Title: Discrepancy between explicit judgement of agency and implicit feeling of agency: implications for sense of agency and its disorders

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Abstract

The sense of agency refers to the feeling of authorship that “I am the one who is controlling external events through my own action”. A distinction between explicit judgement of agency and implicit feeling of agency has been proposed theoretically. However, there has not been sufficient experimental evidence to support this distinction. We have assessed separate explicit and implicit agency measures in the same population and investigated their relationships. Intentional binding task was employed as an implicit measure and self-other attribution task as an explicit measure, which are known to reflect clinical symptoms of disorders in the sense of agency. The results of the implicit measure and explicit measure were not correlated, suggesting dissociation of the explicit judgement of agency and the implicit feeling of agency.

Key words

sense of agency; voluntary action; feeling of agency; judgement of agency; central monitoring; intentional binding

1. Introduction

The sense of agency refers to the feeling of authorship that “I am the one who is controlling external events through my own action”. This sense is a central component of self-awareness (Gallagher, 2000), and its underlying neural mechanisms have been reported (David, Newen, & Vogeley, 2008). Symptoms of psychiatric and neurological diseases can be explained as a disruption of the sense of agency; examples of such are schizophrenia, conversion disorder, anarchic hand syndrome, and anosognosia for one’s own hemiparesis (Kranick et al., 2013; Synofzik, Vosgerau, & Newen, 2008b). For example, delusion of control in schizophrenia is a passivity experience that “My action is being controlled by others”, which is an alteration in the sense of agency. These symptoms teach us that the sense of agency, a fallible process (Blakemore, Wolpert, & Frith, 2002), requires reliable and objective clinical indicators. Measures of agency have been invented and assessed to give a fundamental understanding of self-awareness (Haggard, Clark, & Kalogeras, 2002; Nielsen, 1963). At the same time, these measures have served as objective indicators to assess the subjective symptoms of the diseases (Daprati et al., 1997; Franck et al., 2001; Haggard, Martin, Taylor-Clarke, Jeannerod, &

Franck, 2003; Kranick et al., 2013; Maeda et al., 2013; Wolpe et al., 2014).

There have been two distinct ways in measuring the sense of agency — explicit and implicit. Explicit measures address the sense of agency by obtaining a direct report of how they attribute the effect of their action. In a pioneering experiment, participants were asked to draw a line on a piece of paper, and at the same time the experimenter gave manual visual feedback that was in concordance with or in discordance with their actual movements (Nielsen, 1963). This paradigm has been modified in various works to test the participant's ability to distinguish the actions they have performed and the actions performed by others (Daprati et al., 1997; Farrer et al., 2008; Franck et al., 2001; Maeda et al., 2012). In the study by Franck and colleagues (Franck et al., 2001), participants were given visual feedback of a voluntary action as a virtual hand, which moved in concordance with or in discordance with their movements. They were asked later on if the feedback corresponded with their actual movement or not. Patients with delusion of control in schizophrenia gave more "yes" answers to this question than normal participants did, indicating a correlation of clinical passivity experiences with the experimental attribution of actions.

However, it has been pointed out that explicit measures of agency can be subject to response bias (Wegner, 2003), and the need for indirect markers of agency has been discussed. The "intentional binding" effect focusing on temporal attraction between the perceived time of actions and their effects is a widely used quantitative method (Ebert & Wegner, 2010). Participants perform a volitional button press at the timing of their own choosing. They judge the timing of their volitional button press on the basis of Libet's clock method (Libet, Gleason, Wright, & Pearl, 1983). The button press will be followed by an auditory tone 250ms later. This is considered the effect of the action. They also judge the timing of the tone. A compression of timing judgments in action and its effect (the "intentional binding" effect) is known in the case of volitional actions but not in the case of non-volitional actions, and thus this method has been regarded as an implicit way to measure the sense of agency (Ebert & Wegner, 2010). The intentional binding effect has also been observed to change in accordance with the passivity experiences in diseases (Haggard et al., 2003; Kranick et al., 2013; Wolpe et al., 2014), which can serve as a quantitative indicator.

So far, a two-step distinction in the formation of implicit and explicit sense agency has been proposed (Synofzik, Vosgerau, & Newen, 2008a; Synofzik, Vosgerau, & Voss, 2013), complementary to the central monitoring theory (i.e. “comparator model”) (C. D. Frith, Blakemore, & Wolpert, 2000). In the central monitoring theory, the sensory consequence of our action is predicted based on internal signals such as efference copy of the motor command. Comparison of the prediction with sensory afference will enable us to distinguish self-produced sensory information from externally caused events. Congruency of the predicted with sensory afference will lead to an interpretation that the action has been caused by our self, while incongruency will lead to an interpretation that the action has been caused externally. The sense of agency is explained in the final stage of action execution by a single mechanism in this framework. Recent studies pointed out that the sense of agency is not only based on internal signals but also modulated by various context cues (Moore & Haggard, 2008; Moore, Wegner, & Haggard, 2009; Takahata et al., 2012; Voss et al., 2010; Wegner, 2003). These observations have led to arguments that the sense of agency holds a more complex structure, with multiple levels involving different processes (Fletcher & Frith, 2009; C. Frith, 2012; Moore & Fletcher, 2012; Synofzik et al., 2008a; Synofzik et al., 2013). The presence of problematic cases of the central monitoring theory in explaining the sense of agency both in healthy subjects and in patients with passivity experiences has also been pointed out (Synofzik et al., 2008a). Accordingly, a two-step distinction is proposed between the level of the “feeling of agency” and the “judgement of agency” (Synofzik et al., 2008a). The first-level feeling of agency is the non-conceptual, low-level feeling of being an agent. It refers to the implicit aspect of agency, which is closely related to action regulation or perceptual processing. The second-level judgement of agency is the conceptual, interpretative judgement of being an agent of an action. It refers to the explicit judgement of self-other attribution, which is closely related to background beliefs or context cues (Synofzik et al., 2008a). However, few experimental studies have approached the relationship between these two aspects of the sense of agency (Barlas & Obhi, 2014; Dewey & Knoblich, 2014; Ebert & Wegner, 2010; Moore, Middleton, Haggard, & Fletcher, 2012).

Recently, some efforts have been made to investigate both explicit and implicit measures of agency in a single task (Ebert & Wegner, 2010). However, the majority of previous experimental studies of psychiatric and neurological diseases assessed either explicit or implicit measures of agency (David et al., 2008), and they reported mixed results (e.g. exaggerated or decreased sense of agency in schizophrenia) (Voss et al

2010, Maeda et al 2013). Comparison of the traditional tasks that have frequently been used for clinical cases will facilitate the interpretation of the results of clinical studies from the perspective of the structures of the tasks. Thus, we separately assessed both explicit and implicit agency measures in the same population and investigated their relationships.

2. Materials and Methods

2.1. Participants

Twenty-five subjects (thirteen female, mean age = 64.9 years, SD = 2.9 years) participated in the study. Participants with known neurological or psychiatric history were excluded from the study. All the participants were right-handed according to the Edinburg Inventory (Oldfield, 1971). Participants underwent two experiments. The implicit task was conducted first and the explicit task next, in order to keep the participants naïve to the study purpose. Written informed consent was obtained from each participant. Participants were paid for their participation. This study was approved by the ethics committee of Kyoto University Graduate School and Faculty of Medicine.

2.2. Procedures and analysis

2.2.1. Experiment 1- Implicit task

2.2.1.1. Procedures

The sequence of events from a previous study (Haggard et al., 2002), known as intentional binding task, was employed. The task consisted of four conditions: (1) agency action, (2) agency tone, (3) baseline action and (4) baseline tone. In each condition, a blank screen was first presented, followed by a picture of a clock face and clock hand. The clock-hand was 12 mm long, which rotated clockwise for a full rotation in 2560 ms. The clock face was marked with 12 conventional interval positions (5,10,15, etc.). Initial positions of the clock-hand were chosen randomly from the 12 positions of the clock. The clock-hand remained stationary at the initial position for 500 ms, and then began to rotate. Procedures during the clock-hand rotation were as follows. In the agency action and agency tone conditions, participants performed a voluntary action. Participants performed a key press at a time of their own choosing during the clock-hand rotation. They were instructed to avoid responding at a pre-decided clock position, or during the first half-rotation of the clock hand. Each key press triggered a tone after a fixed period of 250 ms. In the agency action condition, participants were asked to report the perceived onset time of their voluntary key press as judged by the perceived position of the clock hand. Similarly in the agency tone condition, participants were asked to report the perceived onset time of the triggered tone. In the baseline action condition, participants performed a voluntary key press at the time of their own choosing, but it did not yield a tone. Participants reported the perceived onset time of the voluntary key press. In the baseline tone condition, participants did not press a key but instead waited for a tone to be delivered, judging the onset time at which they heard the tone. Before running the experiment, participants performed a practice session. Each category of conditions was tested in separate blocks, in pseudo-randomized order consisting of 24 trials. Missed trials were repeated. After completing the task with one hand, participants conducted the task with the other hand. The order of right and left hand was counterbalanced across participants. All stimuli were displayed using Superlab 4.5 software.

2.2.1.2. Data analysis

For the implicit task (experiment 1), the perceived time of action or tone in each trial was compared with the actual onset time, and a mean temporal estimation was calculated for each block. The mean estimation for actions and tones in the baseline condition was subtracted from that in the agency condition. Subtracting these baseline estimates allowed us to calculate the shift in the perceived time of the tone when caused by the action. These shifts served as measures of action binding and tone binding, respectively. These subtracted measures correspond to the perceived linkage between action and effect, and larger values indicate stronger perceived linkage. Finally, overall binding was defined as action binding minus tone binding. The bindings of the two hands were compared by paired t-tests.

2.2.2. Experiment 2- Explicit task

2.2.2.1. Procedures

A simplified task from a previous study (Franck *et al.*, 2001) was employed. Participants were asked to hold a joystick that was connected to a computer. A black cover covered the joystick so that the participants could not see their actual movement. Instead, an image of an electronically constructed virtual hand was presented to the participants on a computer screen as a feedback during the procedure. Participants were instructed that "their hand" would appear on the computer screen. A specially designed program synthesized images of a virtual hand holding a joystick and the virtual hand moved according to the position that was actually held by the participants. The movement of the joystick was presented dynamically on the screen with an intrinsic delay of 16ms.

In each trial, an image of a virtual hand was presented for 10 seconds after a blank screen, during which time participants were asked to move the joystick according to their own choosing. The movement could be executed in four directions (right, left, back, and forth). Immediately after the virtual hand disappeared, participants were asked a yes-or-no question as follows: "Did the movement you saw on the screen correspond to the movement you made with your hand?"

The task consisted of three categories of conditions: (1) neutral, (2) with angular biases, and (3) with temporal biases. In the neutral condition, the virtual hand moved exactly according to the movements the participants made with the joystick. In the angular biases condition, a given angular value (5°, 10°, 15°, and 20°) was introduced as a gap between the movements of the virtual hand and the joystick. In the temporal biases condition, a given time delay (50, 100, 150, 200, 300, 400, and 500 ms) was introduced as a gap between the movements of the virtual hand and the joystick.

Trials with angular biases and trials with temporal biases were run four times for each type of gap. Neutral trials were run 12 times. The order of presentation of all trials was randomized for each subject. Before running the experiment, participants performed a practice session. Missed trials were repeated. After completing the task with one hand, participants conducted the task with the other hand. The order of right and left hand was counterbalanced across participants.

2.2.2.2. Data analysis

For the explicit task (experiment 2), there could potentially be two types of errors: "yes" responses for trials with a bias, and "no" responses for neutral trials. For data analysis, "yes" responses were focused upon, reflecting the participants' ability to recognize the movement as their own. "Yes" responses of the two hands were examined by repeated measures ANOVA with event (each bias) and hand (right versus left), for angular and temporal gaps separately. The data were converted into a 0-1 estimate (0 for "no" and 1 for "yes" responses), to fit into a logistic regression model of Y=1/(1 + exp(-(a+bX))). The slope coefficient (b) was calculated for each subject, as these slopes provide estimates about how strictly a subject would draw an explicit judgement of agency. The 50% threshold (-a/b) for the total data was also calculated.

Lastly, correlations between the results of the implicit task and the explicit task were explored by Spearman's rank correlation analysis. A *p*-value of less than 0.05 was considered significant in all analyses.

3. Results

3.1. Implicit task

The perceived time of actions of the baseline condition was -176.5 (SD: 106.8) ms in the right-hand trials, and -187.0 (SD: 96.0) ms in the left-hand trials. The perceived time of tones in the baseline condition was -50.6 (SD: 61.5) ms. There was a positive shift in the perceived time of actions in the agency condition compared to the baseline condition (action binding) [right: 64.2 (SD: 119.4) ms, p=0.013; left: 78.3 (SD: 117.7) ms, p=0.003]. At the same time, there was a negative shift in the perceived time of tones in the agency condition compared to baseline condition (tone binding) [right: -113.1 (SD: 155.5) ms, p=0.001; left: -114.5 (SD: 171.3) ms, p=0.003]. These results indicate that actions were perceived later when they were followed by tones, and tones produced by voluntary actions were perceived earlier than baseline tones. Overall binding was calculated as action binding minus tone binding [right: 177.3 (SD: 218.3) ms; left: 192.8 (SD: 214.1) ms].

Action binding, tone binding and overall binding between the right and left hand were highly correlated [action binding: r=0.877, p=0.000; tone binding: r=0.902, p=0.000; overall binding: r=0.908, p=0.000], and did not show significant difference in paired t-tests [action: $t(24)$=1.195, p=0.244; tone: $t(24)$=0.093, p=0.927; overall: $t(24)$=0.762, p=0.453] (Figure 1). The averaged data of the right and left hand for each participant were focused in the following correlation analyses. The averaged action binding was 71.2 (SD = 114.9) ms, tone binding was -113.8 (SD = 159.3) ms, and overall binding was 185.1 (SD = 224.4) ms.

3.2. Explicit task

Repeated measures ANOVA with angular bias (0°, 5°, 10°, 15°, and 20°) and hand (right and left) revealed a main effect of angular bias (F(2.9,70.8)=72,17, p=0.000), no angular bias × hand interaction (F(1.7,41.9)=1.47, p=0.24), and no main effect of hand (F(1,24)=1.37, p=0.25). Similarly, repeated measures ANOVA with temporal bias (0, 50, 100, 150, 200, 300, 400, and 500 ms) and hand (right and left) revealed a main effect of temporal bias (F(3.2,76.8)=92.60, p=0.000), no temporal bias × hand interaction (F(4.3,103.0)=1.19, p=0.319), and no main effect of hand (F(1,24)=1.34, p=0.259). These results indicate that the participants' attribution of the movement was affected by angular biases and by temporal biases, but not by their handedness (Figure 2).

Next, the data as a 0-1 estimate (0 for "no" and 1 for "yes" responses) were fit into a logistic regression model of Y=1/(1 + exp(-(a+bX))). The data of the right and left hand were included together in the following analysis. The slope coefficient (b) was calculated for each subject. The average slope coefficient (b) for each participant was -1.10 (SD = 1.75) for angular biases condition, and -0.022 (SD = 0.014) for temporal biases condition. The 50% threshold (-a/b) for the total data was revealed to be 9.5° for the angular biases condition and 170.9 ms for the temporal biases condition. For this reason, "yes" responses in the 5° and 10° for the angular biases, and 150ms and 200ms for the temporal biases were focused upon in the following correlation analyses. The average percentage of "yes" responses was 75.5% (SD = 27.4) for 5° angular bias, 46.0% (SD = 35.1) for 10° angular bias, 52.0% (SD = 35.8) for 150ms temporal bias, and 38.0% (SD = 31.3) for 200ms temporal bias.

3.3. Relationship between implicit and explicit task

The measures in the implicit task (action binding, tone binding and overall binding) were compared with each of the slope coefficients (b) in the explicit task. Then the measures in the implicit task were also compared with the numbers of "yes" responses around the 50% threshold in the explicit task. There was no significant correlation between bindings in the implicit task and the measures in the explicit task (Table 1).

4. Discussion

In this study we have assessed two distinct methods of measuring the sense of agency and investigated their relationships. We employed methods that are widely recognized as being in accordance with clinical symptoms of the disorders in the sense of agency: "intentional binding" task as an implicit measure and self-other attribution task as an explicit measure. We found a discrepancy between implicit intentional binding and explicit self-other attribution.

In the intentional binding task (experiment 1), participants experienced actions as shifted towards their subsequent effects, while effects were perceived as shifted towards the preceding action. This was compatible with previous findings and can be regarded as a bias to intensify the causal relationship between action and its consequence (Haggard et al., 2002). In the explicit self-other attribution task (experiment 2), participants gave most attribution of the feedback to themselves when the movement had not deviated from their actual movement, and this tendency decreased as the angular bias and temporal bias became more obvious. At the same time, this means that the distorted sensory feedbacks could be attributed to their own movement even in cases of certain discrepancies, with continuous recalibration. This observation does not strictly fit the central monitoring theory in terms of recognizing self as a match and non-self as a mismatch. Additionally, individual differences in these implicit and explicit measures did not correlate, suggesting that these two aspects in the sense of agency do not consist of a single process.

Theoretical works have proposed a distinction between implicit and explicit sense of agency processing systems, owing to the presence of problematic cases of the central monitoring theory in explaining the sense of agency both in healthy subjects and in patients with disorders of the sense of agency (Synofzik et al., 2008a; Synofzik et al., 2013). It has been argued that not of all the predicted sensory signals generated from our own movements will reach awareness (Castiello, Paulignan, & Jeannerod, 1991; Fourneret & Jeannerod, 1998), and thus small discrepancies do not necessarily influence the sense of agency. The importance of emotional valence (Takahata et al., 2012) and beliefs as external contextual cues have also been emphasized (Synofzik et al., 2013). Other studies have shown that central monitoring in patients with schizophrenia is unimpaired when making predictions for the sensorimotor adjustments for grip force (Delevoye-Turrell, Giersch, & Danion, 2002), or when adjusting hand movements in case of discrepancies between their own hand movements and visual consequences (Fourneret, Franck, Slachevsky, & Jeannerod, 2001; Knoblich, Stottmeister, & Kircher, 2004). However, these findings do not deny the importance of sensorimotor prediction and the sensory feedback in the formation of the sense of agency. Recent theories have proposed an integration of various cues in two forms of agency, as an extension of the central monitoring theory (Moore & Fletcher, 2012; Synofzik et al., 2013). Although presented theoretically, only a few experiments have been conducted to support the distinction of implicit and explicit sense of agency (Barlas & Obhi, 2014; Dewey & Knoblich, 2014; Ebert & Wegner, 2010; Moore et al., 2012).

This issue was approached in a single experiment by assessing the effect of action-effect consistency on implicit agency and self-reported authorship (Ebert & Wegner, 2010). Action-effect consistency was defined according to whether the object on the screen moved in the same, or in the opposite direction as the action. Implicit agency was measured on a 10-point scale as interval estimates of how much time has passed from the participants' own movement to the intended movement on the screen. Explicit agency was measured on a 7-point scale in terms of how much the participants felt that their movement made the object on the screen move. It has been shown that action-effect consistency affected explicit self-reported authorship more than implicit interval estimates. Additionally, implicit interval estimates and explicit authorship were correlated when asked in the same block, while they did not correlate when asked in separate blocks. This points out the problems of arbitral linkage of the interval estimates on self-reports when asked simultaneously. A study explored the association of intentional binding and explicit prediction using a dissociation paradigm of implicit and explicit learning (Moore et al., 2012). In their experiment, outcomes were probabilistically caused by actions. Participants conducted the intentional binding task, and at the same time they judged the extent to which they believed there would be a tone in the next trial. The learning history of action binding showed a different pattern from that of the explicit prediction. These preceding experiments have approached the issue by introducing an explicit question into implicit agency measures. In our study we assessed the intentional binding task as implicit measure and self-other attribution task as explicit measure, and we compared the two measures when both were assessed as individual tasks. The possibility of the previous question affecting the later ones was avoided by assessing this in separate experiments. Our findings add the notion that the two systems are separable, in line with individual differences, fitting the theoretical framework as proposed by Synofzik et al. (2008a).

An alternative explanation that could be offered from our results is that this difference is due to the different structures of the two tasks. There are ongoing discussions on the backgrounds of both implicit and explicit measures. For example, there are studies suggesting that causation but not intentional action is the root of intentional binding (Buehner, 2012; Dogge, Schaap, Custers, Wegner, & Aarts, 2012). Also, the explicit task has been discussed in terms of contamination by an aspect of the sense of ownership of body movement instead of evaluating the sense of agency alone (Tsakiris, Longo, & Haggard, 2010). Owing to these limitations, there are possibilities that our results derive from different structural backgrounds including different validity as an agency task. At the same time, our results indicated that cautious interpretations would be needed to evaluate the sense of agency in clinical cases by single measure.

Another limitation of our study is that the intentional binding effect observed in our study was relatively large compared to the original study (Haggard et al., 2002). However, reported amounts of binding in healthy subjects are not constant among studies, and indeed there are works that report rather strong binding in healthy subjects (Kranick et al., 2013; Takahata et al., 2012). Possible causes of this difference can be the forms of button press as voluntary actions, or volumes and pitches of the tones as feedbacks of actions, which are not being controlled among studies. The result of the explicit task is also relatively different from the original study (Franck et al., 2001), under-attributed in angular condition and over-attributed in delay condition. Possible causes for this difference can also arise from the difference in experimental setups. Compared to Franck's original study, which used a horizontal mirror to present the visual feedback, we modified the apparatus and placed the computer screen directly in front of the participants. The intrinsic delay of the feedback, and the time span of the virtual image appearance are also different. Regardless of these differences, the essentials of the evaluations have been preserved.

In summary, by comparing the two distinct methods of measuring the sense of agency, we found supporting evidence for the dissociation of the explicit judgement of agency from the lower-level experience of the feeling of agency. We suggest that a distinction between these two aspects will be essential in evaluating the sense of agency in health and in diseases.

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Conflict of interest

The authors report no conflict of interest associated with this manuscript.

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Figure captions

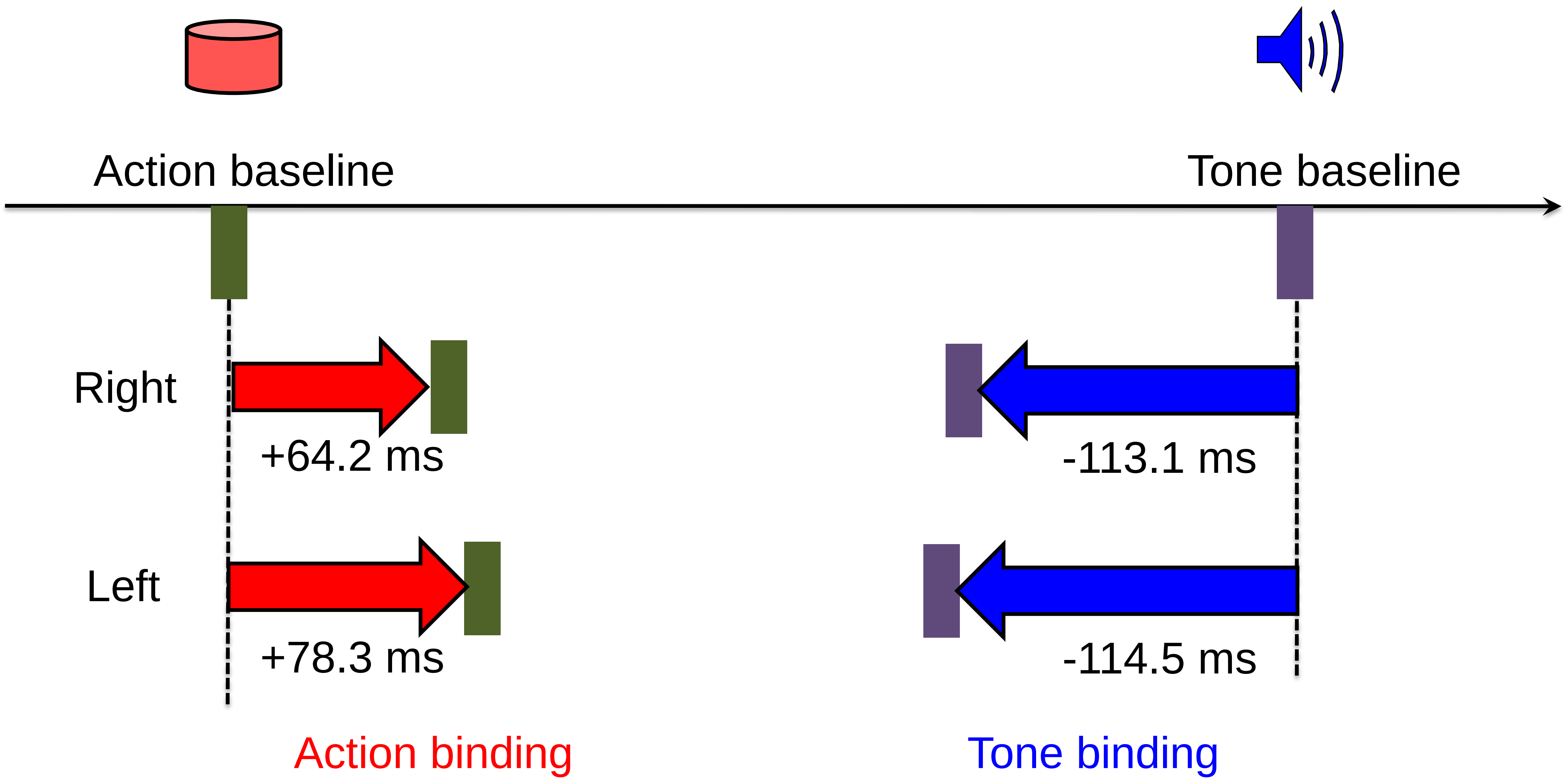
Figure 1

Perceived times of actions and tones in experiment 1. Actions were perceived as shifted toward their subsequent tones, while tones were perceived as shifted towards the preceding action that caused them.

Figure 2

Number of “Yes” responses when participants were asked whether movements on the screen corresponded to their own computer movements in experiment 2. (A) with angular bias, and (B) with temporal bias

Figure 1



Action baseline
Tone baseline
Right
+64.2 ms
-113.1 ms
Left
+78.3 ms
-114.5 ms
Action binding
Tone binding

Figure 2

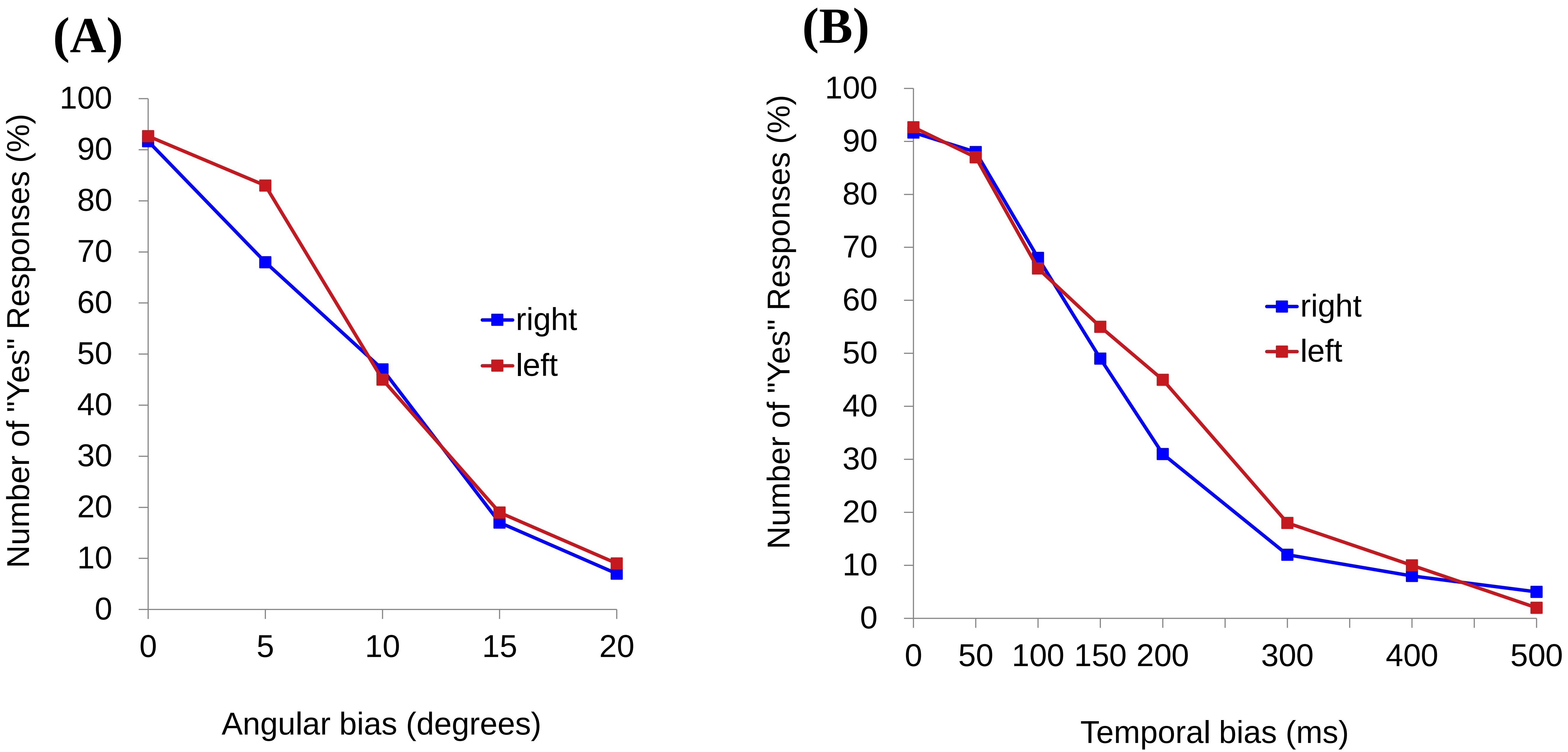

(A)
Number of "Yes" Responses (%)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
right
left
Angular bias (degrees)
(B)
Number of "Yes" Responses (%)
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
300
400
500
right
left
Temporal bias (ms)

Table 1

Correlations between scores of implicit task and explicit task

	Implicit task		
	Action binding	Tone binding	Overall binding
Explicit task			
Slope coefficient			
Angular biases	0.217	0.196	0.013
Temporal biases	0.064	-0.139	0.174
Number of yes responses			
5° angular bias	0.039	0.128	-0.089
10° angular bias	0.201	0.120	0.021
150ms temporal bias	-0.032	-0.315	0.181
200ms temporal bias	0.003	-0.281	0.200

Spearman rank correlations. None showed significant ($p < 0.05$) correlations.