Chapter 5: Implicit agency and causal binding of multi-scale events.

5.1 Introduction

Our voluntary actions not only influence our environment but also our sense of agency (SoA), the conscious mental state of being the agent of those actions. While difficult to tap empirically, SoA is central to all our conscious experiences (Gallagher, 2007). Sense of agency is a complex, multifaceted, phenomenon (Pacherie, 2011) that can be described as the feeling of “I did it” (Engbert et al., 2008), the experience of causing a change in the environment by one’s own action (Kawabe, 2013), the registration that the organism is the initiator of his/her own actions (Synofzik et al., 2013), and as the feeling of one’s voluntary actions causing external events (Takahata et al., 2012). SoA can be understood as a syntax or a framework within which several different experiences may be accommodated (Engbert et al., 2008).

These experiences of agency are linked to ones interactions with the environment, by causing a change, which is marked by an action event, and perceiving some change which is marked by perceptual events (Kawabe, 2013). These events are known as pushmi-pullyu or perceptual and action events respectively (Jeannerod, 2009; Pacherie, 2014). Representations of these perceptual and action events are associated with experience of agency and are classified based on their causal direction (Jeannerod & Pacherie, 2004). Depending upon the strength of the perceived causal relationship between these events, binding between the two events and the sense of agency are modulated (Hommel et al., 2001; Jordan, 2003). Sense of agency is greater when there is
a stronger causal binding between an action event and the consequent event (Desantis, Roussel, & Waszal, 2010; Moore et al., 2009).

SoA is not unitary and distinctions have been made between implicit and explicit SoA (Ebert & Wegner, 2010). Implicit aspects of SoA has been measured using intentional binding. Intentional binding (IB) refers to the finding that participants perceive the self-generated action event and its consequent effect to be temporally close to each other (Haggard, Clark, & Kalogeras, 2002). Due to the fact that IB occurs only when actions are self-generated, the phenomena is used as a measure of sense of agency giving it the name ‘Intentional Binding’ (Haggard & Clark, 2003). Studies associate a greater sense of agency with a stronger IB (Haggard & Moore, 2010).

Multiple factors influence and results in greater IB including unconscious priming, (Aarts & Bos, 2011) with greater felt control (Desantis, Cedric, & Waszack, 2011), and greater temporal control (Desantis, Hughes, & Waszak, 2012). IB is also affected by action-effect contingency (Moore, Lagando, Deal, & Haggard, 2009) and is postdictively attenuated by negative outcomes (Takahata et al, 2012). A recent review (Moore & Obhi, 2012) suggests that IB is also associated with other implicit measures of agency like efference copy, sensory feedback, causal feedback, and intentionality. Engbert et al (2008) suggested that IB represents the relation between an action and its causal effect and IB may reflect the ability of an organism to represent and control the interaction between an action and its effect, linking action-perception interaction closely with the experience of agency. In most of the previous studies using IB as a measure, the
nature and the relationship between the action event and perceptual event was manipulated and its influence on the binding between perceptual and action event was measured using either Libet’s clock task or by asking participants to verbally estimate the duration between two events (Moore & Obhi, 2012).

As discussed earlier in chapter 4, a relationship between perceptual and action events that influences sense of agency is hierarchical control over these multi-scale perceptual-motor events (Jordan, 2013). Chapter 4 investigated how multi-scale hierarchical event-control influences explicit sense of agency in terms of authorship and identification rating. Next, we wanted to investigate the relationship between event-control hierarchy and implicit sense of agency. We used a modification of the paradigm used by Ebert and Wegner (Ebert & Wegner, 2010). They asked participants to move a joystick either towards or away from themselves. Moving the joystick resulted in the movement of an object (towards or away from the observer) after a delay which was manipulated at three levels. This was followed by a verbal estimation task to measure intentional binding. They showed an effect of action-effect congruency on intentional binding especially for shorter SOAs.

We modified the paradigm by embedding the IB task inside a scenario in which participants exercise control at two levels, goal-level and perceptual-motor level. Participants had to control a cross-hair on the screen in a noisy environment to aim and hit a target, using a joystick to control the aim and the joystick trigger to hit the target. This trigger press was followed by a verbal estimation of interval between the trigger
press and appearance of a circle on the screen. We performed a set of two experiments to investigate the relationship between control and intentional binding. The first experiment investigated how control at perceptual-motor level and at goal level influences intentional binding. Based on the event control approach, we expected that more distal goal-level control and the more proximal perceptual-motor control would interact in a hierarchical fashion in influencing IB in a particular trial similar to the pattern of findings seen in Chapter 4 (Experiment 1).

Although all our experiences are understood in terms of discrete environmental events, at a “raw” perceptual level the environment offers a continuous sensory flux of sensory information (Casati, 2008). We make sense of this dynamic and complex environment by segmenting this information into a modest number of events that are segmented simultaneously at multiple time-scales (Kurby & Zacks, 2000). Control over these simultaneous hierarchical events and its link with implicit sense of self is the major theme of investigation in the current study. Events are defined by a segment of time at a given location that is conceived by an observer to have a beginning and an end. In an intentional binding task the event is supposed to begin with an action trigger and ends with a perceptual-outcome. Most of the studies on IB investigate the relationship between trigger and outcome in an isolated fashion, that is, a single voluntary action event is followed by a single pre-specified outcome. In real life the events are not isolated and various events share boundary with each other (as in experiment 1). Studies on event-segmentation suggest that boundaries of events are identified in terms of both bottom up
physical changes in the environment as well as changes in the top-down goals and perceived causal relations between events (Kurby & Zacks, 2000).

Studies have considered that an action constituting an event boundary could belong either what occurred before or the perceptual effect that appear after the action. This has implications for IB and more generally to our SoA. Understanding IB in the context of events that occurred prior to the IB event is critical for a richer understanding of IB in real life in which isolated actions and perceptual effects are not particularly common. In the paradigm used in the first experiment the trigger press and the outcome event (IB events) are embedded inside a control task, sharing the boundary which marks the end of both the events. In the second experiment we investigated how manipulating the nature of control events that share boundary with the IB event would influence the binding of self-generated action and its outcome. The goal-level control and the event boundary containing goal-completion information were manipulated. The intentional binding between trigger press and the perceptual outcome was measured as in Experiment 1. We expected that the nature of goal-level control would influence the way an event boundary is determined and bound to events that occurred prior the boundary (trigger press in this case). This would to recalibration and change the way the trigger press is intentionally bound to the subsequent perceptual effect.

5.2 Experiment 1

Event-control approach proposes that sense of self emerges out of dynamic interaction between hierarchically organized control loops. In a previous study (see chapter 4) which
investigated the role of multilevel control in influencing sense of agency, it was shown that explicit confidence rating of SoA depends on hierarchical levels of control exercised at proximal level of perceptual-motor control and the distal goal-level control. The study supported the claim of event-control approach related to the hierarchical organization of event-control levels based on spatio-temporal distality and their importance in influencing sense of self.

We wanted to explore whether or not implicit measure of agency such as IB would also depends on multiple hierarchical levels of control exercised prior to the IB task. Participants had to first point and shoot at a target in noisy environment with the help of a joystick; this was followed by verbal estimation task (Ebert & Wegner, 2010). We manipulated the perceptual-motor control (in terms of the amount of noise in the environment) and the delay between action and effect for which IB judgment was made. We measured firstly, whether or not participants completed the goal (operationalizing goal-level control) and secondly, participants’ estimated interval (operationalizing IB).

According to the event-control approach, sense of self depends upon the highest level at which control is exercised(Jordan, 2003). In the current paradigm, control can be exercised at two levels; firstly, at the lower, perceptual-motor level, that is the joystick level control and secondly, at the higher goal level, that is, whether or not participant is able to correctly aim at the target. We hypothesized that SoA measured in terms of IB would increase with perceptual-motor control when goal is not completed, but when goal
is completed the estimated interval will not vary with changes in amount of perceptual-motor control.

5.2.1 Method

Participants

Twenty one volunteers with normal or corrected-to-normal vision from University of Allahabad participated in the Experiment. Data from two participants was removed due to a failure in recording complete data.

Stimuli and Apparatus

In the practice session, the stimuli consisted of fixation cross and a circular disc both presented at the center of the screen at an angle of 0.95°. For the main session, in addition to the stimulus used in the practice session, we used eleven high-resolution pictures (3648x2736 pixels) of natural scenes from a custom database. A target region in the form of three concentric circles was superimposed on top of the background scene for every trial (the largest circle with a diameter with visual angle of 0.95° when placed at the center). The location of the target for every trial was determined randomly with the location of the target, in for of three concentric circles, being placed on the visible 800 x 600 pixel window of 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

Participant was seated at a distance of 90 cm from the monitor screen, with line of sight for fixation cross perpendicular to the monitor screen. Participants were instructed that the experiment consists of two phases, a practice phase and the main experiment and in each phase the participant’s task is to estimate the duration between when he/she presses the joystick trigger and when a circular disk appears on screen. As participants had to make judgment on a scale of 0 ms to 900 ms, participants were introduced to the idea of millisecond and were conveyed an approximate duration that it would mean (similar to Ebert and Wegner, 2010)

Practice Session

At the beginning of a trial in the practice phase, a white fixation cross was presented on a grey background. It remained on the screen till participants pressed the joystick trigger. Participants were instructed that they have to press a trigger to initiate the trial and that they can press the trigger when they feel like. As soon as a trigger press was recorded fixation cross colour changed to blue (indicating that the trigger has been pressed). After certain duration a blue circle was flashed on the screen. This interval between trigger press and the blue circle on the screen was manipulated in the practice session at ten levels (0 ms, 100 ms...900 ms). Subjects were asked to estimate the time interval between the trigger press and the circle flashing on the screen, and report it on a ten point scale (0, 100, 200…900) with the help of the numeric keypad (0 for 0 ms, 1 for 100 ms and so on). At the end of every trial, participant was given feedback in terms of the actual interval and the estimated interval (see figure 5.1).
The practice session served two purposes. Firstly, it helped to improve the interval estimation ability of participants and also its assessment. Ebert and Wegner (2010) suggest that practice session also made participants believe that the interval was manipulated at ten levels in the main session too. The practice session consisted of a total of 200 trials with 20 trials each interval condition. The data from the practice session were used to perform preliminary analysis of how good participants were in interval estimation.

**Main Session**

In every trial, a fixation was presented at the center of the screen with an image at the background and with the target (three concentric circles) overlaid on the background at a random location within the screen dimensions. The movement in the scenario was introduced by keeping the fixation cross (which was called the crosshair) at the center of the screen and moving the background image (along with the overlaid target) in a
direction opposite to the movement of joystick (giving rise to apparent motion of the central fixation with respect to the background). Advantage of the design was that participants always fixated at the center of the screen and without the background scene with the embedded target. Participants were instructed that they have to aim at the target, by moving the joystick and press the trigger, within 15 seconds. If they pressed the trigger within the given time limit a blue circle will appear on the screen indicating a hit. Their task was to estimate the duration after which the blue screen appeared on the screen. To introduce noise in the scenario, the background image and the overlaid target were moved together in a random direction (see figure 5.2).

![Figure 5.2: Trial structure for the main session](image)

Perceptual control was manipulated by varying the amount of noise in the movement of background image. Perceptual-motor control was manipulated at three levels (low control- a high amount of random movement, medium control-some random movement, and full control- no random movement) and varied from trial to trial. At a
random interval after the participant had pressed the trigger, a circular blue disc was presented at the location where participant aimed while pressing the trigger.

The SOA between trigger press and presentation of blue circle was manipulated at three levels (100 ms, 400 ms, and 700 ms). The circle remained on the screen for 500 ms, after which participant was asked to report the interval between trigger press and appearance of circle, on a ten point scale similar to the practice session. There were a total of 216 trials in the experiment, with 24 trials in each condition. We recorded the estimated interval and whether or not participants complete the goal. In the main session participant was not given feedback regarding the estimated interval.

5.2.2 Results and Discussion

Preliminary Analysis

Data from the practice session suggest that participants are able to correctly estimate the time interval. Similar to Ebert and Wagner (2010), we calculated the mean correlation between actual time and estimated time (mean \( r = 0.66 \)). The mean correlation was significantly greater than zero \( t(18) = 12.76, \ p < .01, \ d = 2.92 \).
Figure 5.3: Target hit accuracy for the three perceptual motor control conditions

Main session

As we were interested in studying how target completion (goal-level control) and perceptual-motor control influences estimated interval, we first analyzed how accurate participants were in hitting the target and completing goal. Data from one participant was removed from further analysis as that participants target accuracy was beyond the (+3SD) range of the mean accuracy in low control conditions. As expected target accuracy increased with increase in amount of control. Since our primary interest was in comparing the target hit trials with the target miss trials, high perceptual-motor control condition was dropped from the analysis as many participants were successful in hitting the target (95%) resulting in very few ‘target miss’ trials (see figure 5.3).

The data for the remaining three factor repeated measures ANOVA with goal-completion (target hit and target miss), SOA (100 ms, 400 ms and 700 ms), and perceptual-motor control (low and medium) was performed with the estimated interval as
the dependent measure. Analysis showed a significant main effect of SOA, $F(1.14, 19.49) = 22.632, p < .01, \eta_p^2 = 0.57$ (Greenhouse-Geisser corrected for sphericity, $\varepsilon = .57$).

**Figure 5.4**: Estimated interval for goal completion versus high and low perceptual-motor control

Post-hoc comparisons (tukey) suggest that, estimated interval for 100 ms SOA (mean = 335.33 ms) was lower than estimated interval for 400 ms SOA (mean = 458.08 ms), $t(19.48) = 3.19, p = .08$, and 700 ms SOA (mean = 611.77 ms), $t(19.48) = 7.18, p < .01$. Mean estimated interval for 400 ms SOA was significantly less than estimated interval for 700 ms SOA, $t(19.48) = 3.99, p < .05$, indicating that participants estimated interval was sensitive to the manipulation of SOA, establishing the validity of verbal interval estimation task as a measure of participants ability to estimate temporal interval between two events. The main effect of goal completion, $F(1, 17) = 1.047, p = .32, \eta_p^2 = .058$, and the main effect of control, $F(1, 17) = .725, p = .246, \eta_p^2 = .078$, as well as the
interaction between goal completion x SOA, $F(2, 34) = .5, p = .6, \eta^2_p = .029$ and, control x SOA, $F(2, 34) = .3, p = .74, \eta^2_p = .02$ were not significant.

The interaction between control and goal completion was significant $F(1, 17) = 5.74, p < .05, \eta^2_p = .25$. Post-hoc analysis showed that when participants were unable to correctly hit the target, there was a significant greater interval estimation in the low-control condition (496 ms) compared to the medium control condition (mean = 458 ms), $t(17) = 4.4, p < .05$. When participants correctly hit the target there was no difference between low control (mean = 458 ms) and medium control (mean = 461 ms) conditions, $t(18) = .397, p > .5$. Also, estimated interval for goal completion was greater than condition in which goal is not completed in low control condition, $t(17) = 4.402, p < .05$, but not for high control condition, $t(17) = .391, p > .5$ (see figure 5.4).

The results show that when participants missed the target estimated interval was greater for low control condition (lesser IB) compared to high control condition. When the participants hit the target, there was no difference between low control and medium control condition, suggesting that the control at goal level and at perceptual-motor level interact in a hierarchical manner to influence IB (estimated interval). This supports our hypothesis based on the event-control approach that the levels of control will influence IB in a hierarchical fashion.

These results are consistent with the results from earlier study using other measures of agency (Kumar & Srinivasan, 2014) as well as the findings by Berberian et al. (2012) that showed a decrease in IB as a function of automaticity in control. While
both our study and Berberian et al. (2012) manipulated control, a major difference between the two studies is the way in which control was manipulated. They manipulated control along a single dimension (i.e. automaticity level). However, in the current study, control is varied at two different levels (goal-level and perceptual-motor level). The high correlation between estimated and actual interval supports the idea of using interval estimation task as a valid measure of IB (Ebert & Wegner, 2010).

Event-control approach suggests that due to the hierarchical nature of control loops, the lower level perceptual-motor control would play a greater role in influencing sense of self, when participants are not able to exercise control at the higher goal level. Hence, to understand the role of lower, more proximal, perceptual-motor control we looked at trials in which participants are unable to exercise control at higher (more distal) goal level. Results suggest that in trials where participants do not complete the goal, estimated interval is greater (and hence IB is less) for low-level control (high noise) compared to high level of control (low noise). This result is consistent with the finding that greater sense of agency increases with control (Carruthers, 2012; Moore, Lagnado, et al., 2009).
5.3 Experiment 2

An important property that characterizes all our actions is goal-directedness, that is, all our actions have a goal state associated with them (Papies, Aarts, & de Vries, 2009; van der Weiden, Ruys, & Aarts, 2013). Event-control approach postulates that every action pre-specifies effects at multiple levels and these pre-specifications can be understood at simultaneously active goals varying in their distality/proximity with respect to the action. One is said to be in control at a particular level, when the pre-specified effect at that level matches the actual perceptual event at that level. First experiment showed that IB, that is the modulation of perceived time between a self-generated action event and its consequent event, depends on control over pre-specified multi-level goals. The aim of the second experiment was to explore how the nature of the shared event boundaries between the IB event and prior level control influences intentional binding.

The event boundaries play a major role in event-perception (Zacks & Tversky, 2001). These boundaries are shared by either a chain of event segments or form part of partonomic hierarchies (Zacks, Tversky, & Iyer, 2001). These event boundaries have been studied in detail using segmentation tasks where participants are asked to identify boundaries in a continuously changing stimulus. Studies suggest that participants identify event boundaries based on various cues including bottom-up physical changes in the stimulus, as well as top-down conceptual changes in goals and causes. This boundary based segmentation takes place continuously, giving the higher level experience of a meaningful environment classified in terms of discrete events.
These event boundaries are critical in shaping the temporal structure of a particular event and influence the perceived causality between events (Zacks & Tversky, 2001). Previous studies have looked at how the perceived temporal relationship between events is modulated by nature of events (whether or not the events are voluntary in nature, predictability of the events, ambiguity of the events, and complexity of the stimulus involved). Majority of these studies suggest that the modulations in temporal structure of events occurs due to sensory motor recalibration (Heron, Hanson, & Whitaker, 2009; Wenke & Haggard, 2009). The recalibration account suggests that temporal ambiguities resulting out of recalibration of perceived onset of sensory events to match certain criteria such as constancy, causality and agency. However, none of the previous studies have investigated how IB and temporal modulation is influenced by the nature of other events that share boundary with the IB events.

The first experiment investigated how manipulation of control (by introducing noise) at the lower perceptual-motor level influences IB and found an increase in IB for greater control. The control at the goal level was not manipulated by the experimenter, and was measured in terms of whether or not participants correctly hit the target. Previous research on action segmentation has shown that goal completion are important for event boundaries and dynamic human action has been linked to initiation or completion of goals, with considerable inter-rater reliability (Meyer et al, 2010; Zacks, Tversky, & Iyer, 2001). In experiment 2 we manipulated the goal-level control that participants exercised, by introducing a feedback event in the paradigm used in first experiment, this feedback event indicated success on 50% of the trials and failure in 50% of the trials irrespective
of whether or not participants hit the target (*see* methods). This feedback was in form the color of the stimulus, one colour indicating ‘target hit’ and another colour indicating ‘target miss.’ We expected that the nature of binding between prior control task and intentional binding task would help us understand the role event boundaries play in shaping the temporal structure of IB event and hence SoA.

We also manipulated whether this boundary related manipulation was presented at the beginning of the IB event or at the end of the IB. We fixed the perceptual-motor control to a medium control level. The reason for selecting the medium control level was that in the first experiment medium control level produced an accuracy close to 50% and provided participants with an environment in which exercising control was neither too easy nor too difficult. Since in experiment 1 we did not find a significant difference between SOA of 100 ms and SOA of 400 ms, we manipulated SOA at only two levels (400 ms and 700 ms) in experiment 2. To manipulate the control at goal-level we changed the relationship between action and goal completion from fully predictable (participants always complete the goal when at the time of trigger press crosshair overlapped with the target region) to a probabilistic one (participants sometimes hit the target and sometimes missed it, independent of whether the cross-hair overlapped with the target or not). Irrespective of where the participant’s cross-hair was during a trial, participants were given feedback indicating ‘success’ in 50% of the trials and ‘failure’ in the other 50% trials.
The IB effect is due to binding between the action and the subsequent perceptual effect. While this IB event can be independent, it can also become part of the prior events occurring before the action (as in experiment 1). In experiment 2a we investigated how event boundary that precedes the IB event influences binding between trigger and outcome. The nature of the event boundary (trigger press) was manipulated by presenting the goal-completion feedback information at the time of trigger press. The colour of the crosshair at the time of the trigger press was used to convey whether or not goal was completed in a particular trial. When the goal was successfully achieved, both expected goal completion information as well as actual goal completion information was presented at the initiation of the IB event, resulting in a greater binding and recalibration of the trigger event towards the prior control task. This increase in binding will be reflected as an increase in the estimated duration between the trigger press and outcome. Hence, we hypothesized that the estimated interval (or less IB) between the trigger press and the perceptual effect (the IB event) will be greater for goal completion trials compared to trials in which goal is not completed.

In experiment 2b, the nature of boundary at the end of the IB event was manipulated. We achieved this by presenting the goal completion feedback (in form of a color change) along with the perceptual outcome (circle) that follows the trigger press. While, the ‘expected’ goal completion information accompanies the trigger event, the ‘actual’ goal completion information accompanies the target circle, resulting in a stronger binding and recalibration of both trigger press as well as outcome, towards the prior control events. If both the IB events are recalibrated in the same direction, the perceived
duration between them will remain the same. Hence, we hypothesized that there will be no difference in the estimated interval between trials in which goal is completed and trials in which goal is not completed.

5.3.1 Method

Participant

There were a total of 20 participants (10 girls) in experiment 2a and 16 participants (8 girls) in experiment 2b. These naive participants had normal or corrected to normal vision and were students of University of Allahabad.

Stimuli and apparatus

Stimuli and apparatus were same as that used for the first experiment. The experiment was prepared using Psychophysics toolbox-3 on Matlab 2010b. Stimulus was presented on a 17” LCD screen.

Procedure

Similar to the first experiment, participants were seated at a distance of 90 cm from the monitor screen and 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; Kumar & Srinivasan, 2013 for more details).
Practice Session

Practice session was similar to that of first experiment. Participants were instructed that they have to press a trigger to initiate trial following the presentation of the fixation crosshair and that they can press the trigger when they feel like. After the trigger was pressed, the fixation cross on the screen changed color indicating that the trigger has been pressed. For experiment 2a, the color to which the fixation changed was either yellow or green. For experiment 2b, the color to which the fixation changed was always blue.
Participants were told that the color change to the fixation cross did not matter and can be ignored for the practice session. After a random interval (out of 0ms, 100ms, 200ms...900ms), a colored circle was flashed onscreen. For experiment 2a, the color of the target circle was always blue. For experiment 2b, the color of the circle was either green or yellow.

Subjects 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. A total of 100 practice trials were given with 10 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 (a red circle), by moving the joystick, (which moved the background scene and the target position with respect to. a central fixation, in form of a cross hair), and press the trigger within 10 seconds. The perceptual-motor control was fixed at medium level across the experiment. Pressing the trigger changed the color of the central fixation. Similar to the practice session, for experiment 2a the color to which the fixation changed was either yellow or green, whereas for experiment 2b the color to which the fixation changed was always blue. If the participants pressed the trigger within ten seconds, after a random interval, a colored circle was presented at the center of the screen concentric to the crosshair.
Again, as in the practice session, for experiment 2a the color of the target circle was always blue, whereas for experiment 2b the color of the circle was either green or yellow. The SOA between trigger press and presentation of the colored circle was manipulated at two levels (400ms, and 700ms). Circle remained on the screen for 500ms, after which, similar to the practice session, participant was asked to report the interval between trigger press and appearance of circle, on a ten-point scale. In the main session participant was not given feedback regarding the interval estimated. If the participant did not press the trigger within ten seconds target circle and rating question were not given to the participants. (see figure 5.5)

Subjects were instructed that there is a probabilistic relationship between their pressing the trigger and goal being achieved, and that in some trials even if they press the trigger close to the target they might hit the target and sometimes even if they press the trigger accurately, they may still miss the target. The information about whether they hit the target or miss the target was either given by the change in color of the cross hair (Experiment 2a) or given by the change in color of the target circle (Experiment 2b). The color indicating target hit or target miss was either green or yellow and was counterbalanced across participants.

What was not revealed to the participants was that there was an invisible circle of 1.90° diameter, concentric to the target circle (0.95° diameter), such that, the area of the region inside the target circle was equal to the area of the region of the ring between the invisible circle and the target circle. When participants pressed the trigger inside the
invisible circle, in fifty percent of the trials participants were given feedback that they have hit the target, while in the remaining trials participants were given feedback that they have missed the target. When participants pressed the trigger outside the circle or they do not press the trigger within ten seconds, the feedback of target miss was given. Such, trials in which participants either did not press the trigger within ten seconds or they pressed the trigger outside the 30-pixel circle from the target, were eliminated from further analysis and the trial was repeated later on in the experiment. The design was a 2 (SOA) x 2 (Target hit) within subject design. There were a total of 60 trials in each experiment, with 15 trials in each condition. We recorded estimated interval in each trial, which was our measure of interest.

5.3.2 Results and Discussion

Preliminary Analysis

We correlated the SOA in the practice session with the rating for estimated interval to obtain a measure of how well subjects estimated the interval, mean correlation between SOA and binding rating for experiment 2a was 0.61(±0.23), \( t(19) = 11.67, \ p < .01, \ d = 2.61 \). One outlier participant was removed from further analysis due to low correlation in the practice session (\( r = .05 \)). A correlation of .61 suggests that participants are able to accurately estimate the time interval. For experiment 2b, mean correlation between SOA and binding rating was 0.64 (±0.23). One sample t-test suggested that the correlation was significantly greater than zero, \( t(15) = 10.86, \ p < .001, \ d = 2.71 \), suggesting that
participants are able to accurately estimate the time interval. There were no outliers for experiment 2b.

**Figure 5.6:** Target hit accuracy for high and low perceptual-motor control for (a) experiment 2a (b) experiment 2b.
Main Analysis

Even though subjects performed the task in a noisy environment (medium control), their ability to correctly aim at the target was good. The average accuracy of correctly aiming at the target was 71% in experiment 2a and 73% in experiment 2b, (which was higher, compared to nearly 50% aiming accuracy of participants in the first experiment for medium level of control). The performance in both these cases was significantly above 54% (as in the first experiment), $t(19) = 7.12, p < .01, d = 7$, for experiment 2a and $t(15) = 9.29, p < .01, d = 4$ for experiment 2b (see figure 5.6).

In the remaining trials, participants had pressed the trigger while the location of crosshair was outside the target circle but inside the invisible circle. Repeated measures ANOVA between target completion and SOA for aiming accuracy e suggested that the accuracy was independent of our manipulations of SOA and Target completion, for both the experiments (experiment 2a and experiment 2b). For further analysis we considered only the trials in which participants had correctly aimed at the target circle. We conducted a two-way repeated measures ANOVA between two levels of SOA (400 and 700) and two levels of target Completion (target hit and target Miss), for both the experiments for the trials in which participants had accurately aimed at the target.
Figure 5.7: Estimated interval for SOA versus Target completion for (a) experiment 2a (b) experiment 2b.

For experiment 2a we found a significant main effect of SOA, $F(1, 18) = 20.19, p < .001, \eta^2_p = .529$, with lower estimated interval for 400ms compared to 700ms SOA, suggesting that verbal interval estimation task is sensitive to changes in SOA, and can be used as a valid measure of interval estimation. The main effect of target completion was
significant, $F(1, 18) = 6.99, p < .05, \eta_p^2 = .28$, with larger estimations when target is completed compared to condition in which target is not completed. Interaction between Target Completion and SOA was not significant, $F(1, 18) = 0.35, p = .56, \eta_p^2 = .019$. For experiment 2b we found a significant main effect of SOA, $F(1, 15) = 20.51, p < .001, \eta_p^2 = .578$, with lower estimated interval for 400ms compared to 700ms SOA. The main effect of target completion, $F(1, 15) = .02, p = .89, \eta_p^2 = .001$, as well as the interaction between Target Completion and SOA was not significant, $F(1, 17) = .51, p = .49, \eta_p^2 = .033$ (see figure 5.7).

The results suggest that the boundary events that precede the IB event influence the perceived temporal structure of the IB event, resulting in a decrease in binding between trigger press and outcome when the feedback accompanying the trigger press indicates success in the preceding control event compared to when the feedback indicates a miss in the control task. This result supports our hypothesis that estimated interval would be greater when cue indicates goal completion compared to trials in which cue suggests that goal is not completed. However, when the boundary event following the IB event does not influence the temporal structure of IB event, that is, we found no difference between binding in the target miss and target hit conditions. The result is in agreement with our hypothesis.

These results indicate that the IB task is influenced by the presence of other events that share boundaries with the IB task. Results can be understood in terms of a recalibration of IB events when the trigger event contains goal-completion related
information, but not when the goal completion information accompanies the outcome. The study also support the idea of event segmentation based on higher level goal information and that events cannot be studied in an isolated fashion but as a part of other multi-scale event chains (Eagleman & Holcombe, 2002; Kurby & Zacks, 2000; Zacks & Tversky, 2001).

5.4 General Discussion

There have been multiple propositions suggesting close relationship between ‘Self’ and Control (Jordan, 2003, Friston, 2010). One such approach, the ‘Event-control approach’ (Jordan, 2013, 2013) closely links emergence of ‘Self’ and control at multiple hierarchical levels. The basic idea is that sense of self depends is dependent upon the most spatio-temporaly distal level at which control can be exercised. Earlier studies (Jordan, 2003, 2013; Kumar & Srinivasan, 2014) have shown that the approach can be successfully used to explain how explicit rating related to sense of identification and authorship is modulated by control at perceptual-motor level and goal level.

In the current study we found evidence supporting event-control approach for implicit measure of self (IB). The first experiment shows that IB decreases as a function of control both at perceptual-motor as well as goal-level. However, there was an interaction between the two control level, i.e., influence of perceptual-motor control is present only when goal-level control is absent. When Goal-level control was present, the perceptual-motor level control did not influence IB, suggesting that IB is hierarchically influenced by control at multiple levels. This result is in agreement with earlier research showing a
modulation of explicit rating of agency (identification and authorship; Kumar and Srinivasan, 2014).

Although multiple studies have suggested linkages between control, IB and agency (Dewey, Sieffert & Carr, 2010; Desantis, Cedrick & Waszack, 2011, Ebert & Wenger, 2010; Haggard & Clark, 2003), we, perhaps for the first time, show that IB is modulated by control in a hierarchical fashion. Results suggest that control, experience of agency and causal binding of voluntary actions are closely linked to each other and might share certain common mechanism and are intricately linked to each other. In terms of the trial structure, the only difference between trials in which participants complete the goal vs. trials in which participants do not complete the goal is that in former case, at the time of trigger press target stimulus overlaps with the central fixation while in the latter, the target stimulus doesn’t overlap with the central fixation. Hence any difference in binding between action and effect between the two conditions is a result of whether or not participants exercise control prior to the IB task. The results fit with the idea that IB might represent the relationship between action and effect, and reflects organisms’ ability to control its environment (Engbert, Wohlschlager, Haggard, 2008).

The latter portion of the study investigated the effect of shared event boundaries on IB. This was done by fixing the proximal perceptual-motor control at medium level and manipulating whether or not in a particular trial participant completes the goal. A greater estimated interval is reported when participants complete the goal compared to
when they do not complete the goal for experiment 1 and experiment 2a. For experiment 2b no difference is found between ‘goal completed’ and ‘goal not completed’ conditions.

To understand in detail the results of experiment 2a and 2b, let us reconsider the scenario with which the participant interacts. In both the experiments if we select only the trials in which participants are able to correctly aim at the target, we can schematically present the trial in terms of three events prior control event, action event, and effect event. Figure 5.8 shows the schematic presentation for 400ms SOA. We find that in comparison to experiment 1, in experiment 2a and 2b there was an attraction between the control and feedback event. For experiment 2a, the larger interval estimate between action event and effect event when feedback is successful, suggests that there was a greater attraction between control event and action event (feedback is presented along with the action event). For experiment 2b, the interval estimate difference was not significantly different event between the successful-feedback condition and the unsuccessful-feedback condition.

**Figure 5.8: Recalibration of events across experiments**
We find that when binding is stronger between prior control task and trigger press (goal-level control is present), the intentional binding between trigger press and consequent event becomes weak. Suggesting that the trigger event is recalibrated depending upon the strength of event binding. These results are consistent with the recalibration account of agency, which suggests that temporal modulation occurs due to sensory motor recalibration of events based on the relationship between events (Blakemore, Frith, & Wolpert, 1999; Heron et al., 2009). Rohde, Greiner, & Ernest (2014) show that this sensory motor recalibration is present for action led temporal discrepancies but not for vision led temporal discrepancies. The current study shows similar result. In experiment 2a where the feedback is attached with the action event, we find a recalibration of events with the action event perceived closer to prior control event for targets in which feedback indicates a target hit. In experiment 2b where the feedback is attached to the visual event, we do not find any difference between ‘target hit’ and ‘target miss’ conditions.

Conclusions

We have shown that the theory of event-control provides a successful framework to understand sense of agency and that sense of agency is mediated by hierarchical levels of control. If it is actually the case that these nested control loops mediate agency, how exactly these control loops influence IB? Study suggests that a plausible explanation of the phenomenon is using a recalibration account of agency, where ability to exercise control at various hierarchical levels results in shifting of events (trigger press and
appearance of circular disc). Second study further supports the recalibration account of intentional binding for higher level of control. The study has implications for frameworks related to sense of agency, and provides a crucial link between control, sense of agency and time perception using an ecological paradigm.