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Approach of visual stimuli modulates spatial expectations for subsequent somatosensory stimuli

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ABSTRACT

To examine how the approach of visual stimuli toward the body influences expectations regarding subsequent somatosensory stimuli, we recorded event-related brain potentials (ERPs; nose reference) during a simple reaction time to somatosensory stimuli task. Twelve participants were asked to place their arms on a desk, and three LEDs were placed between their arms at equal intervals. Electrical stimuli were presented to the left (or right) wrist at a high probability (80%) or to the opposite wrist at a low probability (20%). Each trial was composed of three visual stimuli followed by one electrical stimulus. In Experiment 1, the right, center, and left (or left, center, and right) LEDs were turned on sequentially toward the wrist to which the high probability somatosensory stimuli was presented (congruent condition), or the center LED were presented three times (neutral condition). Experiment 2 was composed of the congruent condition and the inverse of the congruent condition (incongruent condition). In both experiments, the reaction times to low probability stimuli were longer than those to high probability stimuli. Moreover, the low probability stimuli elicited a larger P3 amplitude than the high probability stimuli. In addition, the P3 amplitude was higher under the visual approach condition (i.e., the congruent condition in each experiment) than under the control condition (i.e., the neutral and incongruent conditions). Furthermore, no effect on the CNV amplitude before the somatosensory stimuli was found. These results suggest that visual stimuli directed toward the body induce an automatic spatial expectation for subsequent somatosensory stimuli.

1. Introduction

In everyday life, we integrate information from multimodal inputs, such that adaptive behavior can occur across diverse environments. For example, we can avoid approaching objects by detecting them using visual information before the objects touch the body. Several studies have investigated interactions between the visual modality and other sensory modalities to better understand how such multimodal information is combined. In particular, the number of visuo-tactile studies has increased in the last 15 years (see Wesslein et al., 2014, for a review). For example, behavioral studies have found evidence that exogenous and endogenous visual spatial attention (e.g., Spence et al., 2000a; see Spence, 2002, for a review), temporal order judgment (TOJ; e.g., Craig, 2005; Spence et al., 2003), and visual motion (e.g., Craig, 2006; Gray and Tan, 2002) influence the perception of somatosensory stimuli. In addition, a few electrophysiological studies have begun to examine such interactions using event-related brain potentials (ERPs) (e.g., Eimer et al., 2002; Forster et al., 2009; for a review, see Sambo and Forster, 2011).

In these studies, visual motion is thought to serve as an indicator of when the body will touch an outside object, and this perception is required to judge whether we must avoid such stimuli approaching the body. Gray and Tan (2002) demonstrated that visual motion facilitates the ability to discriminate between vibration frequencies in tactile stimuli. In their study, the visual stimuli were presented on the participant's left arm, and the tactile stimuli were presented on the same arm after the disappearance of the visual stimuli. The participants were asked to press one of two buttons depending on whether the tactile vibration frequency was high or low. Tactile frequency discrimination was faster when the visual stimuli were presented near the location of the tactile stimuli. This result indicated that visual information facilitated judgments of subsequent somatosensory stimuli. The primary function of the somatosensory modality, particularly in the context of passive touch, is to perceive “what”, “when” and “where” one was touched (Gibson, 1962). Gray and Tan (2002) suggested that spatial attention is attracted by visual stimuli before somatosensory stimuli are presented, such that sensitivity to somatosensory stimuli is enhanced (i.e., by attention to “where”

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the somatosensory stimuli are ultimately presented). In contrast to the above argument, it remains unclear whether the approach of visual stimuli influences anticipatory attention to the appearance of subsequent somatosensory stimuli. In everyday life, we can use visual information to expect when and where a ball will touch our hand; therefore, we become surprised when those expectations turn out to be false. Thus, the approach of visual stimuli is an important factor in the recognition of subsequent somatosensory stimuli. In psychophysiological studies, expectancies are often investigated using an oddball paradigm. In this paradigm, rare (i.e., unexpected) stimuli elicit the P3 component (e.g., Donchin, 1981; Duncan-Johnson and Donchin, 1977; Katayama and Polich, 1998; Verleger et al., 1994). In addition, one previous study revealed that stimuli not conforming to an expectation, that is, when the stimuli were unexpected based on the preceding stimulus sequence (e.g., Sommet et al., 1998), elicited P3, and another study showed that this sequential effect also occurs in the somatosensory oddball paradigm (e.g., Kida et al., 2003).

From the perspective of this paradigm, provided that the approach of visual stimuli influences expectations of subsequent somatosensory stimuli, it can be assumed that rare stimuli, that is, somatosensory stimuli presented at a different site from the direction of the visual stimuli approaching the body, should be more unexpected and should thus elicit a greater P3 amplitude.

In this study, we examined how the approach of visual stimuli influences expectations of subsequently presented somatosensory stimuli. In particular, we focused on spatial expectation (i.e., "where" subsequent somatosensory stimuli were presented). To investigate this expectation, we recorded electroencephalograms (EEGs) while participants were performing a simple reaction to somatosensory stimuli task. The somatosensory stimuli were presented to the left (or right) wrist at a high probability ($p = 0.80$) or to the opposite wrist at a low probability ($p = 0.20$).

Experiment 1 was composed of two conditions. Stimuli were presented to both wrists (high and low probability) under all conditions. Under the *congruent condition*, three visual stimuli were presented sequentially toward the wrist to which the high probability somatosensory stimuli were presented. Alternatively, under the *neutral condition*, three visual stimuli were presented at an equal distance from both wrists. Similarly, Experiment 2 was composed of two conditions. The *congruent condition* was the same as that used in Experiment 1. By contrast, under the *incongruent condition*, three visual stimuli were presented sequentially toward the wrist to which the low probability somatosensory stimuli were presented. Under all conditions, the visual stimuli functioned as the clue for "when" the somatosensory stimuli would be presented. The frequency of stimulus presentation for each wrist was explicitly stated; however, the approach of the visual stimuli was irrelevant information in this simple reaction time to somatosensory stimuli task. We hypothesized that even though this information is irrelevant, the approach of the visual stimuli influences the expectation of the subsequent somatosensory stimuli. We predicted that low probability somatosensory stimuli under the congruent condition would elicit larger P3 amplitudes than those under the neutral and incongruent conditions because it is assumed that low probability stimuli of the congruent condition would be unexpected with regards to the site of subsequent somatosensory stimulus presentation, thereby producing an unexpectedness-related effect of a larger P3 amplitude (e.g., Donchin, 1981; Duncan-Johnson and Donchin, 1977; Katayama and Polich, 1998; Kida et al., 2003; Sommet et al., 1998; Verleger et al., 1994). In addition, we predicted that contingent negative variation (CNV) component amplitudes would not differ between the conditions. The previous studies reported that CNV is related to temporal expectancies (e.g., Walter et al., 1964). If visual stimuli functioned as the timing cue for somatosensory stimuli under all conditions, the CNV amplitude would not differ between the conditions because the visual stimuli were presented at the same frequency and number under all conditions.

2. Experiment 1

In Experiment 1, we examined whether the task-irrelevant approach of visual stimuli influences the expectation of subsequently presented somatosensory stimuli. We recorded EEGs while participants completed a simple reaction time to somatosensory stimuli task, and we compared ERPs in response to the low probability stimuli between the two conditions.

2.1. Method

2.1.1. Participants

Twelve undergraduate and graduate students (9 females, 3 males; 20–27 years of age) participated in the experiment. Two participants were left-handed. Handedness was determined based on self-report. All participants had normal or corrected-to-normal vision. This experiment was approved by the Kwansei Gakuin University (KGU) Research Ethics Review Board under the KGU Regulations for Research with Human Participants. Written informed consent was obtained from all participants, and their rights as experimental subjects were protected.

2.1.2. Stimuli and procedure

Somatosensory stimuli were generated using an electrical stimulus generator (Nihon Koden Corporation, SEN-7203). These stimuli were presented to the participants' wrists via electric isolators (SS-203 J) and Ag/AgCl electrodes with a diameter of 1.0 cm. The anodes were placed on the participants' wrists, and the cathodes were placed 3.0 cm from the anodes toward the elbow. The electrical stimuli were single block pulses of 0.2 ms in duration. The intensities were threefold higher than the stimulus threshold for each participant, which never caused appreciable pain. The average intensity of the stimuli across all participants was 3.3 mA. High probability stimuli were presented to the right (or left) wrist at a probability of 80%, and the low probability stimuli were presented to the opposite wrist at a probability of 20%. These stimuli were presented in a random order from trial to trial, and the order of the location (left or right) of stimulus presentation at high (or low) probability was counterbalanced across blocks.

Visual stimuli were presented using three white light emitting diodes (LEDs). Each LED was a square with 0.8 cm sides. Three LEDs were placed between the arms at 8.0 cm intervals. The visual stimuli were single block pulses of 200 ms in duration. The light intensities were 25 cd.

Each trial was composed of three visual stimuli and one somatosensory stimulus. The stimulus interval (SOA) was set to 1200 ms. The interval between trials was 1000 or 1200 ms. Each block was composed of 84 trials (including 4 catch trials), which took approximately 6 min. A total of four blocks were presented for each condition. The interval between blocks was 2 min, and after the 4th block, the participants rested for 10 min and then started the remaining four blocks. The order of which block was performed was randomized between participants.

Under the congruent (CON) and neutral (NEU) conditions, different patterns of visual stimuli were presented to the participants. Under the CON condition, the right, center, and left (or left, center, and right) visual stimuli were sequentially presented toward the wrist to which the high probability somatosensory stimulus was presented, and then, the somatosensory stimulus was presented to the left (or right) wrist. High probability somatosensory stimuli were presented to the wrist indicated by the visual stimuli at a probability of 80% (CON 80%), and low probability stimuli were presented to the opposing wrist at a probability of 20% (CON 20%). Under the NEU condition, the center LED was stimulated three times with the same timing, and then somatosensory stimulus was presented to the left (or right) wrist. High probability somatosensory stimuli were presented to the left (or right) wrist at a probability of 80% (NEU 80%), and low probability stimuli were presented to the opposite wrist at a probability of 20% (NEU 20%).