Readiness Potential Reflects the Predictive Aspect of Sense of Agency

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Sense of Agency (SoA) refers to the experience of controlling external events. SoA is considered to have predictive and postdictive aspect. Recent studies have investigated the relationship between SoA and event-related potentials, but these studies focused only on the postdictive aspect, while the brain activities related to the predictive aspect of SoA remain unclear. In the present study, we focused on readiness potential (RP) and examined the influence of prediction of SoA on RP. In the experiment, participants pressed a key to trigger a tone, and the event-related potentials before and after the key-press was recorded. In the normal predictive condition, all the tones were presented after key-press, thus participants could predict that their key-press would probably cause a tone. In contrast, in the low predictive condition, one third of the tones were presented before the key-presses, thus the causability of key-presses on tones were doubtful. The results indicated earlier RP in the normal predictive condition relative to the low predictive condition, although the difference did not reach significant level due to the small sample size. We will increase participants to confirm the difference in RP between the two predictive conditions in future work. We believe that our work provides important knowledge for the understanding of the neural basis of SoA.

1 Introduction

When we act an action, we have an experience of controlling the external events. This is called the sense of agency (SoA) [1]. The SoA is an important element which composes self-consciousness, and has been studied in many fields. According to prior studies, SoA is considered to have both the predictive and the postdictive aspects [2], but the neural basis underlying these aspects remains unclear.

There are some studies that investigated the relationship between SoA and neural activity with event-related potential (ERP) [3] [4]. However, these studies focused only on the postdictive aspects, and no study had investigated the neural basis of the predictive aspect of SoA.

We hypothesized that readiness potential (RP) would reflect the predictive aspect of SoA. RP is a preconscious brain activation which precedes the voluntary action. Previous studies show that RP reflects the intention for action [5]. Prediction of SoA is probably closely related to intentions of actions and might also reflected by RP. In the present study, two conditions differed in the amount of the prediction of the feedback, and the ERPs nearby the actions were recorded.

2 Methods

2.1 Participants

Seven participants (five males; mean age 21.9 years, SD = 2.7, range 20-28 years) took part in the experiment. All participants gave informed consent.

2.2 Normal predictive condition

In the normal predictive condition, each trial began with a black screen, with gray 2 mm square shown at the center. The square was changed to cross mark after few seconds. Participants were instructed to push the space key at their voluntary timing, taking some interval (from 2 s to 4 s) after the appearance of the cross mark. After participants pushed the key, a 400 Hz tone was presented for 200 ms from the earphone at a random delay (100, 300 or 600 ms). These procedures are shown in Fig. 1. Participants were told that tone could be either produced by themselves or by the experimenter who was seated in front of the computer outside their sight. After each trial, participants answered the following question with a " yes " or " no " response: " Did you feel that you caused the tone by your key press? "

2.3 Low predictive condition

Participants did the same task as that in the normal predictive condition. However, trials that tone precedes the participants ' key press (see Fig. 2) were mixed with trials in the normal predictive condition. Participants also made judge about the tone as like normal predictive condition.

2.4 Procedure

In the normal predictive condition, participants performed 120 trials, comprising 40 trials for each delay condition. In the low predictive condition, participants performed 180 trials, comprising same 120 trials as task 1 and 60 trials for tone preceding condition. The two predictive conditions were blocked, and the block order was counter-balanced across participants. Trial order in each block was randomized.

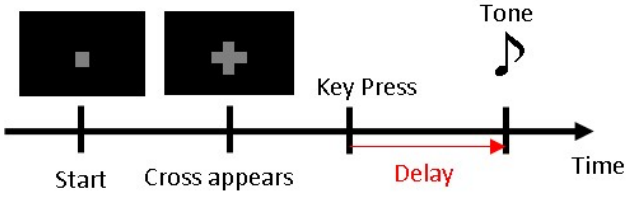

Fig. 1 Procedure in the normal predictive condition

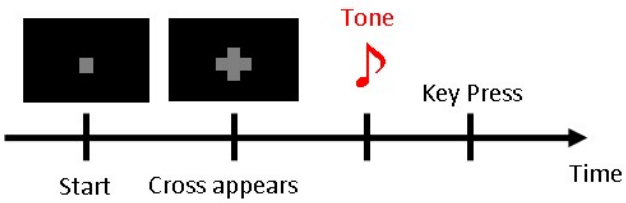

Fig. 2 Procedure of the trial which tones preceded key-press in the low predictive condition

2.5 Electrophysiological recordings

Electrical activities were recorded with an electroencephalography (EEG) device (eegosports 64ch, eemagine, Germany) according to a modified 10-20 setting (with the electrodes Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, O2, FCz, TP7, TP8, Oz). EEG signals were referenced to FCz, and re-referenced offline to Pz in the phase of analyzing. Impedances of the electrodes were kept below 15KΩ. One channel electrooculography (EOG) was recorded to detect ocular artifacts. All data were recorded at a sampling rate of 1024 Hz.

3 Results

Event-related EEG was measured as average over the eight electrodes around Cz (FC1, FCz, FC2, C3, Cz, C4, CP1, CP2). Ranging from -2.5s to 1.0s of the event, the onset of the key press, was analyzed with the baseline correction of the first 200ms. Epochs affected by artifact ($\pm$ 100 μV) of EOG electrode were excluded for analysis.

Fig. 3 shows the grand averaged event-related EEG for the normal predictive and low predictive condition. According to t-test on the RP rising time there was no significant difference between two tasks ($t(6)$ = .760, $p > .05$, 1-β = .201). Also, there was no significant difference in the amplitude of the RP ($t(6)$ = .203, $p > .05$, 1-β = .201). Statistical power was low due to the sample size.

4 Discussion

In the present study, we designed an experiment to examine the influence of prediction of SoA on RP. We proposed two conditions which differ in the amount of prediction of the feedback. The results indicated differences in RP between the two predictive conditions.

Although there was no significant differences between the two predictive conditions due to small sample size, the results indicated that RP raised earlier and larger in the normal predictive condition relative to the low predictive condition (Fig. 3). The prediction of SoA probably influenced the intentions of actions, and influenced the RPs before actions.

Our study is the first one that reveals the neural basis of the predictive aspect of SoA, and we believe that our study will contribute to unravel the neural basis of the SoA. We will increase the number of participants to increase statistical power of the study in future work.

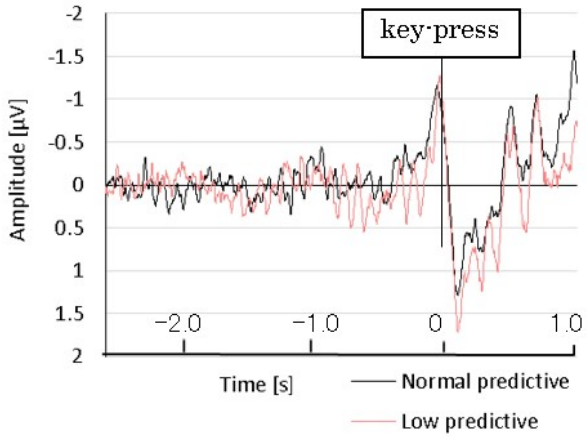

Fig. 3 Grand averaged event-related EEGs from -2.5 s to 1.0 s of the key-press is shown.

5 Conclusion

In this study, we examined ERPs related to the predictive aspect of SoA and found that RP reflects the prediction of SoA. Further experiment is needed to increase the statistical power of the study.

6 Acknowledgments

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