Approach of visual stimuli facilitates the prediction of tactile events and suppresses beta band oscillations around the primary somatosensory area

Tsukasa Kimura

The purpose of the present study was to investigate whether the approach of visual stimuli influences prediction of subsequent tactile events. For this purpose, we examined electroencephalograms (EEGs) during the prediction of tactile events when visual stimuli did or did not approach. Tactile stimuli were presented with a high probability (80%) of being applied to the left (or right) index finger and a low probability (20%) of being applied to the opposite index finger. In the approach condition, visual stimuli were presented towards the hand to which the high-probability tactile stimuli were presented; in the neutral condition, visual stimuli did not approach. The result of time-frequency analysis for the EEGs showed that beta band event-related spectral perturbation at the electrodes around the primary somatosensory area (C3 and C4) was suppressed about 300 ms before the presentation of a tactile stimulus and that event-related desynchronization (ERD) occurred in all conditions. Moreover, the beta band ERD of the approach condition was larger than that of the neutral condition. These results provide evidence that the approach of visual stimuli facilitates prediction itself for subsequent tactile events. NeuroReport 32: 631–635 Copyright © 2021 The Author(s). Published by Wolters Kluwer Health, Inc.

NeuroReport 2021, 32:631–635

Keywords: event-related desynchronization, event-related spectral perturbation, multimodal interaction, prediction, time-frequency analysis, visuotactile processing

The Institute of Scientific and Industrial Research (ISIR), Osaka University, Ibaraki, Japan

Correspondence to Tsukasa Kimura, PhD, The Institute of Scientific and Industrial Research (ISIR), Osaka University, Ibaraki 567-0047, Japan
Tel/fax: +81 06 6879 8426; e-mail: kimura@ai.sanken.osaka-u.ac.jp

Received 18 January 2021 Accepted 17 February 2021

Introduction

Prediction is one of the main cognitive functions of the brain. We adapt to the environment by predicting an event, detecting prediction error as a gap between the prediction and the event, and correcting the prediction (for a review, see [1]). In particular, predicting a tactile event before physical contact occurs is necessary for us to defend ourselves. Recent studies reported that prior visual stimuli approaching the body facilitate prediction of a subsequent tactile event [2–4]. In these studies, the prediction of a tactile event was facilitated by visual stimuli approaching the body; as a result, tactile events that deviated from this prediction elicited large amplitudes of event-related brain responses (ERPs). In other words, these studies focused on prediction error. The detection of prediction error is important for correcting predictions; similarly, prediction itself is also important for defending the body. However, it remains unclear whether approaching visual stimuli influence the occurrence of prediction itself for subsequent tactile events.

Previous prediction studies reported that neuronal oscillations at each sensory cortex decrease during the prediction of each sensory event [5] for a review, see [6–7]. This phenomenon is called event-related desynchronization (ERD); in particular, ERD for a tactile event occurs in the beta band (14–30 Hz) during prediction of the event about 300 ms before the event occurs [8]. Therefore, it seems likely that this ERD in the beta band before the tactile event will occur if the approach of visual stimuli influences prediction itself for subsequent tactile events.

The purpose of the present study was to investigate whether the approach of visual stimuli influences prediction itself for subsequent tactile events. For this purpose, we examined electroencephalograms (EEGs) during the prediction of tactile events when visual stimuli did or did not approach. Participants were asked to perform a simple reaction time task to tactile stimuli, which were presented after the presentation of visual stimuli. Tactile stimuli were presented with a high probability (80%) of being applied to the left (or right) index finger and a low probability (20%) of being applied to the opposite index finger. In the approach condition, visual stimuli were presented towards the hand to which the high-probability tactile stimuli were presented; in the neutral condition, visual stimuli did not approach. The frequency with which the tactile stimuli would be presented to each index finger was told to participants before the experiment. Therefore, the conditions differed only in the presentation of visual stimuli; participants could predict the location of a high-probability tactile stimulus regardless of the approach of visual stimuli. We predicted that...
ERDs in the beta band would occur in each condition before the presentation of the tactile stimulus if participants can predict the tactile stimulus [8], and that the ERD in the approach condition would be larger than that in the neutral condition if the approach of visual stimuli facilitates prediction itself for a subsequent tactile stimulus. In addition, as in a previous study [2], we examined contingent negative variation (CNV) [9] before the presentation of tactile stimuli to ensure that temporal prediction of tactile stimuli did not differ between conditions. We predicted that the amplitude of CNV would not differ between conditions if participants can predict the timing of the presentation of the tactile stimulus in both conditions.

Methods

Participants

Eighteen undergraduate and graduate students (10 females and 8 males; 18–25 years of age) participated in the experiment. All participants were right-handed, according to their self-report, and had normal or corrected-to-normal vision. This experiment was approved by The Institute of Scientific and Industrial Research's Research Ethics Review Board under Osaka University regulations. Written informed consent was obtained from all participants, and their rights as experimental subjects were protected.

Stimuli and procedure

The stimuli and procedure were set according to a previous study [2]. In the experimental room, participants were seated and put their hands and forearms on an obliquely oriented board in front of them. Their hands were 32.0 cm apart. Tactile stimuli were presented to participants’ index fingers by a vibration stimulus generator and a solenoid vibrator (Uchida Denshi Corporation, FB-2006D and FB-1005). The vibration was 250 Hz of 200 ms in duration. These stimuli were presented to the left (or right) index finger with a high probability (80%), and to the opposite index finger with a low probability (20%). These stimuli were presented in random order from trial to trial, and the order of the location (left or right) of the stimulus presentation at high (or low) probability was counterbalanced across blocks.

Three white light-emitting diodes (LEDs) were used as visual stimuli. Each LED was a square with 0.8 cm sides. Three LEDs were placed at equal distances (8.0 cm intervals) between the arms on an obliquely oriented board. The visual stimuli were single block pulses of 25 cd and 200 ms duration.

Each trial was composed of three visual stimuli and one tactile stimulus. The stimulus onset asynchrony was set to 1000 ms. The interval between trials was either 1000 or 1200 ms at random with equal probability. Each block was composed of 84 trials [high-probability tactile stimuli: 64 trials; low-probability tactile stimuli: 16 trials; no tactile stimuli (catch trial): four trials], which took approximately 7 min. Two blocks were presented for each condition. The interval between blocks was 2 min, and after the second block, the participants rested for 10 min and then started the remaining two blocks. The order of conditions was randomized between participants.

The two conditions were distinguished by the pattern of visual stimuli, and the patterns were administered in separate blocks. In the approach condition, LEDs flashed sequentially towards the hand where the high-probability tactile stimulus was presented (i.e., if the high-probability tactile stimulus was set at the left index finger, the LEDs flashed sequentially right, center, and left), and the subsequent tactile stimulus was presented to the left (or right) index finger. In the neutral condition, the center LED flashed three times with the same timing, and then the subsequent tactile stimulus was presented to the left (or right) index finger. The participants were required to gaze at the center LED, in order to control their eye movements, and not to move their eyes and bodies more than necessary in each condition. Moreover, the participants were instructed to respond by pressing a button with the left (or right) foot whenever the tactile stimuli were presented, and to not respond when tactile stimuli were not presented (i.e., the catch trials). Half of the participants used the left foot and the other half used the right foot. Finally, they were told at the start of each block which hand would be presented with the high-(low-) probability stimuli.

Recording and analyses

EEG data were recorded by Polymate AP1132 (Miyuki Giken, Japan) and an electrode cap (EasyCap GmbH, Germany) using Ag/AgCl electrodes at 26 sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FC3, FCz, FC4, T7, C3, Cz, C4, T8, CP3, CPz, CP4, P7, P3, Pz, P4, P8, O1, Oz, O2) according to the modified 10–20 System. In addition, electrodes were also placed on both earlobes (A1 and A2). The reference electrode was on the tip of the nose, and the ground electrode site was AFz. The data from all channels were recorded using the Mobile Acquisition Monitor Program (Miyuki Giken, Japan). The electrode impedances were kept below 10 kΩ. A DC filter was used at recording. The sampling rate was 1000 Hz.

To analyze the EEG data, the EEGLAB toolbox [10] and ERPLAB toolbox [11] on MATLAB (Mathworks Inc.) were used. Artifacts derived from eye movements and eye blinks were rejected using an automatic EEG artifact detector based on the joint use of spatial and temporal features (ADJUST) of the EEGLAB toolbox [12]. In the time-frequency analysis, the EEG data epoch was 1800 ms (including a 900 ms prestimulus of the third visual stimulus). Epochs in which the EEG signal variation exceeded ±100 μV were rejected. After artifact rejection, EEG data were transformed by the Morlet wavelet transformation function applied in a Hanning-tapered window in EEGLAB. The settings were as follows: epoch time limits: −900 to 900 ms,
Approach of visual stimuli and beta band ERD

Kimura 633

Using 400 time points; frequency limits: 8–30 Hz; baseline limits: −900 to −500 ms; wavelet cycles: 3–0.5. The processed data was output from −691.88 to 690.88 ms (400 time points) and from 8 to 30 Hz (22 frequency points). The beta band (14.29–30 Hz) ERSPs for time range 300–0 ms at the electrodes of C3 and C4 (i.e., the neighboring electrodes for the primary somatosensory area) were averaged in each block, consistent with a previous study [8]. In addition, these electrodes were distinguished by prediction of a tactile stimulus. C3 (C4) is ipsilateral and C4 (C3) is contralateral when the block with the high-probability tactile stimulus is presented to the left (right) hand. The averaged beta band ERSP for ipsilateral and contralateral were calculated in each condition. After this processing, the numbers of the remaining trials were 155–160 (0–3.1% rejected) for the approach condition and 157–160 (0–1.9% rejected) for the neutral condition.

(a) The beta band event-related spectral perturbations (ERSPs) in each condition and each laterality, and (b) the mean beta band ERSPs at the time range of −300 to 0 ms in both conditions. The error bars indicate the standard errors (SEs) of the means across participants. An asterisk indicates a significant difference in the mean beta band ERSPs between conditions (*P < 0.05).
To extract CNV, the EEG data were digitally band-pass filtered at 0.01–30 Hz (6 dB/octave) using an IIR Butterworth analog simulation filter. After this, the data epoch was 1200 ms (the baseline was a 200–0 ms prestimulus of the third visual stimulus, and the onset of the tactile stimulus occurred at 1000 ms). Epochs in which the EEG signal variation exceeded ±100 μV were rejected. After artifact rejection, the numbers of remaining trials were 151–160 (0–5.6% rejected). The mean CNV amplitude was obtained from a latency window of 500–1000 ms. The appropriate latency window was defined based on observation of the resultant ERP waveforms.

Figure 2 illustrates the grand average CNV elicited at the Cz electrode sites. The gray area denotes the time range of contingent negative variation (CNV) (500–1000 ms).

Results

Behavioral data

Averaged reaction times of all participants were 426 ms (SE = 15.13), 444 ms (SE = 15.41), 419 ms (SE = 13.89), and 428 ms (SE = 17.57) for the approach-high-probability, approach-low-probability, neutral-high-probability, and neutral-low-probability stimuli. The results of the ANOVAs revealed that the main effect of stimulus probabilities was significant [F(1, 17) = 20.70, P < 0.001, \( \eta^2_p = 0.55 \)], and the reaction time to the low-probability stimulus was longer than the reaction time to the high-probability stimulus. The main effect of conditions [F(1, 17) = 3.11, P = 0.10, \( \eta^2_p = 0.15 \)] and the interaction [F(1, 17) = 1.99, P = 0.18, \( \eta^2_p = 0.10 \)] were NS.

Beta band event-related spectral perturbations

Figure 1 illustrates (a) the beta band ERSPs in each condition and each laterality and (b) the averaged beta band ERSPs at the time range of −300 to 0 ms in all conditions and lateralities. The results of the one sample t-test revealed that the beta band ERSPs were smaller than zero in all conditions and lateralities [\( t_{(17)} > 2.76, P < 0.01, d_s > 0.92 \)]; therefore, ERD occurred in all conditions and lateralities. The results of the ANOVAs revealed that the main effect of conditions was significant [F(1, 17) = 6.48, P = 0.02, \( \eta^2_p = 0.28 \)], and that the ERD of the approach condition was larger than that of the neutral condition. The main effect of laterality [F(1, 17) = 3.57, P = 0.08, \( \eta^2_p = 0.17 \)] and the interaction [F(1, 17) = 1.04, P = 0.32, \( \eta^2_p = 0.06 \)] were NS.

Contingent negative variation

Figure 2 illustrates the grand average CNV elicited in all trials at Cz, where the CNV was elicited at maximum amplitude. The gray area indicates the time range of CNV (500–1000 ms). Comparisons between conditions by paired t-tests of mean amplitude of CNV revealed no significant difference [\( t_{(17)} = 0.30, P = 0.57, d = 0.08 \)].

Discussion

The present study aimed to investigate whether the approach of visual stimuli influences prediction itself for subsequent tactile events. For this purpose, ERDs in the beta band, reaction times, and CNVs were compared between the approach condition and the neutral condition. Our results showed that the amplitude of CNV did not differ between the conditions and that the reaction time to the low-probability stimulus was longer than the reaction time to the high-probability stimulus. These results are the same as in a previous study [2] and indicate that the participants could predict the timing of the presentation of the tactile stimulus and the location of the presentation of the high-probability tactile stimulus in both conditions.

Moreover, the beta band ERSPs were suppressed about 300 ms before the presentation of the tactile stimulus in
In summary, the present study indicated that the approach of visual stimuli influences not only prediction error but also prediction itself for a subsequent tactile stimulus. This result suggests that the approach of visual stimuli is important information for prediction of subsequent tactile events and that it influences a gradual tactile prediction process. This study extended our understanding of the predictive function based on multisensory interaction.

Acknowledgements
This study was supported by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (No. 19K23363) to Tsukasa Kimura.

Conflicts of interest
There are no conflicts of interest.

References
1. Clark A. Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behav Brain Sci 2013; 36:181–204.
2. Kimura T, Katayama J. Approach of visual stimuli modulates spatial expectations for subsequent somatosensory stimuli. Int J Psychophysiol 2015; 96:176–182.
3. Kimura T, Katayama J. Visual stimuli approaching toward the body influence temporal expectations about subsequent somatosensory stimuli. Brain Res 2017; 1644:95–101.
4. Kimura T, Katayama J. The approach of visual stimuli influences expectations about stimulus types for subsequent somatosensory stimuli. Exp Brain Res 2018; 236:1563–1571.
5. Jasper H, Penfield W. Electroencephalograms in man: effect of voluntary movement upon the electrical activity of the precentral gyrus. Arch F Psychiatr U 2 Neur 1949; 183:163–175.
6. Pfurtscheller G, Lopes da Silva HF. Event-related EEG/MEG synchronization and desynchronization: basic principles. Clin Neurophysiol 1999; 110:1842–1857.
7. Engel AK, Fries P, Singer W. Dynamic predictions: oscillations and synchrony in top–down processing. Nat Rev Neurosci 2001; 2:704–716.
8. van Ede F, Jensen O, Maris E. Tactile expectation modulates pre-stimulus beta-band oscillations in human sensorimotor cortex. Neuroimage 2010; 51:867–876.
9. Walter WG, Cooper R, Aldridge VJ, Mccallum WC, Winter AL. Contingent negative variation: an electric sign of sensorimotor association and expectation in the human brain. Psychophysiology 2001; 38:229–240.
10. Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods 2004; 134:9–21.
11. Lopez-Calderon J, Luck SJ. ERPLAB: an open-source toolbox for the analysis of event-related potentials. Front Hum Neurosci 2014; 8:213.
12. Magnon A, Jovicich J, Bruzzone L, Buatti M. ADJUSTER: an automatic EEG artifact detector based on the joint use of spatial and temporal features. Psychophysiology 2011; 48:229–240.
13. Greenhouse SW, Geisser S. On methods in the analysis of profile data. Psychometrika 1959; 24:95–112.
14. Shaffer JP. Modified sequentially rejective multiple test procedures. J Am Stat Assoc 1986; 81:826–831.
15. Cohen J. Statistical Power Analysis for the Behavioral Sciences. New York: Academic Press; 2013.
16. Guiponi O, Cîrlej O, Oduoard S, Wardak C, Ben Hamed S. Whole brain mapping of visual and tactile convergence in the macaque monkey. Neuroimage 2015; 117:93–102.
17. Graziano MS, Yap GS, Gross CG. Coding of visual space by premotor neurons. Science 1994; 266:1054–1057.
18. Duhamel JR, Colby CL, Goldberg ME. Ventral intraparietal area of the macaque: congruent visual and somatic response properties. J Neurophysiol 1998; 79:126–136.
19. Guiponi O, Wardak C, Ibarola D, Comte JC, Sappey-Marinier D, Pinède S, Ben Hamed S. Multimodal convergence within the intraparietal sulcus of the macaque monkey. J Neurosci 2013; 33:4128–4139.
20. Cîrlej O, Guiponi O, Oduoard S, Pinède S, Wardak C, Ben Hamed S. The prediction of impact of a looming stimulus onto the body is subserved by multisensory integration mechanisms. J Neurosci 2017; 37:10656–10670.
21. Graziano MS, Cooke DF. Parieto-frontal interactions, personal space, and defensive behavior. Neuropsychologia 2006; 44:845–859.
22. Salenius S, Schnitzler A, Salmelin R, Jousmäki V, Hari R. Modulation of human cortical rolandic rhythms during natural sensorimotor tasks. Neuroimage 1997; 5:221–228.
23. Nikouline VV, Linkenkaer-Hansen K, Wikström H, Kesäniemi M, Antonova EV, Ilmoniemi RJ, Hari R. Dynamics of mu-rhythm suppression caused by median nerve stimulation: a magnetoencephalographic study in human subjects. Neurosci Lett 2000; 294:163–166.

Copyright © 2021 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.