although there was no significant difference unfortunately. It maybe expected that people can easily feel the sensation that they can move a tool like a part of the body in the way they intend by adding a slight delay.

V. EXPERIMENT 3

A. Difficulty experiment

Although appropriate delay might improve the operational performance in experiment 1, favorable result was not obtained in experiment 2 for performance. On the other hand many subjects felt the other as cooperator without any actual support in experiment 2. We examined them repeatedly with other subjects. And also to examine the effect of the difficulty of a tool, the system used in experiments 1 and 2 was modified for this experiment. The shaft length of the virtual reach extender can be changed to three different length: 0.5, 1.0 and 1.5 times (Fig. 8). The subjects were 9 undergraduate and graduate students in their 20s. Consent to participate in the experiment

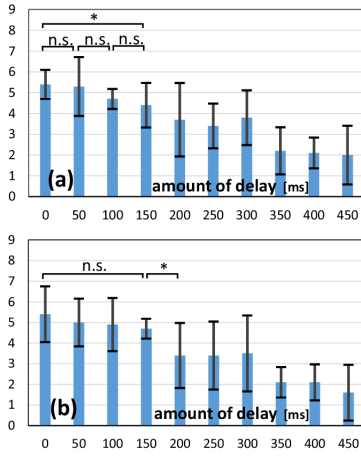


Fig. 4. Transition and variability between amount of delay and evaluation of (a) the sense of self agency, (b) the sense of self ownership (experiment 1).

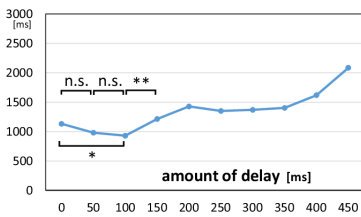


Fig. 5. Transition between amount of delay and average operation time in the experiment 1.

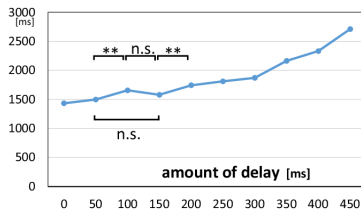


Fig. 6. Transition between amount of delay and average operation time in the experiment 2.

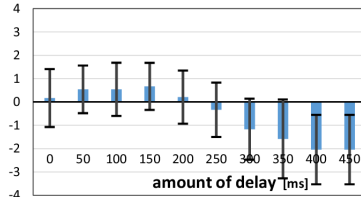


Fig. 7. Transition and variability between amount of delay and evaluation of the sense of the other presence in the experiment 2.

was obtained from all subjects. It was focused on how positive peak of the sense of the other presence as cooperator (Fig. 7) was changed depending on the difficulty, so the delay was set as 25 to 175[ms], with 7 steps of 25[ms]. We assigned just 14 patterns for each subject as 14 trials in random order from 3 lengths and 7 delay patterns. Note that no subject was assigned the same combination of length and delay pattern again. This

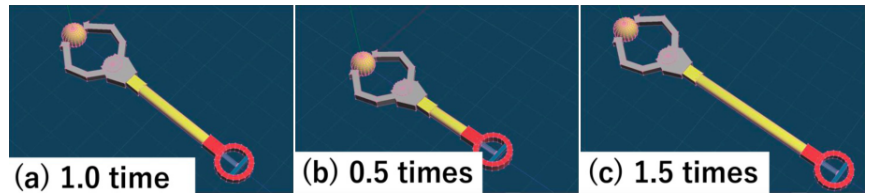


Fig. 8. Three lengths of reach extender.

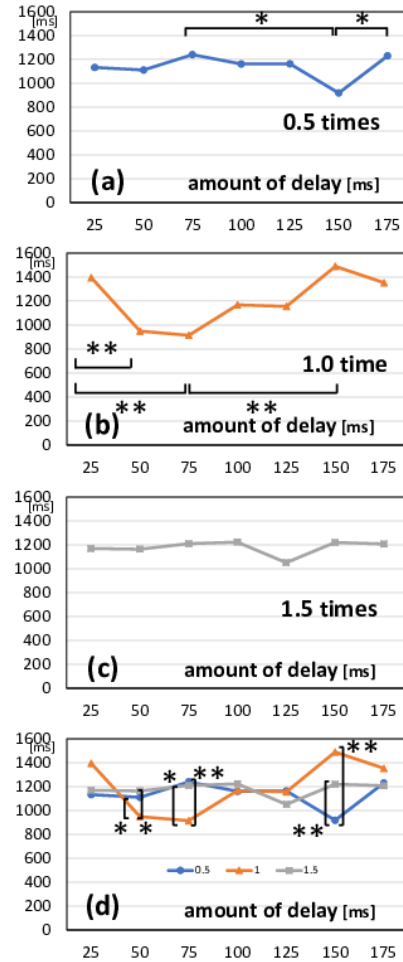


Fig. 9. Transition between amount of delay and average operation time for (a) 0.5 times length, (b) 1.0 time length, (c) 1.5 times length, (d) all pattern lengths (experiment 3).

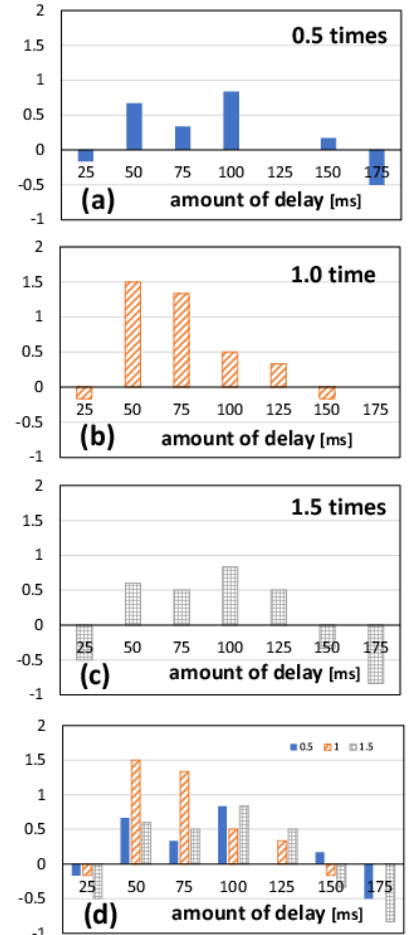


Fig. 10. Transition and variability between amount of delay and evaluation of the sense of the other presence for (a) 0.5 times length, (b) 1.0 time length, (c) 1.5 times length, (d) all pattern lengths (experiment 3).

experiment procedure was almost same as experiment 2. When subjects experienced the standard actions, only original length reach extender was used.

B. Result of experiment 3

The average operation time was constant overall when the length was 0.5 or 1.5 times as the delay increased in the

experiment 3 (Fig. 9). However, the average operation time in the range of 50-75[ms] was shorter than the time at 25[ms] when the length was 1.0 time (Fig. 9 (b)). It was analyzed whether there was a significant difference between the average operation time with a delay of 25 and 50[ms], 25 and 75[ms]. There was significant difference at the 1% level. The average operation time at 150[ms] was shorter than the time at 75[ms] of the 0.5 times length (Fig. 9 (a)), and the transition was almost constant of the 1.5 times length (Fig. 9 (c)). The appropriate delay really improved the operational performance for the original size, however the appropriate delay for different difficulty might change, and the delay did not work well for more difficult tool. By the way, the operation time of the 1.0 time length was longer than the time when the length was 0.5 or 1.5 times at 25[ms]. Although the task is more difficult (longer length reach extender), the operation time is longer in general, this result were not. It might suggest that the subjects prepared for more difficult task before starting if the reach extender was too long.

The subjects felt the other as cooperater between 50 and about 125[ms], and felt the other as obstacle for delay longer than about 175[ms] for all lengths (Fig. 10). This suggested that it almost did not depend on the length whether they felt the other as cooperater or obstacle. However, It depended on the length whether they felt the other presence strongly. Comparing sums of positive average values and negative ones, the value of the 1.0 time length was grater than the value of the 0.5 and 1.5 times length. This was thought that subjects felt the other presence weakly when the task was easy (shorter length reach extender), whereas the subjects were too concerned about task operation to feel the other presence when the task was difficult. It is considered the relation between the operation time and the other presence here. (1) The values of the other presence for the 1.0 time length were relatively grater than the values for the 0.5 and 1.5 lengths in the range of 50-75[ms] (Fig. 10 (d)). There was significant difference between the average operation times for the length of 1.0 time and both of 0.5 and 1.5 times in the same range of 50-75[ms] (Fig. 9 (d)). (2) The subjects felt the other as cooperater when the length was 0.5 times, whereas they felt the other as obstacle when the length was 1.0 and 1.5 times at 150[ms] (Fig. 10 (d)). It meant that they felt the other more cooperative relatively at the time. There was significant difference between the average operation times for the length of 0.5 times and both of 1.0 and 1.5 times at 150[ms] (Fig. 9 (d)). (3) Although this was a same result as experiment 1, when the subjects felt the other as most cooperative in the range of 50-75[ms] for the 1.0 time length (Fig. 10 (b)), the operation times decreased certainly for other delay trials (Fig. 9 (b)). These considerations suggested that the operation time decreased when they felt the other as cooperater, and the appropriateness and effectiveness depended on the difficulty of manipulation.

VI. CONCLUSION

We examined the effect of the delay between input operation and output response, and the effect of the difficulty to

operate. Experiments were conducted to test the hypothesis that appropriate delay in the control system would help a user to understand the characteristics of a tool (the other stuff), and thus the delay might lead to the sense of self ownership. It was suggested that appropriate delay gave subjects cooperative sensation of the other, and this sensation might give subjects the sense of self ownership, and improved operational performance for a little difficult operation. However, the positive effect of the delay was not noticeable in the case of very easy and difficult tasks. It maybe expected that people can easily feel the sensation that they can move a tool like a part of the body in the way they intend by adding a slight delay.

This finding is expected to provide insights to develop interfaces also for VR system that enables even person who is not skilled in manipulation to effectively acquire the sense of self ownership. In the future, the number of subjects should be increased to get more accurate data. Consideration of statistics, such as p-value, degree of freedom, and testing methods, should be deepened. In order to be confirmed that subjects perceived it as an obstacle for delay above 175[ms], it should be analyzed 200[ms] and above. By the way, some subjects felt pseudo support without any actual support, so we would like to consider how the sense of the other presence changes when actual support is also provided.

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