# How Anticipation for the Sense of Agency Affects Readiness Potential

Rin Minohara[1*], Wen Wen[1], Shunsuke Hamasaki[1], Takaki Maeda[2], Qi An[1], Yusuke Tamura[1], Hiroshi Yamakawa[1], Atsushi Yamashita[1], Hajime Asama[1]

[1]Department of Precision Engineering, the University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656
Japan

[2]Department of Neuropsychiatry, Keio University School of Medicine, Tokyo, Japan
35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582
Japan

**Abstract:**

**In recent Japanese society, we are facing a severe increase in the number of patients who suffer from motor paralysis and other dysfunctions. Establishing an effective rehabilitation system for them is important, and the key to attain this target is to clarify the mechanisms of one's body perception in the brain. The feeling of controlling our action and external event is an important aspect of body perception, and thus is a topic we have to investigate. This feeling is called the Sense of Agency (SoA), and in order to clarify the mechanism of the SoA, it is necessary to clarify neuro-physiological indices that reflect the arising of this feeling. Recent investigated the relationship between SoA and neural activity with event-related potential (ERP) but these studies focused only on the feedback processing after the action-feedback (e.g. N100, P300), while no study investigated the neural basis of the action-preceding part during SoA paradigm. In this research we focused on feedback-anticipation as an action-preceding factor of SoA, and the purpose of this research is to find a neuro-physiological indices which reflect this factor. We hypothesized that readiness potential (RP) would reflect this factor. In the Libet's clock task based experiment, two conditions which differed in the state of the anticipations for the feedback were prepared. In order to manipulate the anticipation, the probability of the tone occurrence was manipulated in each condition. Earlier and larger RP was observed when the feedback-anticipation was inconsistent in relative with the consistent condition, and additional experiment by increasing the sample size is needed. Our study is the first one that reveals the neural basis of the action-preceding factor of SoA, and we believe that our study will contribute to unravel the neural basis of the SoA.**

## 1. INTRODUCTION

In recent Japanese society, we are facing a severe increase in the number of patients who suffer from motor paralysis and other dysfunctions. To overcome these motor dysfunctions, establishing an effective rehabilitation system is important. The key to attain this target is to clarify the mechanisms of one's body perception in the brain. The feeling of controlling our action and external event is an important aspect of body perception [1], and thus is a topic we have to investigate. This feeling is called the Sense of Agency (SoA) [2], and in order to clarify the mechanism of the SoA, it is necessary to find neuro-physiological indices that reflect the arising of this feeling. There are some studies that investigated the relationship between SoA and neural activity with event-related potential (ERP) [3,4]. These studies focused only on the feedback processing after the action-feedback (e.g. N100, P300), and no study investigated the neural basis of the action-preceding part during SoA paradigm, although previous studies claim that action-preceding circumstances is also an crucial factor of SoA arising [5]. Clarifying the neural basis of this action-preceding aspect is also important for more precise understanding of the SoA arising mechanism.

In this research we focused on feedback-anticipation as an action-preceding factor of SoA, and the purpose of this research is to clarify the neuro-physiological indices which reflect this factor. We hypothesized that readiness potential (RP) would reflect this factor. RP is a preconscious brain activation which precedes the voluntary action [6]. Our main focus was the RP amplitude and the onset, which are said to reflect action preceding factors including one's level of intention of action and preparatory states preceding the action [7]. Our hypothesis was that inconsistent anticipation for the feedback would affect these action-preceding factors and lead to larger and earlier RP relative to when the feedback-anticipation was consistent. In the present study, two conditions which differed in the state of the anticipations for the feedback were prepared in the experiment, which was designed based on the Libet's clock task. ERPs nearby the actions were recorded for RP measuring.

## 2. METHODS

### 2.1 Participants

Six participants (five males and one female; mean age 24.2 years, *SD* = 1.1, range 22 - 25 years) took part in the experiment. All participants gave informed consent before the participation.

## 2.2 Task Design and Procedure

In order to manipulate the anticipation for the action-feedback, we changed the probability of the feedback occurrence during a SoA paradigm which was a modified version of those of Libet et al. [8].

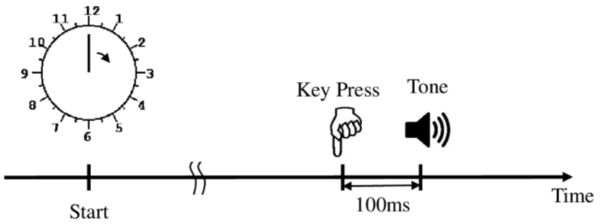



**Figure 1.** A timeline of a single trial is shown.

The timeline of one trial is shown in Figure 1. Each trial began with a clock presented on the screen. A clock hand of radius 1.3 cm appeared on the screen with the participants' simultaneous pressing of a space key, and started rotating with a period of 2560 ms. Participants were instructed to make another voluntary space key pressing in their own time, after at least one full rotation of the clock hand. The clock hand continued to rotate for a random interval between 1.5 s and 2.4 s after the movement. Participants' movement was followed by a tone of 500 Hz (presented for 100 ms) after an interval of 100 ms with a certain probability. After this single trial, participants were instructed to report "when you first began to prepare your movement" in clock units.

Two conditions were prepared in this experiment, and the probability of tone occurrence differed between these conditions and the feedback-anticipation was manipulated by this probability. In the consistent anticipation condition, all participants' movements were followed by the tone, whereas half of the movement was followed by the tone in the inconsistent anticipation condition. Each condition contained 40 trials with tone, meaning 40 trials in consistent anticipation condition, and 80 trials in inconsistent anticipation condition. Neural activities in these conditions were compared using trials in which the movement was followed by the tone.

## 2.3 Electrophysiological Recordings and Analysis

Electrical activities were recorded with an electroencephalography (EEG) device (g.USBamp, g.tec, Austria) according to a modified 10-20 setting (with the electrodes Fp1/2, F3/z/4, FC5/1/z/2/6, T7/8, C3/z/4, CP5/1/2/6, P3/z/4, O1/2). Ground electrode was placed on the forehead and an initial reference was placed at right earlobe. Two channel electrooculography (EOG) was recorded around the right eye to detect ocular artifacts. All data were recorded at a sampling rate of 512 Hz, with a 0.1 to 100 Hz band-pass filter and a 50 Hz notch filter.

Offline analyses were conducted with EEGLAB (version 13.6.5b) [9]. Signals were re-referenced to the link of the right and left ear lobes, and a 30 Hz low-pass filter was applied. Continuous EEG data was segmented into epochs ranging from - 2.5 to 1.0 s from the onset of the key press, which was baseline corrected with the first 200 ms. Except for the ocular artefacts, epochs that exceeded ± 100 μV at any channels were rejected. Ocular artefacts were then corrected using independent component analysis [10]. Trials which participants pressed their key during the first rotation were also excluded. Remaining epochs were used for further analysis. Readiness potential for each participant was calculated by averaging the epochs at Cz. RP amplitude was evaluated using the negative peak value. Regarding the RP onset, it was calculated using the jackknife procedure [11], and were quantified as the time when the amplitude exceeded 10% of the peak amplitude.

## 3. RESULTS

Figure 2 shows the grand averaged RP data in each condition at Cz electrode. A student's $t$-test analysis on the RP peak amplitude revealed a significant difference between the two anticipation conditions ($t(5) = 2.656$, $p < .05$, $1\text{-}\beta = 0.571$). A student's $t$-test analysis on RP onset revealed a significant difference between the two anticipation conditions ($t(5) = 3.533$, $p < .05$, $1\text{-}\beta = 0.804$).

## 4. DISCUSSION

In the present study, we examined the influence of feedback-anticipation during SoA arising on neural activity. Our hypothesis was that larger and earlier RP would be observed when anticipation for the action-feedback was inconsistent, and we designed an experiment which consisted of two conditions which differed in the state of the feedback-anticipation. The results indicated differences in RP amplitude and onset between the two conditions. RP raised earlier and larger in the inconsistent anticipation condition relative to the consistent anticipation condition (Figure 2). Since the tone occurrence probability was 100% in the consistent anticipation condition, participant probably learned a robust causality between their key presses and the tone. The attenuated RP in the consistent anticipation condition probably reflected the stable anticipation of the consistent feedback when the participants prepared the action. In contrast, the amplitude of RP was larger and the onset of RP was earlier in the inconsistent condition, probably reflecting the larger mental effort during the motor preparation. In addition, such mental effort during motor preparation may contribute to feeling of agency as an implicit factor. However, because SoA is influenced by both predictive and postdictive factors, we do not suggest that stable anticipation would result in stronger SoA. In summary, anticipation of feedback of an action may influence the

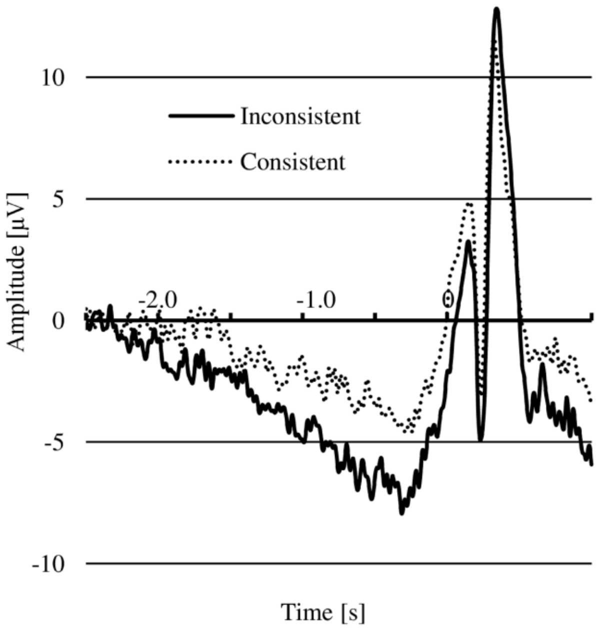



**Figure 2.** Grand averaged EEGs at Cz electrode from -2.5 s to 1.0 s of the key-press is shown.

mental status of motor preparation, and stable anticipation is associated with an attenuated RP. Our study is the first one that reveals the neural basis of the action-preceding factor of SoA, and we believe that our study will contribute to unravel the neural basis of the SoA.

Additionally, although we found a significant difference between the two experimental conditions, the statistical power was weak due to the small sample size. We will increase the sample size in order to increase the statistical power.

## 5. CONCLUSION

In conclusion, we demonstrated that the state of anticipation for the feedback affected the RP onset and amplitude. Earlier and larger RP was observed when the feedback-anticipation was inconsistent in relative with the consistent condition. Additional experiments by increasing the sample size and with other experimental design are required for further understanding. We believe that this study would greatly contribute to the understanding of the neural basis of the SoA arising.


## 6. ACKNOWLEDGEMENTS

This work was partially supported by JSPS KAKENHI, Grant-in-Aid for Scientific Research on Innovative Areas "Understanding brain plasticity on body representations to promote their adaptive functions" (Grant Number 26120005).


## REFERENCES


[1] M. Jeannerod, "The Mechanism of Self-recognition in Humans," Behavioural Brain Research, Vol. 142, pp. 1-15, 2003.

[2] S. Gallagher, "Philosophical Conceptions of the Self: Implications for Cognitive Science", Trends in Cognitive Sciences, Vol. 4, pp. 14-21, 2000.

[3] S. Kühn, I. Nenchev, P. Haggard, M. Brass, J. Gallinat and M. Voss, "Whodunnit? Electrophysiological Correlates of Agency Judgements", PLoS ONE, Vol. 6, Issue. 12, e28657, 2011.

[4] J. G. Bendmark and E. A. Franz, "Agency Attribution: Event-related Potentials and Outcome Monitoring", Experimental Brain Research, Vol. 232, pp. 1117-1126, 2014.

[5] M. Synofzik, G. Vosgerau and M. Voss, "The Experience of Agency: an Interplay between Prediction and Postdiction", Frontiers in Psychology, Vol. 4, pp. 1-8, 2013.

[6] H. H. Kornhuber and L. Deecke, "Hirnpotentiala¨nderungen beim Menschen vor und nach Willkurbewegungen, dargestellt mit Magnetband-Speicherung und Ruckwartsanalyse", Pflugers Arch, Vol. 281, p. 52 1964.

[7] H. Shibasaki and M. Hallet, "What is Bereitschaftspotential?", Clinical Neurophysiology, Vol. 117, pp. 2341-2356, 2006.

[8] B. Libet, C. A. Gleason, E. W. Wright and D. K. Pearl, "Time of Conscious Intention to Act in relation to Onset of Cerebral Activity (Readiness-potential). The Unconscious Initiation of a Freely Voluntary Act", Brain, Vol. 106, pp. 623-642, 1983.

[9] A. Delorme and S. Makeig, "EEGLAB: an Open Source Toolbox for Analysis of Single-trial EEG Dynamics including Independent Component Analysis", Journal of Neuroscience Methods, Vol. 134, No. 1, pp. 9-21,2004.

[10] T. P. Jung, S. Makeig, C. Humphries, T. W. Lee, M. J. Mckeown, V. Iragui and T. Sejnowski, "Removing electroencephalographic artifacts by blind source separation", Psychophysiology, Vol. 37, pp. 163-178, 2000.

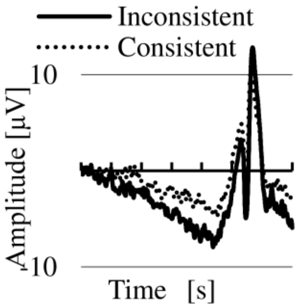
[11] J. Miller, T. Patterson and R. Ulrich, "Jackknife-based Method for Measuring LRP Onset Latency Differences", Psychophysiology, Vol. 35, pp. 99-115, 1998.

# How Anticipation for the Sense of Agency Affects Readiness Potential

*Rin Minohara[1*], Wen Wen[1], Shunsuke Hamasaki[1], Takaki Maeda[2], Qi An[1], Yusuke Tamura[1], Hiroshi Yamakawa[1], Atsushi Yamashita[1], Hajime Asama[1]*

[1]Department of Precision Engineering, the University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656
Japan

[2]Department of Neuropsychiatry, Keio University School of Medicine
35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582
Japan




In recent Japanese society, we are facing a severe increase in the number of patients who suffer from motor paralysis and other dysfunctions. To overcome these motor dysfunctions, establishing an effective rehabilitation system is important. The key to attain this target is to clarify the mechanisms of one's body perception in the brain. The feeling of controlling our action and external event is an important aspect of body perception, and thus is a topic we have to investigate. This feeling is called the Sense of Agency (SoA), and in order to clarify the mechanism of the SoA, it is necessary to find neuro-physiological indices that reflect the arising of this feeling. There are some studies that investigated the relationship between SoA and neural activity with event-related potential (ERP). These studies focused only on the feedback processing after the action-feedback (e.g. N100, P300), and no study investigated the neural basis of the action-preceding part during SoA paradigm, although previous studies claim that action-preceding circumstances is also an crucial factor of SoA arising. Clarifying the neural basis of this action-preceding aspect is also important for more precise understanding of the SoA arising mechanism.

In this research we focused on feedback-anticipation as an action-preceding factor of SoA, and the purpose of this research is to find a neuro-physiological indices which reflect this factor. We hypothesized that readiness potential (RP) would reflect this factor. RP is a preconscious brain activation which precedes the voluntary action. Our main focus was the RP amplitude and the onset, which are said to reflect action preceding factors including one's level of intention of action and preparatory states preceding the action. Our hypothesis was that inconsistent anticipation for the feedback would affect these action-preceding factors and lead to larger and earlier RP relative to when the feedback-anticipation was consistent.

In the present study, two conditions which differed in the state of the anticipations for the feedback were prepared in the experiment, which was designed based on the Libet's clock task. In order to manipulate the anticipation, the probability of the tone occurrence was manipulated in each condition. Event related EEGs nearby the actions were recorded for RP measuring. Earlier and larger RP was observed when the feedback-anticipation was inconsistent in relative with the consistent condition (shown in the figure), and additional experiment by increasing the sample size is needed. Our study is the first one that reveals the neural basis of the action-preceding factor of SoA, and we believe that our study will contribute to unravel the neural basis of the SoA.