



Research report

Visual stimuli approaching toward the body influence temporal expectations about subsequent somatosensory stimuli

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ARTICLE INFO

Article history:

Received 31 July 2016

Received in revised form 13 March 2017

Accepted 29 March 2017

Available online 4 April 2017

Keywords:

Temporal expectation

Visuotactile processing

Multimodality interaction

ERP

ABSTRACT

The present study investigated whether visual stimuli approaching the body influence temporal expectations about subsequent somatosensory stimuli. To examine this question, we recorded event-related brain potentials (ERPs) during a simple reaction time task using somatosensory stimuli. Fourteen participants were asked to place their arms on a desk, and three light-emitting diodes (LEDs) were placed at equal distances between their arms. Each trial was composed of three visual stimuli (i.e., LEDs), and one subsequent electrical stimulus (i.e., somatosensory stimulus) to one wrist. The stimulus onset asynchrony (SOA) between the visual stimuli was set to 1000 ms. The SOA between the third visual stimulus and the somatosensory stimulus was set to 1000 ms (standard; $p = 0.75$), 500 ms (early deviation; $p = 0.125$), and 1500 ms (late deviation; $p = 0.125$). In the approach condition, the left, center, and right LEDs (or reverse) were turned sequentially toward the wrist to which the somatosensory stimulus was presented. In the neutral condition, the center LED was flashed three times. The N1 amplitudes for early deviations of stimuli were larger under the approach condition than under the neutral condition. These results show that prior visual stimuli facilitate temporal expectations about subsequent somatosensory stimuli, i.e., visual stimuli approaching toward the body facilitate the processing of early deviant stimuli. The present study indicates the existence of a function of supramodal temporal expectation and detection of deviation from this expectation using the approach of visual stimuli toward the body.

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1. Introduction

Although a main function of somatosensory modality is to identify “when”, “where” and “what” somatosensory events occur (Gibson, 1962), expectation of the event is difficult, because somatosensory sensation is evoked after physical contact occurred. It is necessary for us to expect physical contact before dangerous object (e.g., knife) touches our body to defend ourselves. The expectation for somatosensory events is enabled by using other sensory information. In particular, the number of studies reported that visual information influences the processing of following somatosensory sensation, e.g., facilitation for somatosensory target detection in visually attended space (e.g., Spence et al., 1998; for a review, see Spence, 2010). Moreover, a recent study reported that the task irrelevant approach of visual stimuli toward the body facilitates spatial expectations for subsequent somatosensory events (Kimura and Katayama, 2015). However, it remains unclear

whether the prior approach of visual stimuli influences temporal expectations about subsequent somatosensory events.

In order to generate temporal expectation, i.e., when subsequent events will occur, people extract information about frequency and temporal regularity of occurrence of, as well as the context from, prior events. For example, it is known that the response to a subsequent event is facilitated by regularity of prior events. Specifically, judgment about when visual stimuli will arrive at a goal becomes faster when the prior visual stimuli move at regular intervals (e.g., Doherty et al., 2005; Rohenkohl et al., 2011). These studies suggest that temporal expectations about targets are influenced by regularity of the stimulus onset asynchrony (SOA) of prior visual information (e.g., for a review, see Nobre et al., 2007).

This prior visual information influences temporal expectations about subsequent somatosensory events. For example, the temporal order judgment (TOJ) for somatosensory stimuli is influenced by prior visual information (e.g., Fujisaki and Nishida, 2009; Spence et al., 2001); thereby, the existence of temporal interactions between visual and somatosensory modalities assumed. Furthermore, TOJ for a somatosensory event is modulated by visual stimuli

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presented near the hands and the same location as the somatosensory event (e.g., Spence et al., 2003). Thus, it is possible that the distance between visual stimuli and the body affects temporal expectations about subsequent somatosensory events. In everyday life, people can predict when an object will contact the body by evaluating the speed and trajectory of the moving object (i.e., visual information), and we can choose adaptive behavior (e.g., avoid or catch) in response to expected events. Thus, it is possible that visual stimuli approaching the body also influence temporal expectations for subsequent somatosensory events.

In psychophysiological studies, electroencephalograms (EEGs) and event-related brain potentials (ERPs) are often used as an index for temporal expectations. Specifically, stimuli that deviate from temporal contexts modulate ERPs not only voluntary component (P3b and RON; e.g., Schwartze et al., 2011; for a review, see Correa et al., 2006) but also involuntary (N1; e.g., Ford and Hillyard, 1981) and preattentive components (MMN and P3a; e.g., Alain et al., 1998; Takegata et al., 2001). Hence, we examined whether visual stimuli approaching toward the body influence temporal expectations about subsequent somatosensory stimuli, using ERP.

As described above, although the expectation of somatosensory event is necessary to defend our body from dangerous event, this expectation is difficult using only somatosensory information and visual information supports to create the expectation. Kimura and Katayama (2015) shows that approaching visual stimuli toward the body facilitates spatial expectations for subsequent somatosensory events. To examine this effect on temporal expectations, we recorded EEG while participants were performing a simple reaction to somatosensory stimuli, and then analyzed ERP components. Each trial was composed of three visual stimuli, and then one somatosensory stimulus to only one wrist (left or right) in a block. The SOA between visual stimuli was set to 1000 ms. The SOA between the third visual stimulus and the somatosensory stimulus was set to either the same amount of time (1000 ms; $p = 0.75$), shorter (500 ms; $p = 0.125$), or longer (1500 ms; $p = 0.125$). In the *approach condition*, three visual stimuli were presented sequentially, moving toward the wrist where a somatosensory stimulus was presented. In the *neutral condition*, visual stimuli located at an equal distance from both wrists were presented three times, the same number as under the approach condition. Under the both conditions, somatosensory stimuli invariably occurred after the third visual stimulus. The approaching visual stimuli were irrelevant information in this simple reaction time task because participants were told what the location of the somatosensory stimulus would be (i.e., left or right wrist) before each block.

We predicted that participants would expect the presentation of somatosensory stimuli 1000 ms after the third visual stimulus because this timing was the most frequent. Furthermore, we consider that shorter and longer SOA stimuli modulate different ERPs. Previous studies reported that stimulus repetition with the same SOA produced habituation leading the decrement of N1 amplitude for the stimulus (e.g., Budd et al., 1998). In the present study, prior visual stimuli are presented repeatedly with the same SOA (i.e., 1000 ms), thus shorter and longer SOA stimuli would elicit larger N1 amplitude at the between frontal to central region because these stimuli are deviant from temporal expectation. In particular, shorter SOA stimuli would elicit a larger N1 amplitude response to an early deviation from temporal expectations (e.g., Ford and Hillyard, 1981) than other SOA stimuli. Moreover, another previous study showed that shorter SOA stimuli elicit P3b and longer SOA stimuli elicit P3a component at the between central and parietal regions (Jongsma et al., 2007). They interpreted their results as that the modulation of N1 and P3b amplitude to early deviant stimuli reflected deviation from temporal expectation, whereas

modulation of P3a amplitude to later deviant stimuli reflected stimulus omission from prior stimulus context. In the present study, we examined which ERPs are affected by the temporal deviation. In addition, these ERP amplitudes in the approach condition would be larger than in the neutral condition, if visual stimuli approaching toward the body facilitate temporal expectations about subsequent somatosensory stimuli. The facilitation of temporal expectations about subsequent somatosensory stimuli by the approach of visual stimuli is demonstrated if these results are obtained.

Finally, the previous study reported that the contingent negative variation (CNV) is elicited between the third visual stimulus and the somatosensory stimulus at the between frontal to central region (Kimura and Katayama, 2015). The modulation of the CNV caused by the early and late deviation would be critical for evaluation of the temporal expectation created by the preceding context.

2. Results

2.1. Behavioral data

Trials with an incorrect response or with reaction time (RT) shorter than 200 ms or longer than 1500 ms were discarded from RT analysis. Table 1 shows the mean RTs of all participants. A two-way repeated measures analysis of variance (ANOVA) of the RTs revealed a main effect of stimulus timing ($F(2, 26) = 45.31$, $p < 0.001$, $\epsilon = 0.71$, $\eta_p^2 = 0.78$). Post hoc comparisons revealed that the RTs for early deviant and late deviant stimuli were longer than that for the standard stimuli ($ps < 0.05$). The main effect of condition type was not significant ($p > 0.10$) and the interaction between condition type and stimulus timing was weak trend ($F(2, 26) = 2.71$, $p = 0.10$, $\epsilon = 0.82$, $\eta_p^2 = 0.17$).

2.2. Electrophysiological data

2.2.1. N1

Fig. 1 illustrates the grand average of ERPs elicited by the somatosensory stimuli during the approach and neutral conditions, recorded from the FCz, Cz, and Pz. Fig. 2 shows (a) the topographic maps at the time range of N1 (100–180 ms), and (b) the mean amplitude of N1 for both conditions. The early deviant stimuli of the approach condition elicited a larger N1 amplitude than other conditions and other timing at FCz; N1 elicited maximum amplitude at this electrode.

The two-way interaction of condition type and stimulus timing was significant ($F(2, 26) = 6.22$, $p = 0.009$, $\epsilon = 0.89$, $\eta_p^2 = 0.32$). Post hoc comparison indicated that the early deviant stimuli elicited larger N1 amplitude than the standard stimuli in the approach condition ($p < 0.05$). Additionally, the early deviant stimuli under the approach condition stimuli elicited larger N1 amplitudes than the early deviant stimuli under the neutral condition ($p < 0.05$). In contrast, N1 amplitudes did not differ between stimulus timings in the neutral condition ($ps > 0.10$). Moreover, in the both conditions, N1 amplitudes were not significant different for standard stimuli and late deviant stimuli ($ps > 0.10$). These results revealed that the N1

Table 1
Mean RTs (ms) for somatosensory stimuli and standard errors of RTs in each condition.

	Standard (ms)	Early deviant (ms)	Late deviant (ms)
Approach	363 ± 18.52	452 ± 17.06	446 ± 19.41
Neutral	367 ± 20.26	455 ± 20.31	439 ± 19.60

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