ISASE 2019

Effect of Latency and Space Discrepancy on Sense of Agency

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Abstract: The sense of agency (SoA) is an important Kansei quality in interactive design. It refers to the feeling that one is in control of his/her actions and, through them, of events in the outside world. Our living world consists of two dimensions: space and time. One perceives and operates objects in time and space. Thus, time and space are essential factors in interaction design. The objective of this study is to find how congruency of space discrepancy and latency affect the SoA while interacting an object through an interface and whether they have interaction effect. We conducted an experiment with participants to compare between varied space discrepancy and latency with respect to SoA. We used intentional binding and questionnaire to measure both implicit and explicit SoA, respectively. The result showed that both latency and congruency of space discrepancy affect the explicit part of sense of agency, while only latency affects the implicit part of sense of agency. Interaction effect was observed between latency and congruency of space discrepancy only in the explicit part of SoA. The result provided an explanation to how these two factors affect SoA. Furthermore, we proposed a standardization method for the result of intentional binding supporting that latency has similar effect on the explicit and the implicit part of SoA. That is, as latency increases, the SoA decreases.
Keywords: *Interaction design, Sense of agency, Latency, Space discrepancy, Intentional binding, Interaction*

1. INTRODUCTION

1.1 Background

The sense of agency (SoA) is an important Kansei quality for designing an interactive system. SoA refers to the feeling that one is in control of our actions and, through them, of events in the outside world [1]. Nowadays, there are systems like autonomous driving and remote surgery by which the operations are done. People need to supervise the working conditions of these systems and need to feel that they are in control of the machines. This can be scientifically said that we need to ensure and increase their SoA when we design the product interface. If the user lacks SoA, s/he may feel that s/he isn't controlling the system, which leads to the neglect of some system errors. This will cause severe security problems. The purpose of this study is to provide a guide to interaction, product design and to ensure the security. When designers design the user interface of these systems, they can know a method that can increase the SoA and make the users feel that they are in control of the system.

There are two common models explaining the mechanism of SoA. One is the comparator model [2]. Our actions start with intentions or goals, which enables a representation of the desired state of the motor system. Then, a movement is produced using this information, which changes the state of the motor system and generates sensory feedback. The SoA comes from the comparison of the predicted state of the system with the actual state. Another is the theory of apparent mental causation [2]. If one's intention to act happens before s/he acts, and is consistent with the action, then s/he feels as though s/he has caused the action.

There are both implicit and explicit measurement for SoA. Intentional binding is one of the implicit measurements that has been studied for over 10 years [3]. Intentional binding refers to the subjective compression of the temporal interval between a voluntary action and its external sensory consequence. The relationship between the intentional binding and SoA have been observed. Previous studies showed us how to design experiments and obtain results for engineering purpose. Libet clock is a common method which researches use to measure intentional binding [3].

Effects of several single factors on SoA have been studied such as temporal delay between the action and feedback [4], input modality [5], modality and quality of sensory feedback [6], degree of assistance [7], difficulty of action selection [1], causal belief [9], and outcome prediction [10]. Several combinations of two different factors have also been done, for example, degree of

assistance with latency [7], action choice and outcome congruency with latency [11], sensory outcome prediction with latency [12].

Our living world is made up by space and time. We perceive an object through these two dimensions. These dimensions are essential in designing interactive systems. Therefore, we focused on both space and time as factors of SoA. We choose space discrepancy and latency in an interface of an interactive system and try to find how these two factors work together. Congruency of space discrepancy means the congruency between when users control the object and make actions through the user interface. It is a common factor in user interfaces when users are controlling an object or using a software. Latency means the time interval between users' action and the reaction of the machine. It is an important factor that has been studied alone and with some other factors, such as degree of assistance [7], action choice and outcome congruency [11], sensory outcome prediction [12]. Previous studies have founded that intentional binding is weaker at longer delays [8]. The combination of different factors may have different effect compared to the situations when each parameter exists alone. We studied how latency and interaction design affect SoA, and whether there is interaction effect between them.

1.2 Objective

The objective of this study is to find how congruency of space discrepancy and latency in a man-machine system affect SoA that is measured both implicitly and explicitly, and whether these two factors have an interaction effect. The outcome will provide knowledge of how to design the user interface, for example, what kind of stimulus and feedback should be used, how to choose the combination of latency and space discrepancy to increase users' SoA.

1.3 Hypothesis

Former studies have founded how latency and outcome congruency affect SoA. Also, they have founded some interaction effect between them [12]. According to results of former studies, we made the following hypothesis.

For the explicit part of SoA, we used questionnaire as the measurement. We hypothesized that as the latency increases, users' SoA decreases under both congruent and incongruent conditions of space discrepancy. Users have more SoA under congruent conditions than incongruent conditions. These two factors have an interaction effect between each other.

For the implicit part of SoA, we used intentional binding as the measurement. The implicit part means that the measurement doesn't directly reflect the meaning of SoA. We hypothesized that the similar results can be observed as the explicit part of SoA. That is, as the latency increases, intentional binding decreases. Intentional binding is smaller in incongruent conditions of space discrepancy than in congruent conditions. These two factors may have an interaction effect between each other.

2. METHOD

We designed the experiment setting under a common situation that participants needed to control an object on a screen. In this research, different levels of latency and congruency of space discrepancy were combined. Five different levels of latency were set, 0ms, 50ms, 150ms, 300ms, and 600ms. The largest latency was 600ms because intentional binding could only be found when latency was shorter than 600ms. Both congruent and incongruent condition of space discrepancy existed.

Both the implicit and explicit SoA were evaluated using questionnaire and intentional binding, respectively. The experiments consisted of three sections.

Session 1 (Practice section): Before the main part of the experiment, several trials of different latency and congruency were given to make sure that participants fully understood how the experiment worked.

Session 2 (Questionnaire section): In this section, a ball appeared on the screen. When participants pressed the direction button, the ball moved to the same or opposite direction after a certain latency. Participants needed to give a number between 1 and 10 to report what extent they felt that they were in control of the object. Five levels of latency and two types of congruency formed the ten different conditions. Each condition had 20 trials. There were 200 trials in total.

Session 3 (Intentional binding section): A Libet clock was set on the screen to measure intentional binding [3]. The pointer turned one round in 2.56s. When the ball appeared, participants needed to press the direction button. Then the ball moved to the same or opposite direction after a certain latency. Participants needed to record the position of the pointer when they pressed the button and when the ball started to move. Five levels of latency and two types of congruency formed the ten different conditions. Each condition had 20 trials. There were 200 trials in total.

Ten healthy students from the University of Tokyo took part as participants in the experiment. During the

experiment, they received the explanation of the experiment first, and then sat in front of a screen using mouse to control the object. About 45 minutes were taken to finish the explanation and two parts.

Two-way ANOVA and multiple comparison were conducted to compare the effects of factors on both subjective score of SoA and the intentional binding, respectively.

3. RESULT

3.1 Subjective responses of SoA

Table 1 showed the statistics of two-way ANOVA with respect to the effects of congruency of space discrepancy and latency on subjective scores of SoA. Figure 1 showed average scores of the questionnaire for each level of latency and congruency of space discrepancy.

TABLE 1 Statistics of Two-way ANOVA of SoA score for latency and congruity

Source	SS	df	MS	F	P-value	F crit
Congruency	12816.9845	1	12816.9845	2736.17317	0	6.64764204
Latency	1286.317	4	321.57925	68.6508217	1.685E-54	3.3285961
Interaction	388.673	4	97.16825	20.7435032	9.096E-17	3.3285961

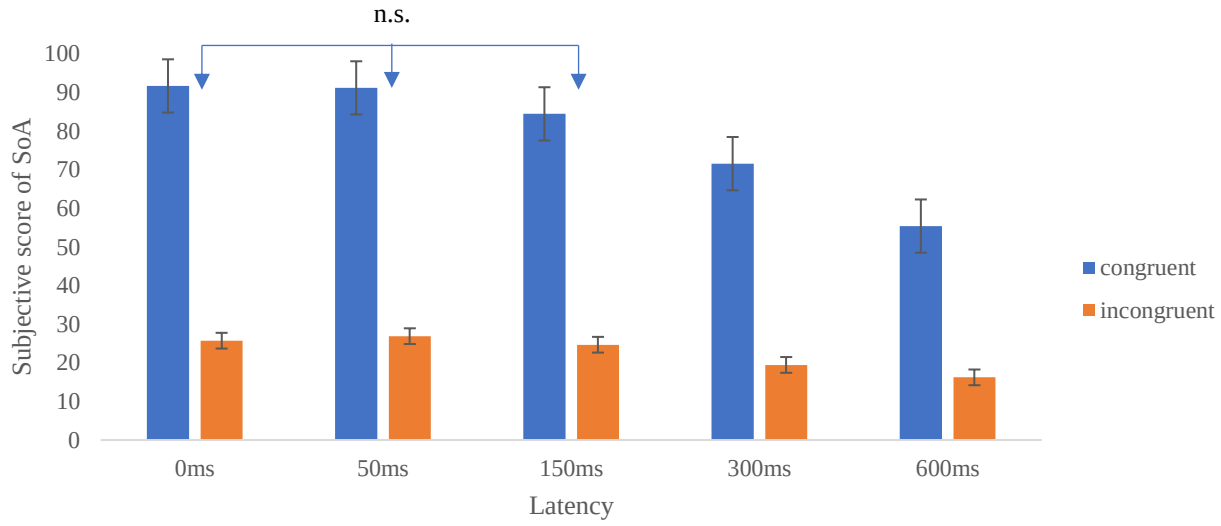

FIGURE 1 Average score of SoA for combination of latency and congruity. Error bars represent standard errors.

From Table 1, the main effects of congruency (F=2736.2, p<0.001) and latency (F=68.65, p<0.001) on the response were significant. The interaction effects of congruency and latency were significant (F=20.7, p<0.001).

From Figure 1, latency had large effect under the condition of congruent trials (F=133.3, p<<0.0003), while it had small effect under the condition of incongruent (F=5.1, p=0.0003). The average of subjective score of SoA decreased as latency increased under both congruent and incongruent conditions. Multiple comparison showed that the scores between levels of latency were significantly different except between the condition of 0ms, 50ms and 150ms.

3.2 Intentional binding

Table 2 showed the statistics of two-way ANOVA of intentional binding. Figure 2 showed average scores of intentional binding for each level of latency and congruency of space discrepancy.

TABLE 2 Two-way ANOVA of intentional binding for latency and congruity

Source	SS	df	MS	F	P-value	F crit
Congruency	8214.755555	1	8214.75556	0.59323008	0.4412642	6.64764204
Latency	6856350.492	4	1714087.62	123.783152	1.9291723E-94	3.3285961
Interaction	13061.68889	4	3265.42222	0.23581307	0.91823839	3.3285961

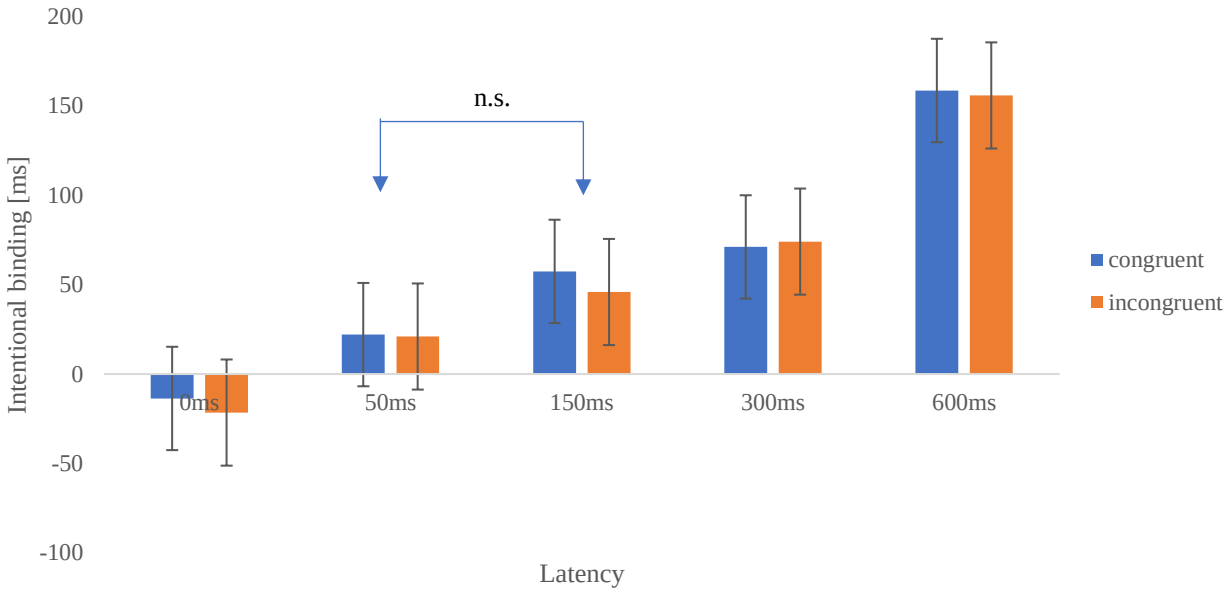

FIGURE 2 Average intentional bindings for combination of latency and congruity. Error bars represent standard errors.

From Table 2, main effect of latency was significant (p<0.000, F=123.78) as a factor of the implicit part of SoA.

From Figure 2, intentional binding increased when latency increased, which contradicted to our hypothesis. Multiple comparison showed that intentional binding was significantly different except between the condition of 50ms and 150ms.

4. DISCUSSION

On the one hand, the results of the subjective score of SoA supported our hypothesis. These results suggested that the SoA scores decreased as the latency increased under both congruent and incongruent conditions of space discrepancy. The participants had more SoA under congruent conditions than incongruent conditions. Latency and congruency of space discrepancy had interaction effects between each other. Latency had a large effect on congruent trials, while it only had a small effect on incongruent trials.

On the other hand, the results of intentional binding were different from our hypothesis. The result showed that only latency affected the intentional binding, and intentional binding increased when latency increased. There was no interaction effect between latency and congruency of space discrepancy. These results were similar to the results from a previous study [13]. We discussed the reasons of differences between the results and our hypothesis. In the experiment of intentional binding, participants needed to observe the object and the Libet clock at the same time, which led to relatively large errors. This might explain why congruency didn't affect SoA. Further improvement should be done to the experiment design to reduce the error.

As the intentional binding became larger when latency became larger, we applied a standardization method. Because human-beings perceive short intervals and long ones in the same way with an absolute number, it was impossible for participants to perceive the same interval under the condition of different latency. There were more possible answers in trials of longer latency. Also, the error in trials of longer latency were larger. In order to reduce the error and compare perceived intervals under different conditions, we used the quotient which equals to intentional binding divided by the actual latency for standardization. Figure 3 shows the standardized result. The quotient became smaller when latency became larger, which corresponds to our hypothesis that intentional binding decreased as the latency increased. This meant that congruency and latency had similar effect on implicit and explicit part of SoA.

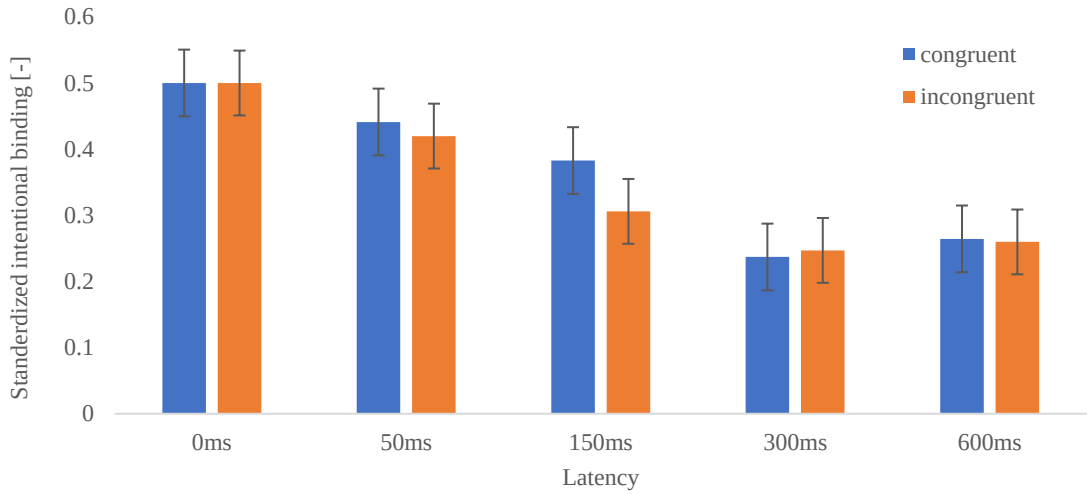

FIGURE 3 Intentional bindings divided by actual latency for standardization

5. CONCLUSION

We investigated how latency and congruency of space discrepancy affect SoA. We used both implicit and explicit measurement of SoA and tried to find whether there is the interaction effect between them.

The experimental results suggested that both latency and congruency of space discrepancy affected the explicit part of SoA, while only latency affected the implicit part of SoA. Interaction effect was observed between latency and congruency of space discrepancy only in the explicit part of SoA. For the latency, as it increased, SoA decreased in the explicit part of SoA. This rule also worked in the implicit part of SoA after standardization was made.

These findings provided an explanation to how these two factors affect SoA. We proposed a standardization method for the result of intentional binding, which supported that latency had the same effect in the explicit and the implicit part of SoA. That is, as latency increased, SoA decreased.

The outcome of this study is expected to be applied in user interface design. When users control an object or make actions, designers will know how to design the latency and the space discrepancy in the reaction of the machine to optimize user's SoA.

ACKNOWLEDGMENTS

We thank Professor Tamotsu Murakami of the University of Tokyo, and members of Design Engineering Lab of the University of Tokyo for supporting this study.

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