Positive Effect of Slight Delay and Task Conditions for Operational Performance

Yakumo Miwa
Nagoya Inst. of Tech., JAPAN
y.miwa.915@stn.nitech.ac.jp

Kenji Funahashi
Nagoya Inst. of Tech., JAPAN
kenji@nitech.ac.jp

Koji Tanida
Kinki University, JAPAN
tanida@mech.kindai.ac.jp

Shinji Mizuno
Aichi Inst. of Tech., JAPAN
s_mizuno@aitech.ac.jp

***Abstract*—We have hypothesized that providing the control system with an appropriate delay would improve its operational performance. Previous experiments in our laboratory have suggested that slight delay in the operation of a tool improves operational performance. However, another experiment with slight changes in appearance and task details did not show positive effects. In this study, we investigated the requirements for slight delay to improve performance. By adjusting the task while keeping the appearance unchanged, we again obtained results suggesting an improvement in tool operational performance. The effect of the difficulty of the operation task was also inferred.**

***Index Terms*—User Interface, Tool Operation, Positive Effect of Delay**

I. Introduction

We have investigated the effects of latency to tool operation [1]. It is generally believed that latency only negatively affects the feeling of operation [2] [3]. 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* (last part of section 2.2 in reference [4]). Based on the findings from experiments on delay [5], we have hypothesized that providing the control system with appropriate delay would improve its operational performance. We conducted an experiment on relatively simple tool operation to investigate the effect of delay. The experiment was conducted in a VR environment in order to easily implement delay in tasks that were somewhat more complex than simple button pressing operations [5]. A reach extender was displayed on the screen. The subjects operated the reach extender with a 3D position input device. The reach extender moved a ball from one table to the other in the screen (Figure 1 and 2). Delay was intentionally added between the operation of the input device and the reaction of the reach extender on the screen. As a result, the performance was improved (i.e. the time to move the ball decreased) at small delay of about 50 to 100 ms, and degraded at larger delay [6] (Figure 3, called experiment 1 in this paper, described again in English [7]). We performed a same experiment again to reconfirm this result [7] (called experiment 2 in this paper). In addition, the subjects were informed in advance that it might assist or disturb them with a force display device even though any force was not

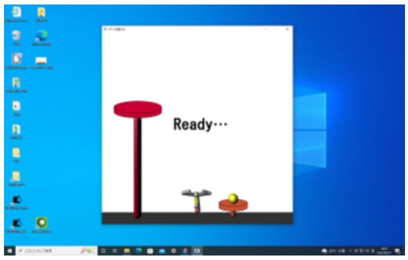

Fig. 1. Screen of experiment 1

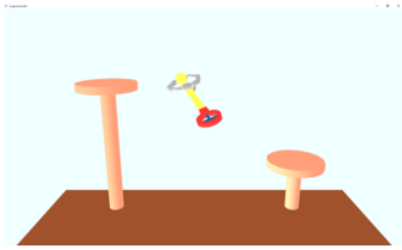

Fig. 2. Screen of experiment 2

provided actually. Sensory evaluation was conducted after the experiment. The result showed that although the subjects felt that they were assisted at delays of 50 to 150 ms (Figure 4, positive value means assistance), no clear improvement in performance was observed (Figure 3). At larger delay, the performance clearly decreased, and the subjects felt that they were disturbed. The experimental system for experiment 2 was a same as that for experiment 1, but was revised to use 3DCG in the hope that a more pronounced trend would emerge. Initially, it was assumed that the slight differences would have no essential effect on the results and that similar trends would be obtained. However, the results were as described above. In this study, we first sort out the differences between the two experiments. And then, additional experiments are conducted to evaluate what factors lead to a positive effect of delay. It is expected that delay in tool operation would alter the sense of agency and the sense of self-ownership [8], and slight delay may be useful for interface design. However, the main objective of this study is not to focus on the mechanism by which delay improves tool operation performance, but rather to identify the conditions under which performance improvement occurs.

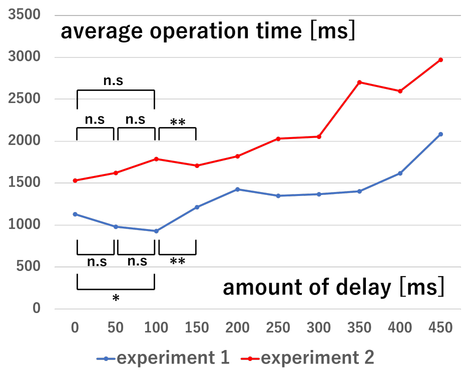

Fig. 3. Result of operating time of experiment 1 & 2

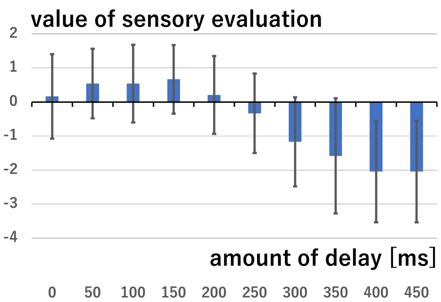

Fig. 4. Sense of the other presence in experiment 2

II. Experiment 1 & 2

A. Experiment System and Procedure

In the experiment, a PHANTOM (Geomagic Phantom Omni) was used as an input device (successor product [9]), and a 22-inch LCD display was used as the output device (Figure 5). The reach extender displayed on the screen was linked to the PHANTOM stylus. The subject operated the reach extender on the screen and moved the ball object on the screen from a table to another table through the PHANTOM. Delay is added between the PHANTOM and the reach extender to implement the delay from the subject's hand to the extender and the movement of the object. It was necessary to measure the movement time of the object to obtain the operation scores. It was also needed to clearly distinguish between steady state and transient state. A "lid" was drawn on the object to visually indicate that it was fixed. The reach extender on the screen was also restricted to move, and the PHANTOM was fixed. A 3-second countdown was displayed in numerals to announce the start of the movement operation. After the countdown, the subject could move the reach extender. If the positional relationship between the tables was always the same, the subject might become accustomed to the operation, so the position of the tables could be changed. However, these distances should not differ significantly, because changing the distance between each other would not maintain fairness among tasks and would interfere with the evaluation of movement time.

Prior to the experiment, subjects were asked to experience

Fig. 5. Appearance of experiment 2

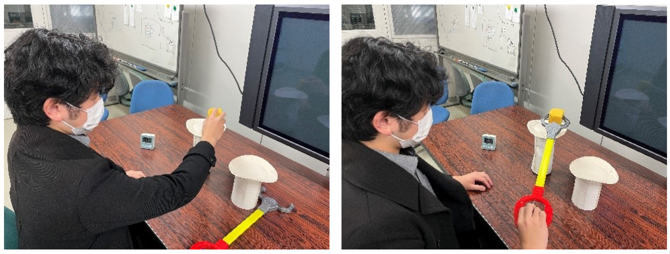

Fig. 6. Actual operation by (Left) a hand, (Right) a reach extender

the following standard actions 1 to 4 in order to understand the positioning of the task.

- Action 1: Operate an actual object (sponge ball) directly by a hand.
- Action 2: Operate an actual object (sponge) directly by an actual reach extender.
- Action 3: Operate a virtual object with no delay by a virtual reach extender.
- Action 4: Operate a virtual object with the maximum delay in this experiment.

This action 1 meant direct operation by their own hand without any tool (Figure 6 (Left)). Action 2 was the operation with a reach extender as a tool in real world (Figure 6 (Right)). It assumed that the action 3 was equivalent to action 2. And the subjects had an experience about delay with action 4. The delay in the experiment was 0 ms (although about 5 ms in experiment 1 and 16 ms in experiment 2 were included as a PHANTOM communication and drawing time, each delay was treated as no delay) to 450 ms, with 10 steps of 50 ms. The past positions of the PHANTOM stylus were stored, and the scene was drawn with the position according to the delay. The refresh rate was not affected by the delay. Subjects performed 10 movement tasks (5 round trips) in a trial as follows.

- 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).
  - Step 3-1: Waited for 3 seconds in the countdown.
  - Step 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 only in experiment 2. (Note that the subjects were informed in advance that it might assist or disturb them with a force display device even though any force was not provided actually.)

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

In experiment 1, 20 subjects were assigned 5 trials and 5 delays per subject in random order. In experiment 2, 30 subjects were assigned 8 trials and 8 delays per subject in random order.

B. Differences of Experiment 1 & 2

In this section, we discuss the differences between the experimental systems. First, the differences are listed.

- (1) Operating movement
  - (1)-1 With/without depth movement restrictions
  - (1)-2 Movement ratio of reach extender on screen to input device
- (2) Table
  - (2)-1 Size of table
  - (2)-2 Positioning of table
- (3) Visual size
  - (3)-1 Size of monitor
  - (3)-2 Size of window
- (4) Depth perception
  - (4)-1 Angle of depression
  - (4)-2 Projected shape of floor
- (5) Appearance
  - (5)-1 Color tone
  - (5)-2 Shading

Each item is described in detail as follows.

(1)-1: In experimental system 1, depth movement was completely restricted to simplify the task (Figure 7, 8 (Top)). In experimental system 2, depth movement was allowed within a certain range in the hope three-dimensional movement would increase the sense of realism and make the delay effect more positive (Figure 7, 8 (Bottom)). It was expected that the difficulty of the operation would not change because the depth movement direction was limited to the diameter of the table. However, the range of the left and right coordinates of the target table differed according to the depth coordinates.

(1)-2: The relationship between the actual hand movement and the movement of the reach extender is considered here. It means the ratio of the hand coordinates to the screen coordinates. The experiment system 1 was projected orthographically, and the system 2 was projected perspectively, but they were not displayed stereoscopically. Because it is unknown how subjects perceive depth, the actual distance from the monitor surface was used as the distance in screen coordinates. The table is drawn smaller at the edge of the monitor than at the center in the perspective projection. Therefore, they are measured around the tables in experiment 2. Table 1 shows the relationship between the distances based on the hand coordinate distance. When the hand moves a certain distance, the reach extender on the screen moves about twice as far in experiment 2 as in experiment 1.

(2): The position and the size of the table for each experiment were set experimentally. There were three different layouts of the tables for each experiment. Each closest layout in each experiment was called as type 1, 2 and 3. Table 2 shows the relationship of the size and position of each table. The distance values are: the diameter of the table / the vertical distance between the centers of the tables / the horizontal distance between the centers of the tables / and the direct distance between the centers of the tables. One layout was symmetrical with another in both experiments, and one layout was overall higher than another in the experiment 2. Note that the starting table size was different in experiment 1: 43.1 mm in the hand coordinate system, and 34 mm in the screen coordinate system. The averages of the horizontal hand coordinate distance were approximately a same, but others were different.

(3): Both monitors were the same: BenQ G2200W 22 inches with 1680 × 1050 pixels. The window size was 800 × 800 for experiment 1, as shown in Figure 1. Experiment 2 was 1680 × 1050 (full screen), expecting that a wider viewing angle would have more positive effect by increasing the sense of presence.

(4), (5): The depression angle of the gaze is difficult to indicate simply because the pseudo-three-dimensional effect was expressed based on orthographic projection in experiment 1. The angle was 15.8 degrees looking down in experiment 2. Each floor is shown in Figure 1 and 2. The color tone, shading, etc. are also as shown in Figure 1 and 2.

In the following sections, we first focus on (1)-1 mentioned above and conduct experiment 3 based on experiment 2, i.e. keeping (2)-(5) the same as in experiment 2 but completely restricting movement in the depth direction as in experiment 1. Next, focusing on (1)-2, we conduct experiment 4 based on experiment 2, where only the ratio of the actual hand movement to the reach extender movement in the screen is the same as in experiment 1. Finally, experiment 5 is conducted based on experiment 2, in which both the restriction of depth movement and the ratio of the movements are adjusted to those of experiment 1.

III. Experiment 3

Based on the experimental system 2, we conducted experiment 3 in which the depth movement was restricted in the same way as in experiment 1. The object could only be moved in a vertical plane. Consent to participate in the experiment was obtained from all participants. Each of the 24 subjects was assigned 10 trials with 10 delays in random order. The preparation and procedure of the experiment were the same as in experiment 1 and 2 described in Section II.A. The average time of the task operation was longer for larger delay (Figure 9). However, the operating time was shorter

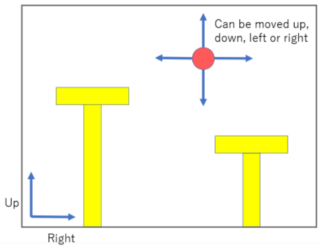

Fig. 7. Side view of experiment

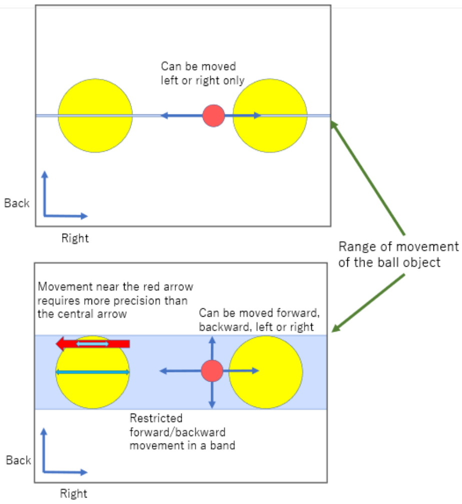

Fig. 8. Ground view of (Top) experiment 1, (Bottom) experiment 2

with 50 ms delay than with 0 ms delay. There was no significant difference between the time with a delay of 0 ms and that with the experiment 1, and it was expected that the depth-movement restriction had effect on the improvement of operational performance due to the delay.

IV. Experiment 4

Based on the experimental system 2, experiment 4 was conducted in which the ratio of the movement of the reach extender on the screen to the movement of the input device was the same as the experiment 1 (Table 1). The size and position of the table were the same as in experiment 2 and 3, and the hand movement during task operation was also the same. The movement of the reach extender and the ball object in the screen was about a half. In experiment 4, the size and position of the table (Table 2, experiment 2) did not change in the hand and table coordinates. The average distances in the screen coordinates were 36/46/114/124mm (Table 2). The actual hand movements were smaller in experiments 2 and 3 than in experiment 1, but they were larger on the screen. The hand movement remained small, and the movement on the screen was also small in experiment 4. In experiment 4, the actual movement and the size of the table were not changed, but only the appearance on the screen was changed. So the ease of the task should not have changed, but it might be perceived as easier in terms of impression. The subjects were 10 students. All participants consented to participate in the experiment. Each subject was assigned 10 trials with 10 delays in random order. Preparation and procedure for the experiment were the same as in experiments 1, 2 and 3. The average time of the task operation was longer for larger delay (Figure 10). The average operating time was slightly shorter with 50 ms than with 0 ms delay like the result of experiment 3. There was no significant difference between the time with a delay of 0 ms and that with a delay of 50 ms as a result of Mann-Whitney U test. The trend of the operating time was slightly similar to that of experiment 1, and it was expected that the movement ratio of reach extender on screen to input device had effect on the improvement of operational performance due to the delay.

TABLE I
Relationship of hand and screen coordinate distance

	Hand coord. dist. [mm]	Screen coord. dist. [mm]
Expt.1, 4 & 5	1	0.78
Expt.2 & 3	1	1.48

TABLE II
Size and position of table

(diameter/vertical distance/horizontal distance/linear distance)

Expt. - Type	Hand coord. dist. [mm]	Screen coord. dist. [mm]
1-1	71.8/144/144/203	56/113/113/160
1-2	71.8/162/162/229	56/127/127/179
1-3	71.8/162/162/229	56/127/127/179
Avg. of expt.1	71.8/156/156/220	56/122/122/173
2-1	46/67/147/161	72/88/221/238
2-2	46/67/147/161	72/91/225/242
2-3	46/67/147/161	72/88/221/238
Avg. of expt.2 & 3	46/67/147/161	72/89/222/239
Avg. of expt.4 & 5	46/67/147/161	36/46/114/124

V. Experiment 5

Experiment 5 was also based on the experimental system 2, its depth movement was restricted as in experiment 1 and 3, and its ratio of the reach extender to the input device was the same as the experiment 1 and 4. The subjects were 10 students. All participants consented to participate in the experiment. Each subject was assigned 10 trials and 10 delays in random order. Preparation and procedure were the same. The average time of the task operation was longer for larger delay (Figure 11), but the operation time was shorter with 50 ms delay than with 0 ms delay. And there was 5% significant difference between the time with delay of 0 ms and that with delay of 50 ms as a result of Mann-Whitney U test, the same as the improvement in experiment 1. The result clearly suggested a positive effect of slight delay as in experiment 1. Both the limitation of movement and the ratio of movement might be necessary to indicate the positive effect of the delay. However, it is not clear whether further decreasing the movement ratio would lead to better results.

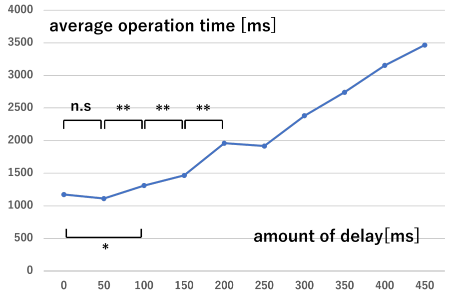

Fig. 9. Result of operating time of experiment 3

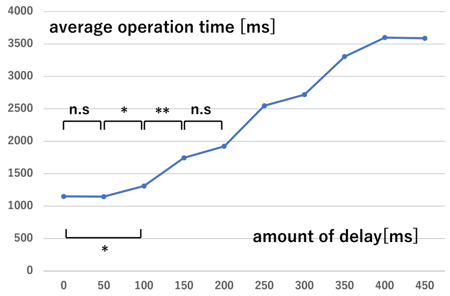

Fig. 10. Result of operating time of experiment 4

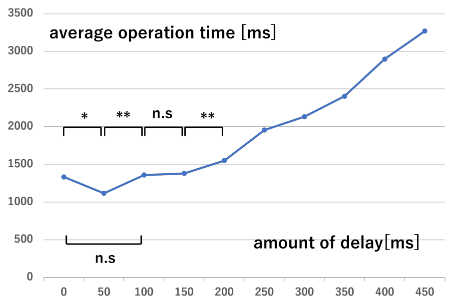

Fig. 11. Result of operating time of experiment 5

VI. Conclusion

We sorted out the differences between two experiments that gave different results in confirming the positive effect of slight delay, and investigated which differences lead to positive effect on delay. The experiments focused on the restriction of depth movement, and the ratio of the reach extender movement on the screen to the actual hand movement. The experiments only with restricted depth movement and only with readjusted ratio of the extender to hand showed trend toward improved performance, but there were no significant differences. The experiment with the depth restriction and the readjusted ratio showed improvement in performance with 5% significant difference. These may be simplifications of the task itself, and simplifications in mental images. In other words, the task difficulty may have strong influence on the performance improvement due to slight delay. These findings will contribute to user interface design. In the future, we would like to investigate the simplified task about the tables; increase the size or decrease the distance in the hand coordinate with/without changing it in the screen coordinate.

Acknowledgment

This work was supported in part by JSPS KAKENHI Grant Number JP20K11918 and JP23K11182.

References

[1] T. Kataoka, K. Funahashi, K. Tanida and K. Yashiro. A Study of Sense of Self-Agency Focused on Noise and Delay in Multiple Input Operation, Proc. of the GCCE 2017, pp. 484–487, 2017.

[2] T. Waltemate, I. Senna, F. Hulsmann, M. Rohde, S. Kopp, M. Ernst, and M. Botsch. The impact of latency on perceptual judgments and motor performance in closed-loop interaction in virtual reality. Proc. of the VRST 2016, pp. 27–35, Nov. 2016. doi: 10.1145/2993369.2993381

[3] H. Tochioka, H. Ikeda, T. Hayakawa and M. Ishikawa. Effects of latency in visual feedback on human performance of path-steering tasks. Proc. of the VRST 2019, Article No. 65, Nov. 2019. doi: 10.1145/3359996.3364726

[4] H. Watanabe, K. Tanaka, Y. Hujioka, H. Kuniwake and T. Yamaguchi. Performance feel for new demio. MAZDA TECHNICAL REVIEW (in Japanese), No.32, pp.42–47, 2015.

[5] C. Farrer, G. Valentin, and J. M. Hupé. The time windows of the sense of agency. Consciousness and Cognition, 22(4): 1431–1441, Dec. 2013. doi: 10.1016/j.concog.2013.09.010

[6] M. Miyaji, K. Funahashi and K. Tanida. A Study of Influence of Delay to Sense of Self-Ownership for Tool Operation. Proc. of the 24th Annual Conference of the Virtual Reality Society of Japan (in Japanise), 5B–01, 2019.

[7] R. Akimoto, M. Miyaji, K. Funahashi, K. Tanida and S. Mizuno. Positive Effect of Slight Delay for Operational Performance, Proc. of the GCCE 2021, pp.162–166, 2021.

[8] S. Gallagher. Philosophical conceptions of the self: implications for cognitive science. Trends in Cognitive Sciences, 4(1):14–21, Jan. 2000. doi: 10.1016/S1364-6613(99)01417-5

[9] 3D Systems, Inc. Touch Haptic Device. https://www.3dsystems.com/haptics-devices/touch