Intentional Binding in Direct and Indirect Manipulation for Pointing Task

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***Abstract*—Sense Of Agency (SOA) has the potential to be a useful indicator for the evaluation of the indirect manipulation of devices in in-car systems. In this study, we examined whether intentional binding, which is used as an implicit evaluation index of SOA, is confirmed when engaging in a task in which a series of sequential operations are required. Sixteen subjects were tested, and the results showed that both direct and indirect manipulation of devices indicated the same patterns of intentional binding as in previous studies. However, no difference in the magnitude of binding was detected between direct and indirect manipulation.**

Keywords - Sense of agency; Intentional binding; Indirect manipulation.

I. INTRODUCTION

A. Indirect manipulation

In recent years, automotive infotainment systems have been developed to integrate advanced driver assistance and entertainment functions in addition to vehicle-related information. Consequently, Human Machine Interactions (HMIs) have become highly complex [1].

In this context, recent in-car devices incorporate interfaces that can be operated using touch, voice, and gestures. Early in-car devices were operated by directly touching a physical interface, consisting of combinations of knobs, buttons, and switches. However, as devices became increasingly digitalized, the target device was operated not by touching it directly, but via an input device that mediated the operation. For example, a navigation system installed on a dashboard could be operated using a touch panel. In this paper, the former is called direct operation, and the latter is called indirect operation.

In indirect manipulation, operations are performed by a cursor and a pointer that are displayed on the operating device. Such a cursor and pointer are considered extensions of the user's body (in this case, a finger), which Seinfeld et al. call user representations [2]. In an indirect operation, the space that the user touches for manipulation is called the input space (in the above example, the touch panel), and the display screen of the target device is called the output space (the navigation system operation screen).

In indirect manipulation, two interfaces, the input space and output space, arise. One of the drawbacks with the emergence of these two interfaces is the lack of feeling of direct manipulation. Lack of feeling causes problems in that, additional cognitive resources must be allocated to manipulating the device, and the user experience is degraded. It is important to clarify how this sense of direct manipulation can be maintained during the design and evaluation of increasingly complex in-car systems.

B. Sense of Agency

An important concept related to the feeling of direct manipulation is Sense Of Agency (SOA) [3]; SOA is the sense that one is the subject who causes the result that appears, and that one intentionally controls that result. In recent years, the importance of SOA has been widely recognized in the field of human-computer interaction [4].

For instance, in the field of VR (Virtual Reality), how one perceives SOA for one's own avatar in a VR space has been intensively studied [5]. Avatars are considered to be one form of user representation, as mentioned above. In indirect manipulation in in-car device operation, the feeling of SOA in the movements of a cursor or pointer displayed in the output space is an essential requirement for improving the feeling of direct manipulation.

There are two main types of SOA measurements: explicit and implicit measurements [3][6]. The most common method of explicit measurement is to directly and subjectively rate the degree to which participants perceive SOA. This method is widely used in many SOA studies because it is easy to implement, and its usefulness has been confirmed. On the other hand, it is pointed out that such subjective ratings are prone to many cognitive biases, and its limitations have been discussed [7].

C. Intentional Binding

In contrast, implicit measurement measures SOA using behavioral indicators that are not directly related to the subjective sense of SOA. The most widely used method is the one using Intentional Binding [8][9], a phenomenon in which the time interval between intentional action and the sensory stimulus caused by the action, which is fed back after a certain time is perceived as short. It has been widely confirmed that SOA is related to Intentional Binding, and a method of measuring

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Intentional Binding using a temporal sensory evaluation device called the Libet clock has been established and widely used in SOA research.

On the other hand, measurements using the Libet clock requires high visual attention to the clock displayed on the screen. Therefore, there are significant limitations to its use, such as interference with the context of the main task and heavy measurement loads on participants. In recent years, new methods for measuring Intentional Binding have been developed.

Early experiments on Intentional Binding used button pressing as an intentional action and audio feedback as the result of that action. In recent years, various intentional actions have been taken, such as input by finger movement in a hollow space without a physical input device [10], and experiments using auditory and tactile stimuli have also been conducted for feedback [11][12]. Thus, examining the circumstances under which Intentional Binding occurs is important in SOA research.

D. The present study

As mentioned above, in-car devices have become increasingly digitalized in recent years, and indirect manipulation has become mainstream. In this context, a major issue is ensuring the feeling of the direct manipulation of complex in-car devices. Intentional binding is a valuable indicator for evaluating the feeling of direct manipulation.

So far, Intentional Binding measurement has been examined using simple action-feedback pairs. However, when attempting to apply this method to the development of devices for in-car systems, it is necessary to measure Intentional Binding in situations in which a series of sequential operations is engaged. Therefore, in this study, we measure Intentional Binding when engaging in such a task. We then answered the following two research questions.

- Research Question 1:
  Is Intentional Binding confirmed for each of direct manipulation and indirect manipulation?
- Research Question 2:
  Is there a difference in the degree of Intentional Binding between direct and indirect manipulations?

Section 2 introduces the summary of the experiment, and the measures of the results. Section 3 indicates the experimental results. Section 4 summarizes the discussion and conclusions.

II. Experiment

A. Participants

Sixteen participants, recruited from the general public, participated in the experiment (8 males, 8 females, age: M=46.69, SD = 16.62). All the participants were right-handed.

B. Task

Figure 1 shows a screenshot of the task in which the participants engaged. Participants were asked to trace the numbers from 1 to 3 displayed on the tablet in sequence, and finally, to tap the last number 3. Upon tapping the number 3, a beep sound was fed back approximately 250 ms later. The Libet clock was displayed so that they reported the timing of tapping and hearing the beep sound.

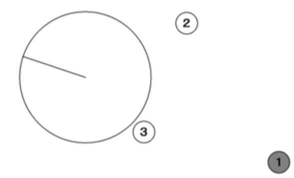

Figure 1. Screenshot of the task.

C. Experimental Design

The experimental design was a three-factors (Direct-Indirect × Action-Outcome × Baseline-Operant) within-participant factorial design.

1) Direct-Indirect Factor: In the Direct condition, participants directly manipulated the tablet (Figure 2 (a)). In the Indirect condition, participants indirectly manipulated the target tablet by tracing another tablet placed underneath the target tablet (Figure 2 (b)). In the Indirect condition, participants could not see their own hands as they manipulated.

(a) Direct condition (b) Indirect condition

Figure 2. Direct and Indirect conditions of experiment.

The same tablet was used as the input and display devices in the Indirect condition, and the input from the input device was output to the display device for presentation. Therefore, the hardware performance under both conditions was identical, including the time lag between the finger movements reflected in the pointer displayed on the display tablet.

Figure 3 illustrates the settings controlled by the Action-Outcome factor and the Baseline-Operant factor.

2) Action-Outcome Factor: In the Action conditions, the participant's perceived timing when the last 3 number was tapped was measured using the Libet clock, while in the Outcome conditions, the participant's perceived timing when the beep sounded was measured.

3) Baseline-Operant Factor: In the Baseline conditions, no beep sounded in response to the participant's action; or a beep sounded without the participant's action. In the Operant conditions, a beep sounded approximately 250 ms seconds after the participant's action.

D. Procedure

The participants were informed about the overview of the experiment, followed by a practice phase. They then moved on to the main phase, which consisted of twelve trials for each condition.

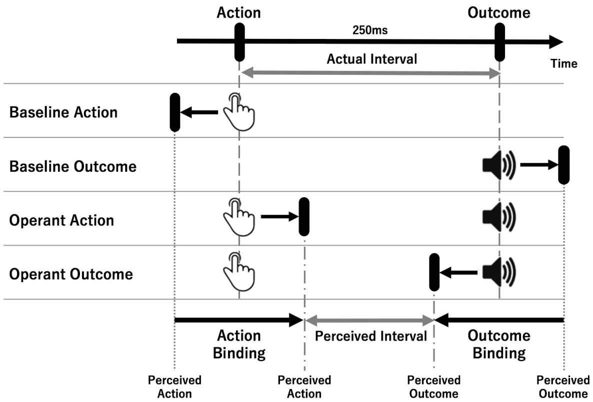

Figure 3. Action Binding, Outcome Binding, and total binding.

Half of the participants engaged in the task in the Direct condition followed by the Indirect condition; the other half engaged in the task in the Indirect condition followed by the Direct condition.

For each of the direct and indirect condition blocks, the Action-Outcome factor and the Baseline-Operant factor were counterbalanced using the Latin square method.

E. SOA

For SOA measurement, participants answered the following two questions after 12 trials under the following conditions [13][14].

1) SOA for control: In the conditions in which the action operation is performed, specifically the Baseline × Action, Operant × Action, and Operant × Outcome conditions, participants were asked, "How much did you feel you had control over your pointing?" and responded on a seven-point scale ranging from not at all to very strongly.

2) SOA for causality: In the conditions in which sound feedback on the action was given, specifically the Operant × Action and Operant × Outcome conditions, participants responded on a seven-point scale to the question, "How much did you feel that your button press caused the sound to beep?"

F. Action, Outcome, and Total Binding

Three types of binding are defined, as shown in Figure 3.

Generally, the perception of the timing of an action is delayed in a situation where there is feedback (Operant × Action condition), as opposed to a situation where there is no feedback (Baseline × Action condition). This delay is called action binding.

Similarly, the perception of the timing of the sound is brought forward when an action is performed (Operant × Outcome condition), as opposed to a situation in which there is no action (Baseline × Outcome condition). The time carried forward is called outcome binding.

The total of the action binding and the outcome binding is the total binding.

III. Result

A. Performance

Figure 4 (a) shows the completion time, that is, the duration from the start of the task through the time that the final number 3 was tapped. Figure 4 (b) shows the distance traveled by the cursor on the tablet.

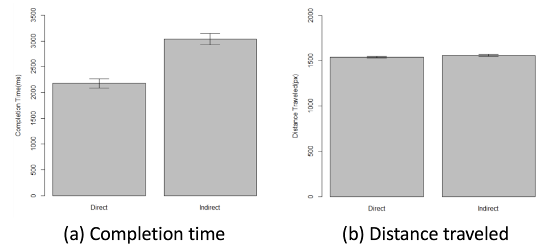

Figure 4. Completion time and distance traveled.

The completion time in the Direct condition was significantly shorter than that in the Indirect condition ($t(15)$ = 12.78, p = .001), and the distance traveled in the Direct condition was marginally significantly smaller than that in the Indirect condition ($t(15)$ = 1.82, p = .09).

B. SOA

Figure 5 (a) shows SOA for control and Figure 5 (b) shows SOA for causality.

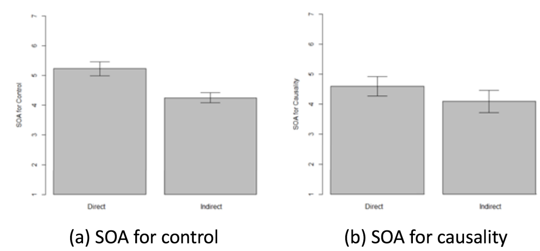

Figure 5. SOA for control and SOA for causality.

The SOA for control in the Direct condition was significantly larger than in the Indirect condition ($t(15)$ = 2.63, p = .002), but the SOA for causality shows no significant difference between the Direct and Indirect conditions ($t(15)$ = 0.28, n.s.)

C. Binding

Figure 6 (a) shows the action, outcome, and total bindings in the Direct condition, while Figure 6 (b) shows the three bindings in the Indirect condition.

The expected effects in all three bindings were confirmed under both the Direct and Indirect conditions.

D. Comparison of Binding

Figure 7 (a) shows a comparison of the action bindings in the Direct and Indirect conditions, Figure 7 (b) shows a comparison of the outcome bindings, and Figure 7 (c) shows a comparison of the total bindings.

No significant differences were detected between the Direct and Indirect conditions in action binding, outcome binding, or total binding ($t(15)$ = 0.21, n.s. for action binding, $t(15)$ = 0.20, n.s. for outcome binding, $t(15)$ = 0.15, n.s. for total binding).

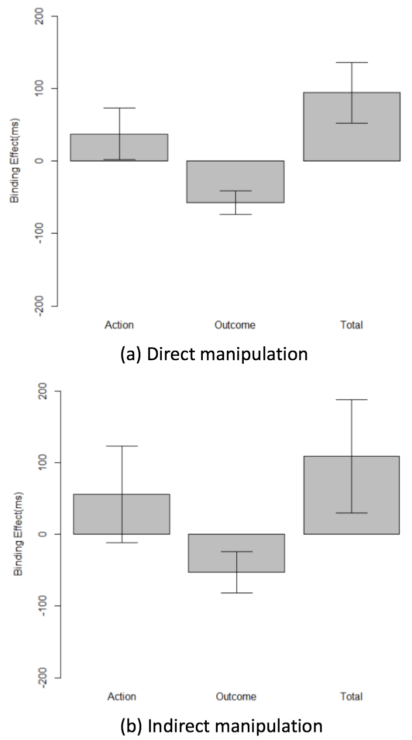

Figure 6. Action, outcome, and total bindings

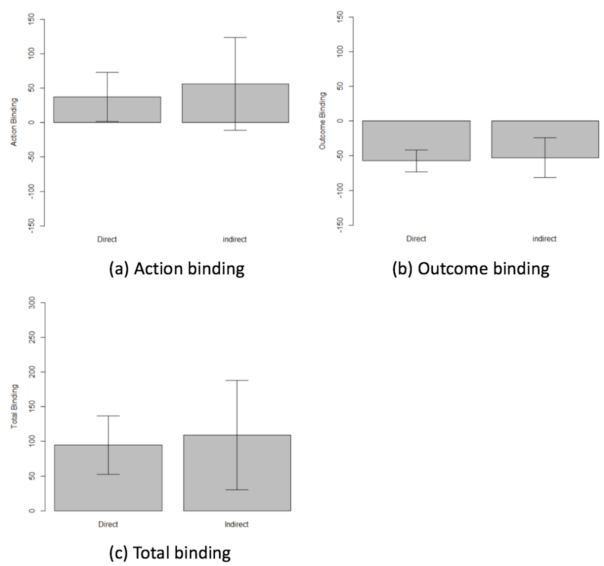

Figure 7. Comparison of action, outcome, and total bindings in the Direct and Indirect conditions.

IV. Discussion and Conclusions

Intentional binding was measured by using a serial manipulation task. Two situations were set up: one in which the tablet was manipulated directly and the other in which the tablet was manipulated indirectly, using another input device. Direct manipulation showed a higher manipulation performance than indirect manipulation.

The experiment results show that expected binding was detected for both direct and indirect manipulation situations. However, there was no difference in the magnitude of the bindings between the two situations.

Regarding the subjective evaluation of SOA, direct manipulation exceeded indirect manipulation in terms of the evaluation of the sense of control. However, there was no difference in causal perception between the two situations. This suggests that the magnitude of bindings may be related to causal perception rather than the perception of the sense of control. We investigate this point using an experimental paradigm that allows us to control for causal perception, such as delaying the feedback of the action [15][16].

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