

Hierarchical Control and Sense of Agency: Differential Effects of Control on Implicit and Explicit measures of Agency

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Abstract

While recent studies show dissociation between the implicit and explicit aspects of 'sense of agency', the mechanisms underlying these different aspects of agency are not yet clearly understood. We argue that the control achieved at different levels of hierarchy is important for different aspects of agency. In the current study, we investigate how changes in control at the perceptual-motor level and at goal level influence implicit and explicit measures of sense of agency. In a given trial, participants were first required to aim at a target in a noisy environment and then shoot at the target. After certain interval, a circle flashed at the location where participant aimed while pressing the trigger. Participants estimated the interval between action and presentation of the circle that acted as a measure of intentional binding, an implicit measure of agency and also rated an explicit sense of authorship. The results suggest that different aspects of agency and dissociation between implicit and explicit aspects of agency are mediated by control achieved at various levels.

Keywords: Sense of agency; event-control approach; intentional binding; control; hierarchical system; interval estimation.

Introduction

With every action that we perform, we not only influence our environment but also modify our conscious mental state of being the agent of the action. This feeling is known as sense of agency (Pacherie, 2011). While elusive, this sense of agency (SoA) is central to our conscious experience and has recently gained popularity among philosophers as well as scientists (see Gallagher, 2006, for a review and insight on related issues).

Sense of agency is a complex, multifaceted, phenomenon (Pacherie, 2011). In general two aspects of SoA have been emphasized and studied in detail. Firstly, sense of Agency as first order experience, in which agency is generally linked to the intentional aspect of task. Here an action is considered to be self-generated when the effect of an action matches the intention of the participant (Moore, Lagando, Deal, & Haggard, 2009; Farrer & Frith, 2002), or when agency is linked to bodily movement as in the famous rubber hand illusion (Farrer, Frank, Georgieff, Frith, Decety, & Jeannerod, 2003). This aspect of agency is also called pre-reflective or implicit sense of agency. Secondly, sense of agency as reflective attribution (or sense of

authorship), in which participant is asked to report his/her subjective sense of belief in causing an action (Ebert & Wegner, 2010; Haggard & Moore, 2010). Recent models of 'self' (Synofzik, Vosgerau, & Newen, 2008) take into account these two aspects of agency.

An important measure of agency that has gained prominence in the last decade is intentional binding. Intentional binding refers to the finding that participants perceive the self-generated action and its effect to be temporally closer to each other (Haggard, Clark, & Kalogeras, 2002b). The concept of intentional binding has been linked in the literature strongly to the sense of agency, that is, the experience of agency is greater when intentional binding is stronger. A recent review (Moore & Obhi, 2012) suggests that intentional binding has been associated with implicit measures of agency like efference, sensory feedback, causal feedback, and intentionality. Haggard and Clark (2003) have suggested that when motor cortex is stimulated to produce a movement similar to a voluntary movement, intentional binding is not affected, suggesting that intentional binding does not depend on the sensory signals produced during movement, but rather it depends on the efference copy generated during action planning.

Desantis and colleagues (Desantis, Cedric, & Waszack, 2011) showed that, when participant believes that he/she has control over the environment, intentional binding is stronger. In the original study showing intentional binding, (Haggard, Clark, & Kalogeras, 2002b) the outcome of a participant generated action was manipulated in terms of intention (intended or unintended). Results indicate that intentional binding is stronger for the intended effect compared to the unintended effect. These and many more studies indicate a strong link between the implicit measures of agency and intentional binding, suggesting that intentional binding can be used as a reliable measure of implicit sense of agency.

In addition, researchers have investigated the relationship between intentional binding and explicit sense of agency or reflective sense of agency (Moore & Obhi, 2012). In one such study (Ebert & Wegner, 2010), participants were presented with a picture, which can either move congruent or incongruent to the direction participant moved the joystick. The delay between the participant's movement of the joystick and the movement of the object on the screen

was manipulated at three levels (100ms, 400ms, and 700ms). At the end of the trial participants were asked to perform a interval estimation task (to measure intentional binding) and give rating of authorship (explicit measure of agency). Authors reported dissociation between the two measures, with the congruency between action and effect, having a greater effect on intentional binding compared to the explicit measure of sense of authorship. The mechanisms underlying these two different measures and aspects of SoA are still not fully understood necessitating a study to understand the mechanisms involved in SoA. The current study investigates the mechanisms involved in determining the implicit and explicit measures of sense of agency and the way in which these two measures might be related to each other.

We argue that the concept of control exercised by the participant over perception-action events can provide us a basic framework to understand both explicit and implicit sense of agency. Recent studies have shown that control might play a crucial role in influencing sense of agency (Desantis, Cedric, & Waszack, 2011; Moore, Lagando, Deal, & Haggard, 2009; Jordan, 2003; Kumar & Srinivasan, 2012; Kumar & Srinivasan, under review). Studies based on event-control approach (Jordan, 2003; Kumar & Srinivasan, 2012) suggest that all our interactions with the environment (which are in form of perceptual-action couplings) are constrained by multiple hierarchical control loops extending across organism and his environment (see Jordan, 2003 for details). Sense of agency, according to this framework is determined by the highest level of control loop at which participant is able to exercise control.

We used a modification of the paradigm used by Ebert and Wegner (Ebert & Wegner, 2010). In the current experiment, the participant had to aim and shoot at a noisy target with the help of joystick and the noise in the environment was manipulated. By changing the amount of noise, we manipulated the perceptual-motor control that the participant can exercise. After the first task, the scenario was made static and a circle flashed at the location where subject aimed during the first task. The duration interval between the time when subject presses the trigger and when the circle is flashed was manipulated. Participant is later asked to estimate this interval and give a confidence rating for authorship of action. Estimated interval acted as a measure of intentional binding and confidence rating measured participant's subjective sense of authorship.

According to the event-control approach, sense of self depends upon the highest level at which control is exercised. In the current paradigm, control can be exercised at two levels; firstly, at the perceptual-motor level, that is the joystick level control and secondly, at the goal level, that is, whether or not participant is able to correctly aim at the target. We hypothesized that when participant misses the target, sense of agency would increase as a function of perceptual-motor control. When the participant hits the target, SoA would be independent of perceptual-motor control.

Method

Participants

Thirteen volunteers from University of Allahabad participated in the Experiment.

Stimuli and Apparatus

Stimuli consisted of eleven natural scenes (resolution 3648x2736) from a custom database. Every scene contained a target region in the form of three concentric circles, placed randomly somewhere in the scene. Experiment was conducted on a 14" monitor at a resolution of 800 x 600, with input from keyboard and joystick. The experiment was designed using MATLAB 2010b and psychophysics toolbox 3.

Procedure

Participants were instructed that the experiment consists of two phases, practice phase and the main experiment. They were also told that they have to perform time interval estimation and were instructed about what millisecond stands for and an approximate idea of the concept (see Ebert and Wegner, 2010 for more details).

Practice Session

In the practice session, a fixation cross was presented on the screen. Participants were instructed that they have to press a trigger to initiate trial and they can press the trigger when they feel like. After the trigger was pressed, the fixation cross on the screen turned blue in color indicating that the trigger has been pressed. After a random interval (out of 0ms, 100ms, 200ms, ..., 900ms), a blue circle was flashed on screen. Participants were asked to estimate the time interval between trigger press and the circle flashing on the screen. Response was made using a ten point scale (0, 100, 200, ..., 900). At the end of every trial, participant was given feedback about his/her estimate. The practice session served two purposes. Firstly, it helped improve interval estimation ability and also its assessment. Secondly, it made participants believe that the interval is manipulated at ten levels in the main session too. A total number of 200 practice trials were given with 20 trials for each of the ten intervals. Data from the practice session was used to perform preliminary analysis.

Main Session

In the main session, for a particular trial, participants were instructed that they have to aim at a target, by moving the joystick and press the trigger, within 15 seconds. To manipulate the amount of control, a random movement was added to the scene. To decrease the amount of control that participant can exercise, amount of random movement was increased. This control varied from trial to trial. We manipulated control at three levels (low control, medium control, and full control). At a random interval after the participant pressed trigger, a blue circle was presented at the

location (always at the centre of the screen) where participant aimed while pressing the trigger. The SOA between the trigger press and the presentation of blue circle was manipulated at three levels (100ms, 400ms, and 700ms).

The circle remained on the screen for 500ms, after which the participant was asked to report the interval between trigger press and appearance of circle, on a ten point scale similar to the practice session. In the main session participant was not given feedback regarding the interval estimated. This was followed by a second question, in which participant had to report the sense of authorship, on a seven point scale (similar to the questions used by Ebert & Wegner, 2010). There were a total of 216 trials in the experiment, with 24 trials in each condition. We recorded estimated interval, rating of authorship, and whether or not the participant hit on the target in each trial. In the main session participants were not given feedback regarding the estimated interval.

Results

Preliminary Analysis

Data from the practice session suggest that participants in general are able to correctly estimate the time interval. Similar to Ebert and Wagner (2011), we calculated the mean correlation between actual time and estimated time (mean $r = 0.683$) that was significantly greater than zero $t(12) = 12.3489, p < .01$. Data from one participant that was beyond two standard deviations from the mean ($r = 0.2112$) was removed from further analysis. In the main experimental session, the outcome (target hit/miss) was not controlled or counterbalanced across SOA (given that this is completely dependent on the performance of the participant in a given trial). Hence, to remove bias due to the unbalanced aspect of target hit/miss, we performed a correlation between target accuracy and SOA. The correlation between accuracy and SOA was not significant (mean $r = -0.0129$) indicating a lack of relationship between them.

Interval estimation task

Repeated measures ANOVA with SOA and control as factors on the estimated interval showed an expected significant main effect of SOA, $F(2, 22) = 23.46, p < .01$ indicating that participants' estimates increased as SOA increased. The effect of control as well the interaction between control and SOA was not significant. We categorized data further into two categories: (1) when participants hit the target and (2) when participants missed the target. For each category, we performed a two-way repeated measures ANOVA across three levels of SOA and three levels of control.

When participants were successful in hitting the target, there was a main effect of SOA, $F(2, 22) = 27.17, p < .001$. Estimated interval for 100 ms, $t(11) = 7.76, p < .01$ and 400 ms SOA, $t(11) = 4.21, p < .05$, was significantly different from that for 700 ms SOA. The main effect for control ($p = 0.98$) and interaction between control and SOA ($p = 0.26$)

was not significant. When participants were not successful, there was a main effect of SOA, $F(2, 22) = 34.01, p < .01$, with mean rating for 100ms significantly different from rating for 400ms, $t(11) = 7.55, p < .01$, and rating for 400ms significantly less than rating for 700ms, $t(11) = 8.6, p < .01$. The main effect of control was significant, $F(2, 22) = 6.86, p < .01$. Paired t -tests between different control conditions suggested a decrease in estimated interval with increase in control, with close to significance difference between, low control and medium control, $t(11) = 1.619, p = .057$, and a significant difference between medium control condition and full control condition, $t(11) = 3.14, p < .01$. The interaction between SOA and control was not significant ($p = 0.7$).

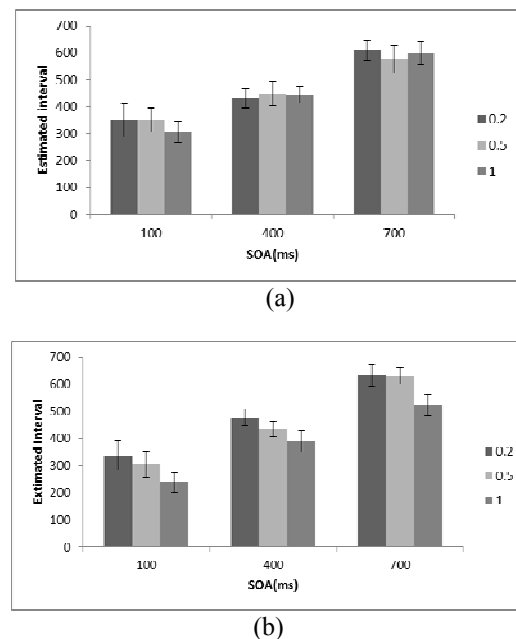


Figure 1: Estimated intervals as a function of control and SOA (a) when goal was accomplished and (b) when goal was not accomplished

We used the interval estimation task to assess intentional binding between self-triggered event (cause) and a second perceptual event (effect). Results suggest that intentional binding is greater (estimated interval is less) as the amount of control increases, that is when higher level goal is not achieved. When higher level goal is achieved, intentional binding (interval estimate) is not influenced by the amount of control.

Self-reported control

When subjects were successful in hitting the target, there was a main effect of control, $F(2, 22) = 35.57, p < .01$. There was an increase in self-reported control as amount of control was increased, from low to medium, $t(11) = 3.91, p < 0.05$ and from medium to full, $t(11) = 12.35, p < .05$. The

main effect of SOA ($p = 0.28$) and the interaction effect ($p = 0.26$) was not significant.

When subjects were not successful, there was a main effect of control, $F(2, 22) = 5.62$, $p < .05$. Post-hoc comparisons show a significant difference between low control and medium control conditions, $t(11) = 4.5$, $p < .05$ as well as low control and high control conditions, $t(11) = 6.3$, $p < .01$. The main effect of SOA ($p = 0.88$) and the interaction ($p = 0.4$) was once again not significant.

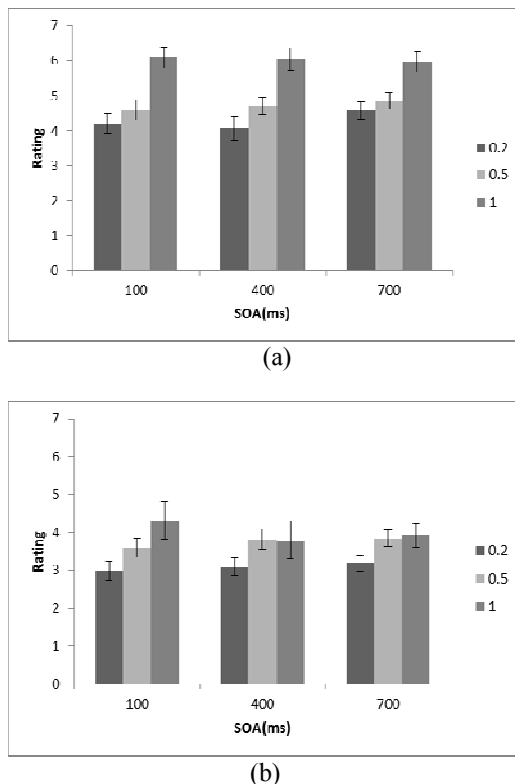


Figure 2: Rating for the sense of Authorship as a function of control and SOA (a) when target is achieved and (b) when target is not achieved

Self-reported control was a measure of subjects' sense of control and authorship (Ebert & Wegner, 2010). The results suggest that participant's sense of authorship depends on the amount of control and is independent of success or failure in achieving target.

Relationship between the Two Measures

Results show dissociation between the sense of agency and sense of authorship with respect to various control levels. To further analyze how these dependent measures are related, we performed a correlational analysis between the measure of intentional binding (interval estimate) and authorship (self-reported control) for the two levels of control. When the target goal is not achieved, there was a significant positive correlation between the two measures ($r(108) = 0.2$, $p < .05$). When target goal is achieved, the

correlation between the two measures is not significant ($r(108) = 0.13$, $p = .16$) indicating differences between the two measures. Sense of authorship seems to depend on the amount of control that a participant exercises at the perceptual-motor level, whereas intentional binding depends on both lower joystick control level as well as the higher goal level control.

Control & SOA as Predictors

To further explore how control and SOA can be used to explain the differences in intentional binding as a function of goal, we performed two simultaneous multiple linear regressions for the estimated interval, treating target hit/miss as a dichotomous variable, with control and SOA as independent factors and intentional binding as the dependent measure.

In target miss condition, control ($\beta_1 = -92.3$, $t = -2.5$) and SOA ($\beta_2 = 0.48$, $t = 15.6$) were significant (adjusted- $R^2 = 0.19$, $F(2, 1035) = 124$, $p < .01$). In target hit condition, SOA ($\beta_1 = 0.49$, $t = 18.65$, $p < .05$) was significant, but the β -value for Control ($\beta_2 = 4.5$, $t = 0.21$, $p = 0.82$) was not significant (adjusted- $R^2 = 0.24$, $F(2, 1094) = 174$, $p < .01$). The analysis suggests that estimated interval decreased as the amount of control increases for the trials in which participants missed the target but control is not a significant predictor when the target goal was achieved.

Discussion

In the current experiment, we investigated the role of control at multiple hierarchical levels in determining the sense of agency (both implicit, via measuring intentional binding and explicit, via rating on sense of authorship). There are a few important results that can be inferred from the data. Firstly, the high correlation between estimated and actual interval supports the idea of using interval estimation task as a valid measure of intentional binding (Ebert & Wegner, 2010). Secondly, consistent with the findings from that study, our findings show dissociation between the two measures of agency. Thirdly, our study provides support to the hierarchical event-control framework in understanding self and sense of agency (Kumar & Srinivasan, under review; 2012; Jordan, 2003).

Control and Intentional Binding

The results for the measure of intentional binding support the hypothesis that sense of agency depends hierarchically on the amount of control at various levels. The results support to the framework provided by event-control approach (Jordan, 2003; Kumar & Srinivasan, 2012) suggesting that control might play a key role in determining sense of agency. The results of the study are consistent with findings by Berberian and colleagues (Berberian, Sarrazin, Blaye & Haggard, 2012), who showed the presence of intentional binding in a complex task and a decrease in intentional binding as a function of automaticity in control. A major difference between our study and that by Berberian et al. (2012) study was that although both studies

manipulated control at different levels, the manipulation of control in the two studies is different in nature. In their study, (Berberian et al., 2012), manipulated control along a single dimension (i.e. automaticity level). However, in the current study, control is varied at two different levels (at goal level, and at perceptual-motor level). A second difference is that, in their study, the authors report a strong correlation between the two measures of agency and we find dissociation between the two measures when subjects are able to achieve control at the goal level (hit the target). Both the studies, along with others (Jordan, 2003; Desantis, Cedric, & Waszack, 2011; Kumar & Srinivasan, under review) provide evidence that control is correlated to the amount of intentional binding and plays a key role in determining sense of agency.

Control and Sense of Authorship

For the sense of authorship, our hypothesis was not completely supported by the results. Participants did show an increase in rating with control for the sense of authorship, when participants missed the target, thus supporting first part of our hypothesis. But, this increase in sense of authorship with control was also present when participants accurately hit the target indicating that the explicit measure of sense of agency is independent of control when participants hit the target. In combination, these results suggest dissociation between the intentional binding and sense of authorship. This dissociation has also been found in earlier studies (Ebert & Wegner, 2010), but the underlying mechanisms are not yet clear (Haggard & Moore, 2010; (Moore & Obhi, 2012).

Underlying Mechanism

Haggard and Moore (2010), commenting on the Ebert and Wegner (2010) study raised certain issues that remain unanswered from the study. Firstly, whether the exact mechanism of consistency is retrospective or prospective in nature? In the current study, control is predictive in nature, the control at perceptual-motor level was based on the prior expectation of participant when they moved joystick to aim at the target. At the goal level, participant's expectation of the outcome occurred prior to the event (as with congruency in the case of Ebert and Wegner. But, unlike congruency (Ebert & Wegner, 2010), the effect at the goal level occurred immediately before (or at the time) they pressed the trigger. Hence, goal level control can also be assumed to be predictive in nature. This suggests that the mechanism linking control and intentional binding is influenced by predictive processes.

A second issue was the exact causal nature of the link between intentional binding and sense of authorship. Our results suggest that intentional binding is sensitive to the hierarchical levels of event-control. In comparison, the sense of authorship seems to be less sensitive to the event-control hierarchy. Hence, we would like to suggest that intentional binding and sense of authorship are not causally linked to each other, but are rather mediated by amount of

control at different levels that can be exercised by participants.

Conclusions

We have shown that the theory of event control provides a successful framework to understand sense of agency. We suggest that both implicit and explicit aspects of sense of agency are mediated by hierarchical levels of control, but differently. The dissociation between implicit and explicit aspects of agency can be attributed to a difference in the way hierarchical nested control at multiple levels mediate the different aspects of agency. We have also confirmed that interval estimation task can be used to successfully measure intentional binding.

If it is actually the case that these nested control loops mediate agency, what exactly causes these control loops to mediate various aspects of agency in a different fashion? Possible answers might lie in the nature of control and the potential perception-action interactions between the organism and the environment that are dependent on the control. The study provides a pathway to understanding differences in sense of agency and further experiments would enable to naturalize and understand self.

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