### Title

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### Authors

Kumar, Neeraj
Manjaly, Jaison A.
Miyapuram, Krishna P.



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# Role of Error Monitoring Mechanisms in Attribution of Sense of Self-Agency

**NeerajKumar, Jaison A. Manjaly (neeraj, jmanjaly@iitgn.ac.in)**
Cognitive Science Programme, Indian Institute of Technology Gandhinagar
VGEC Campus, Chandkheda, Ahmedabad-382424, INDIA

**K. P. Miyapuram(krishna.miyapuram@cantab.net)**
Center for Mind/Brain Sciences, UniversitàdegliStudi di Trento
Via delleRegole 101, 38060 Mattarello (TN), ITALY

**Abstract**

Sense of agency refers to the sense of authorship of a given action. While the phenomenon seems too obvious to demand further investigation, pathological conditions such as delusions of control suggest the requirement of further investigation into the phenomenon of sense of agency. The traditional view point regarding the role of intention in sense of agency is complemented by computational models of motor control. Accordingly, we hypothesized and tested the role of error monitoring mechanisms in the sense of agency by manipulating the feedback given independent of the responses of the participant while performing a Flanker task. The results point out the potential role of error monitoring mechanisms by modulating the forward model predictions to experience a sense of agency for unintended actions.

**Keywords:** sense of agency; motor control; forward model; error monitoring mechanisms; Flanker task; error feedback; action intention.

## Introduction

In day-to-day life, we encounter various sensorimotor events, in which sensory perception and action are intertwined. A chain of events including intention to act, movement preparation, generating motor commands and sensory feedback are part of the underlying components of our sensorimotor experience (Haggard et al., 2002). The sense of agency for a given action refers to the sense that an agent has that s/he is the author of that action (Pacherie, 2007b). In other words, the sense of agency is a pre-reflective experience which enables the sense of authorship of one's own thoughts and actions. The sense of agency also critically contributes to a sense of self in terms of experiential immediacy (Tsakiris& Haggard, 2005). Though actions are found to be accompanied by a sense of agency, not much is known in terms of its underlying mechanism or set of processes responsible for this experience.

Different prevailing views have explained regarding the mediators between sense of agency and action (see David et al., 2008 for a review). One view proposed by Haggard et al. (2002) is that the intention of an agent, i.e. ''intentional binding" has an important roleon the sense of agency (Haggard et al., 2003; Tsakiris& Haggard, 2003), that contributes significantly to action awareness. Pacherie (2007a, b), on the other hand, claims that the sense of agency contains not only an experience of intentional causation, but a sense of initiation and control. Disturbance in any phase can cause disruption in the sense of agency. Yet another view is based on established models of motor control (Wolpert, 1997) as explained below.

Computational models of motor control (Blakemore et al., 2001, 2002) have an alternative suggestion about the mechanisms responsible for the sense of agency. The computational view is that the sensorimotor loop consists of an inverse model, which identifies the motor commands required to achieve a certain desired state and a forward model, which predicts the sensory consequences of motor actions. These models are represented within the central nervous system in the form of internal models. According to Frith (1992), internal forward model is principally responsible for the sense of agency because it generates an efference copy, which predicts the sensory consequences of motor commands in advance. Predicted sensory information is matched against subsequent sensory information. If predicted and sensed information match, then the sensory events are self-generated, and the subject will experience sense of agency for those events. If there is mismatch, then the sensory information registers it as an external event, and therefore the sense of agency is absent. This model has been used to explain the perceptual attenuation of self-generated stimuli (Blakemore et al., 2000), and pathological experiences, such as delusions of control found in Schizophrenia. For example, Blakemore et al. (2002) have suggested that the misattribution of action shown in patients experiencing delusions of control can be explained by a deficit in the internal forward model (Frith, 1992).

Simulation theory of agency suggests that in understanding or predicting other's action we use our own experiences to simulate those of others (Goldman, 1989). Sebanz et al. (2005) found that subjects within the autism spectrum did not show deficits in representing another person's action but exhibited mentalizing deficits. David et al. (2007) showed autistic subjects show deficits in perspective taking which has been explicitly linked to simulation (Gallese & Goldman, 1998; Langdon & Coltheart, 2001). Children with autism have also shown reduced error monitoring (Vlamings et al., 2008) and altered cerebellar feedback projection (Catani et al., 2008).

Another explanation for experienced agency for unintentional actions is suggested by recent studies on error monitoring mechanisms (Yordanova et al., 2004; Van Schieet al., 2004). It is well known that after an erroneous action is selected, internal monitoring mechanisms gives the feedback that one has committed an error. Such error signals are based on the detection of a conflict that occurred while choosing between several action alternatives, rather than on the comparison between the predicted and actual consequences of a specific action selected for execution. Agency for erroneous actions could be experienced because an error-monitoring signal is used to readjust the system. The readjustment could serve as a direct indication of agency or it could influence post-hoc evaluations of performed actions (Knoblich & Natalie, 2005).

Experiments by Sato and Yasuda (2005) suggest that motor prediction contributes to the experience of agency. Their findings show that agency is experienced not only for intended, but also for erroneous/unintended actions. This result supports the view that the experience of agency depends on the discrepancy between predicted and actual sensory consequences regardless of whether an action was intended or unintended (Fourneret & Jeannerod, 1998; Sato & Yasuda, 2005).

Present study aims to investigate the role of error monitoring mechanism in the attribution of sense of agency. We propose that error monitoring mechanisms can update the 'forward model' efferent prediction to match the actual sensory outcome. The activation of error monitoring mechanisms can cause the online or real time alteration in predictions by forward model. This modulation in prediction can occur before assimilating the actual sensory outcome which can influence the sense of agency. We hypothesized that the feedback should modulate the sense of agency, more particularly when the feedback is inconsistent with the actual responses of the participant. We argue that, this online modulation of forward model prediction through error monitoring mechanisms can explain the sense of agency in unintentional action.

## Materials and Methods

### Participants

15 undergraduate students (Mean age = 19.4 years) have participated in the study. All participants were right-handed having normal or corrected to normal vision. Participants provided informed consent and were paid for participation.

### Design

We have used some of the designs proposed by Sato & Yasuda (2005) to examine the role of error monitoring mechanism and to explore the possibility of modulation of the forward model predictions. Participants performed an Eriksen Flanker task (Eriksen & Eriksen, 1974), which is a forced choice reaction time task in which the target later is flanked by distracter letters (either congruent or incongruent letter). When participants are asked to respond quickly to the flanker array, they tend to make errors and have low reliability on their responses. To activate error monitoring mechanisms, we have given an immediate feedback after the response which could be right (correct feedback) or wrong (incorrect feedback). If wrong feedback can alter the attribution of agency (refer table 1) then it might be possible that error monitoring mechanisms are capable to modulate the efferent predictions of forward model before assimilating the actual sensory outcome.

Thus, the experiment consisted of two within-subjects factors (a) Type of sensory outcome (Congruent tone or incongruent tone with prediction), and (b) type of feedback (Wrong feedback & Right feedback). Notably the error feedback was manipulated independent of the actual response.

Table 1: Prediction of sense of agency in different conditions.

| Response → <br> Condition ↓ | Correct | Incorrect |
|---|---|---|
| Wrong Feedback-Congruent Tone | No | Yes |
| Wrong Feedback-Incongruent Tone | Yes | No |
| Right Feedback-Congruent Tone | Yes | No |
| Right Feedback-Incongruent Tone | No | Yes |

### Procedure

Upon entering the laboratory, participants were seated in front of a computer screen with a pair of headphone. Prior to the experiment, participants performed300 learning trials. On each trial, 1000ms after fixation onset, the target stimulus (i.e., "H" or "N") was presented for 250ms on the center of the screen. Participants were told to press the left button with the left index finger as quickly and accurately as possible whenever an "H" appeared on the center of the screen and the right button with the right index finger whenever an "N" appeared on the screen. After each button press, a certain tone was immediately presented for 200ms through in-ear headphones: a 600 Hz tone or a 1000 Hz tone. The assignment of stimuli and tones to buttons was consistent for each participant and counterbalanced across participants. Participants were explicitly told that each button pressing would evoke a certain tone. Tones were identical in duration and sound pressure throughout the experiment.

In the main experiment, participants performed the Flanker task for 200 trials. Each trial started with the onset of centrally presented fixation sign. After the 1000ms of fixation onset, a five-letter array (i.e., HHHHH, NNNNN, HHNHH, or NNHNN) was presented for 250ms. Participants were instructed to respond to one of the two target letter (central H or N) with one finger and to the other letter with the other finger as quickly as possible and not to correct their responses even if they made errors. The assignment of responding finger to target letter was the same as the learning session. After the response was made, an immediate feedback was provided on the screen for 200ms which could be right (congruent with response) or wrong (incongruent with response). After 200ms of offset of feedback a tone was presented through headphone for 200ms either congruent or incongruent with prediction. Then participants were asked for their rating regarding the sense of agency using a question “I was the one who produced the tone”. The responses could be one of the three options in the form of ‘Yes’, ‘No’ and “Maybe”. To prevent demand effects and any other possible biases in responses such as motor preparation, the question was randomly alternated with a second question “'I was the one who was listening to the tone”. Further, the options Yes and No were counterbalanced across trials. The experiment was designed using Psychophysics toolbox (Brainard, 1997) in MATLAB (Mathworks Inc.) (See figure 1).

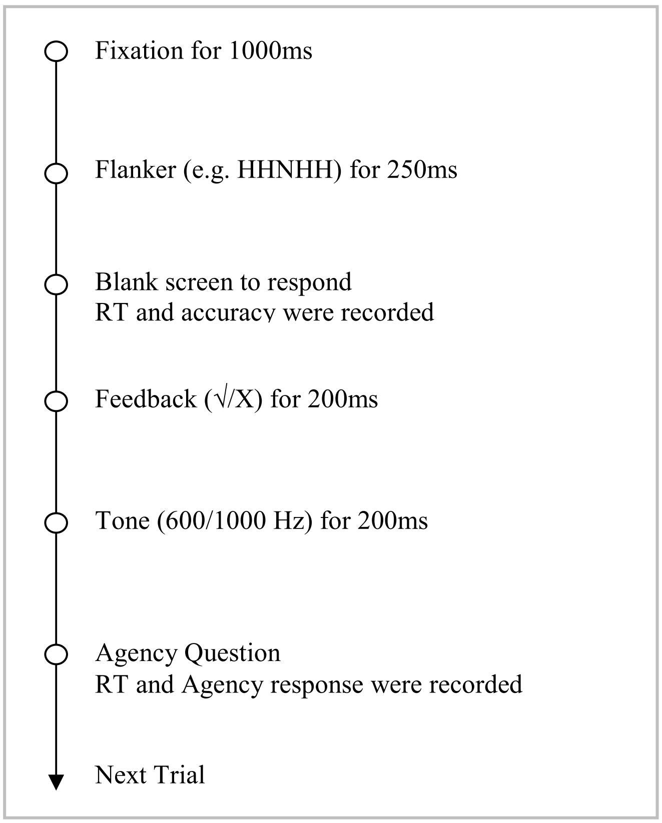


Figure 1: Trial procedure for an experimental trial

### Data Analysis

We present the results for the sense of agency, as this is the main hypothesis of our experiment. We have also analyzed the reaction time data to check our manipulation effect of flanker task. For quantitative analysis we have transformed the ratings into numerical values. Now ‘Yes’ is represented as 1, ‘No’ is represented as 0 and ‘Maybe’ lies in between as 0.5.These ratings of sense of agency were analyzed using 2x2 repeated measures ANOVA separately for correct and incorrect response trials (see results).

## Results

To check the manipulation effect of flanker task, we have analyzed the reaction time to target letter for correct and incorrect trials in both practice and experimental session. We have found that in practice session participants were significantly faster [$t(14) = 2.97$, $p = 0.01$] in incorrect responses [Mean = 0.32 Sec, SD = 0.15] than correct responses [Mean = 0.53 Sec, SD = 0.18]. In experimental session, participants were significantly slower [$t(14) = 3.34$, $p>0.01$] when they made incorrect responses [Mean = 1.3 Sec, SD = 0.5] in comparison to correct responses [Mean = 0.75 Sec , SD = 0.06]. These results suggest that participants face internal conflict between various alternatives of actions in experimental session (target letter was flanked by congruent/incongruent letters) which in turn delayed the response and end up in incorrect action.

The rating scores on sense of agency were analyzed separately for correct-response trials and incorrect-response trials using repeated measure analysis of variance with two factors: Tone congruency (2 levels – Congruent & Incongruent Tone) X Type of feedback (2 levels – Wrong & Right Feedback). For correct responses, this analysis revealed the main effect of tone congruency [$F(1,14)=12.86$, $p<0.01$], but there was no significant main effect of feedback [$F(1,14)=1.02$, $p=0.32$]. More crucially, we have found significant interaction between tone congruency and type of feedback [$F(1,14)=353.0$, $p<0.01$]. Further post-hoc analysis revealed that under congruent tone condition sense of self-agency was significantly reduced ($p<0.01$) in wrong feedback condition (Mean=0.25, SD=0.08) in compare to Right feedback condition (Mean=0.81, SD=0.04). It also revealed that sense of self-agency was significantly increased ($p<0.01$) under wrong feedback condition (Mean=0.68, SD=0.10) than in right feedback condition (Mean=0.18, SD=0.15) when tone was incongruent with prediction (See figure 2).

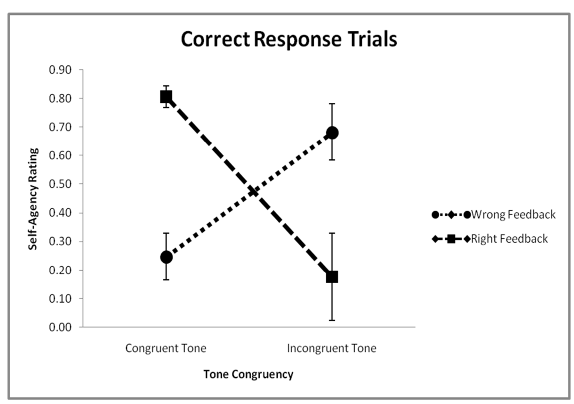


Figure 2: Sense of self-agency for correct responses

For incorrect response, repeated measure analysis of variance revealed that neither tone congruency [$F(1,14)=0.12$, $p=0.73$] nor feedback [$F(1,14)=2.6$, $p=0.12$] had a significant main effect on rating of sense of agency.

But there was significant interaction between tone congruency and type of feedback [F(1,14)=35.40, p<0.01]. Post-hoc analysis revealed that in the Congruent tone condition sense of self-agency was significantly increased in wrong feedback condition (Mean=0.63, SD=0.41) from sense of self-agency in right feedback condition (Mean=0.24, SD=0.16). It also shown that under the Incongruent tone condition, sense of self-agency was reduced when wrong feedback (Mean=0.11, SD=0.12) was given instead of right feedback (Mean=0.75, SD=0.31) (See figure 3).

Post-hoc analysis also has shown the magnitude of manipulation effect. For Correct responses, reduction of sense of self-agency in Wrong feedback – Congruent tone condition is up to level of self-agency in Right feedback – Incongruent tone (p=0.15), but manipulation effect is not that much strong in Wrong feedback – Incongruent tone condition because sense of self agency in this condition is significantly lesser from self-agency in Right feedback – Congruent tone condition (p<0.01).

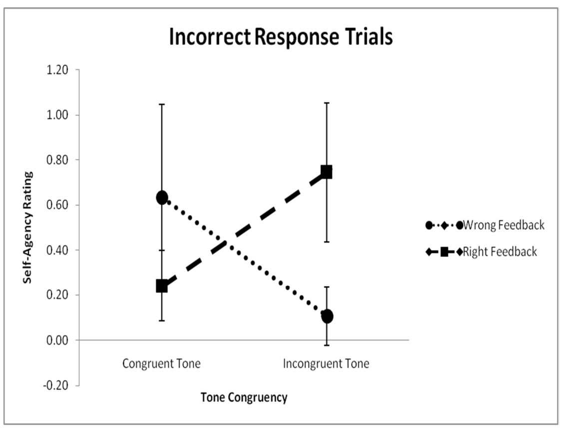


Figure 3: Sense of self-agency for incorrect responses.

These results point towards the potential role of interaction between the feedback and tone congruency on sense of agency.

## Discussion

In this study, we manipulated the effect of error monitoring mechanisms on sense of agency. Participants performed a Flanker task and the error feedback was manipulated orthogonal to the actual responses. Accordingly, we found a differential but consistent behavior between the correct and incorrect responses. For both the correct and incorrect responses, a significant interaction was observed for tone congruency and type of feedback. Consistent with our hypothesis, when participant made a correct choice but the feedback was falsely incorrect, the sense of self-agency increased. In contrast, when participant made an incorrect choice and the feedback was falsely correct, the sense of self-agency decreased. However, a main effect for tone congruency was observed only for correct but not for incorrect responses. These results point out the role of error monitoring mechanisms in attribution of sense of agency.

Previous studies have suggested (Blakemoreet al., 2001, 2002) the profound role of forward model prediction in the attribution of agency to self or an external agent. Forward model predictions are based on motor program which in turn are based on our intentions guided by motor planning. However, forward model of attribution of agency is not able to explain the self-agency attribution for unintended actions – actions which are not congruent with the intentions or motor plan. This incongruency in action could occur because of multiple causes such as (a) action slips due to internal noise (Wolpert & Ghahramani, 2000) in the transformation from motor signal to actual action, (b) the conflict in choosing an action between various alternatives as in a forced choice task. Unintentional action through internal noise or conflict activates the error monitoring mechanisms, and this activation of error monitoring mechanism can play a significant role in attribution of agency by modulating the forward model predictions in real time.

We have found that by activating error monitoring mechanisms by external feedback after the action (but before the actual sensory outcome) alters the attribution of agency. For the correct responses, when forward model prediction was congruent with actual sensory consequences, wrong/falsely incorrect feedback (a cross sign) after the action causes the attribution of agency to an external agent. Similarly, when prediction and actual sensory consequences were not congruent, participants tend to attribute the agency to themselves when their actions were followed by wrong/falsely incorrect feedback. In contrast, when participant made an incorrect response and the feedback was wrong/falsely correct, the sense of self-agency get decreased when consequence of the action is also incongruent with the actual sensory consequences. Similarly, when prediction and actual sensory consequence were congruent, sense of self-agency get increased when actions were followed by wrong/falsely correct feedback.

Previous experiments on error monitoring mechanisms show that cerebellum is involved in error monitoring and optimizing the system (Kawato & Gomi, 1992; Dreher & Grafman, 2002; Menon et al., 2001). Cerebellum is also responsible for predicting the sensory consequences of action (Blakemore et al., 2001). Synofzik et al. (2008) showed that in a motor learning task cerebellum updates predictions about the visual consequences of one's behavior. These findings suggest that error monitoring mechanisms play more profound role in generating sense of agency than just influencing the post-hoc evaluation or serving as direct indicator of agency. Our findings are also in support with the previous findings that cerebellum updates the predictions of forward model. Since, the sensory consequences of actions vary as a result of changes of the effector's efficacy, internal predictions need to updated continuously, our findings suggest that cerebellum as an error monitoring mechanism serves as a device which update predictions of forward model in real time before assimilating any actual sensory consequences.

Alternatively, our results can also be explained by simulation approach to sense of agency. In this line, alteration in attribution of agency can be the result of activation of error monitoring mechanisms which can be used as a signal to navigate within shared representations. Our results also suggest that misattribution of agency in schizophrenia may not be based on imprecise predictions (Synofzik et al., 2010); they misattribute the agency might be because of failure in real time update in predictions by forward model.

These results of alteration in attribution of agency by activating error monitoring mechanisms suggest that forward model predictions are being modulated in real time as soon as they come to know that performed action was not correct. This modulation in prediction before actual sensory consequences helps them to experience a sense of agency for unintended/erroneous actions.

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