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The temporal reliability of sound modulates visual detection: An event-related potential study

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HIGHLIGHTS

- Auditory temporal reliability affects visual detection.
- We observed three ERPs related to the effects of auditory temporal reliability.
- Implicit temporal linking of auditory and visual information occurs.

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ABSTRACT

Utilizing the high temporal resolution of event-related potentials (ERPs), we examined the effects of temporal reliability of sounds on visual detection. Significantly faster reaction times to visual target stimuli were observed when reliable temporal information was provided by a task-irrelevant auditory stimulus. Three main ERP components related to the effects of auditory temporal reliability were found: the first at 180–240 ms over a wide central area, the second at 300–400 ms over an anterior area, and the third at 300–380 ms over bilateral temporal areas. Our results support the hypothesis that temporal reliability affects visual detection and indicate that auditory facilitation of visual detection is partly due to spread of attention and thus results from implicit temporal linking of auditory and visual information at a relatively late processing stage.

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1. Introduction

Many real-world objects and events have multisensory features that stimulate various sensory organs. Our perceptual system can automatically select and integrate multiple sensory information modalities to form unified perceptions. Previous studies have demonstrated that bimodal audiovisual (AV) stimuli can be discriminated or detected more quickly and accurately than unimodal auditory or visual stimuli [1–3]. This phenomenon is referred as "multisensory AV integration."

The temporal factor is one of the fundamental properties of AV integration. A strong multisensory integration effect is obtained if the time difference between the onsets of the auditory and visual stimuli is <100 ms [4,5]. When the visual and auditory stimuli are presented ≥250 ms apart from each other, subjects are able to accurately recognize these onset differences, and visual and auditory stimuli cannot be integrated as a unified object [6]. In addition to the temporal factor, attention also plays an important role. An event-related potential (ERP) study reported that attention can modulate the AV integration process at multiple stages [7].

Some recent studies have shown the effects of AV integration on visual detection tasks. The results showed that the task-irrelevant auditory stimuli facilitated the detection of simultaneously presented visual targets [8–10]. Busse et al. reported that attention to visual stimuli can spread to task-irrelevant auditory stimuli at 220 ms after stimulus presentation, resulting in behavioral facilitation [11]. Although many studies have investigated the phenomenon, the characteristics and neural mechanisms underlying the auditory facilitation of visual detection remain unclear. We hypothesize that a reliable temporal relationship between visual and task-irrelevant auditory stimuli causes temporal regularity and provides temporal expectation for visual detection, which enhances behavioral responses. Our hypothesis is supported by the literature. Talsma et al. reported that no behavioral facilitation was observed in a visual detection task when rapid serial visual presentation confused the temporal and spatial relationships of visual

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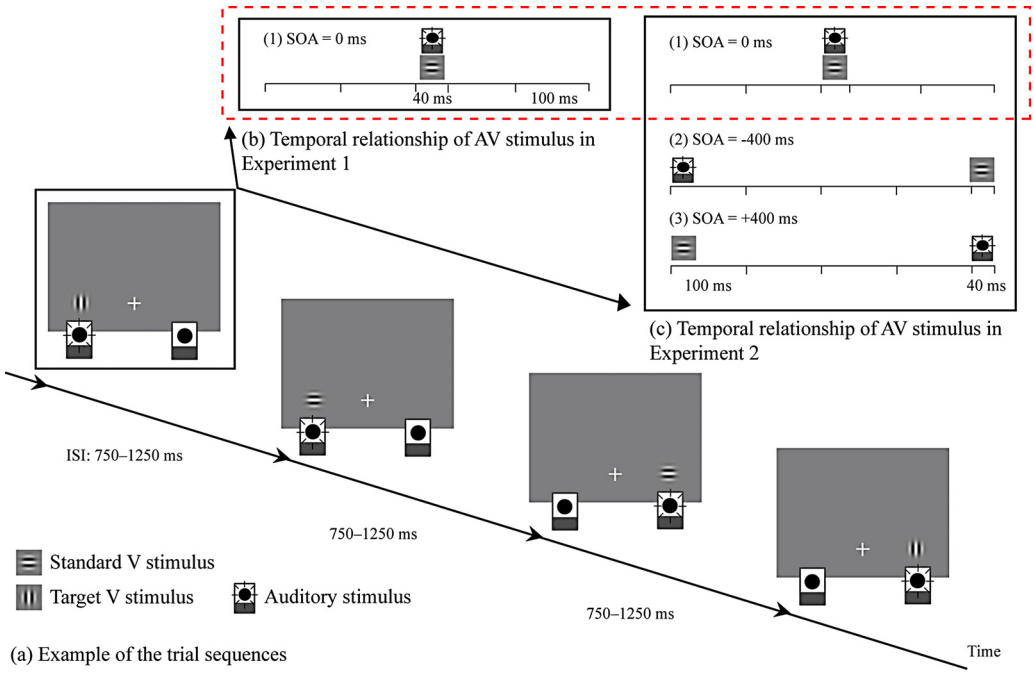

Fig. 1. Schematic of the experimental paradigms. (a) Illustrations showing the possible trail sequences. All AV stimuli were presented peripherally at an angle of approximately 6° from a centrally presented fixation point with random inter-stimulus intervals (ISIs) of 750–1250 ms; (b) temporal relationship of the auditory and visual stimuli in Experiment 1; (c) temporal relationship of the auditory and visual stimuli in Experiment 2. The "−" indicates that the auditory onset preceded the visual onset. "SOA = 0 ms" means the stimuli were synchronous. The "+" means that the auditory onset followed the visual onset. Only the simultaneous AV integration was of interest when the data were analyzed.

and auditory stimuli [12]. Liu et al. reported that high-reliability visual stimuli induced more effective AV integration, enhanced the behavioral responses [13].

The aim of present study was to investigate the effects of auditory temporal reliability on visual detection by measuring ERPs in two experiments. A task-irrelevant auditory stimulus provided reliable temporal information for visual detection in one experiment, while not in the other. We examined the effects of auditory temporal reliability by comparing the processing of cross-modal AV stimuli occurring synchronously in two experiments.

2. Methods

2.1. Participants

Sixteen healthy volunteers (ages 19–24 years, mean age 21.6 years) were paid to participate in this study. All of the participants had normal or corrected-to-normal vision and normal hearing. After receiving a full explanation of the purpose and risks of the study, participants provided written informed consent for their participation. The study was approved by the ethics committee of Changchun University of Science and Technology (CUST).

2.2. Stimuli

Visual stimuli were presented on a 19-in. computer monitor positioned 92 cm from the participant's head. The visual stimuli consisted of horizontal (standard stimulus) and vertical (target stimulus) Gabor gratings (3.2 cm × 3.2 cm, 1.75 cycles/degree; Fig. 1a). We conducted a pre-experiment for each subject to determine one intermediate contrast level so that the stimulus-detection accuracy was approximately 80%. These visual stimuli were peripherally presented for 40 ms each at an angle of approximately 6° from a centrally presented fixation point located directly in front of the participants' eyes.

All visual stimuli were accompanied by a task-irrelevant white noise (70 dB, duration 40 ms, including 10-ms rise and fall periods); these were termed the AV stimuli. The auditory stimuli were presented through one of two speakers placed peripherally approximately 6° from a centrally presented fixation point in front of a monitor. The speakers were hidden by a black curtain. The auditory stimuli were always presented in the same hemispace as the visual stimulus (left or right hemispace).

2.3. Procedure and tasks

The study took place in a dimly lit, sound-attenuated, electrically shielded room. The participants sat on a comfortable chair, and their head positions were fixed with a chin rest. Each participant was required to perform two experiments.

Experiment 1. Reliable temporal information

The task-irrelevant auditory stimulus synchronously appeared with the visual stimulus (Fig. 1b). The auditory stimulus indicated the onset time of the visual stimulus and provided reliable temporal information to facilitate visual detection.

Experiment 2. No reliable temporal information.

This experiment was similar to Experiment 1, but the stimulus onset asynchrony (SOA) between the task-irrelevant auditory and visual stimuli varied (−400, 0, and +400 ms) (Fig. 1c). The synchronous stimuli (SOA = 0 ms) accounted for 50%. For the other half of the stimuli, SOA = −400 ms or SOA = 400 ms were 25% each. Because of the variability, the task-irrelevant auditory stimuli did not provide reliable temporal information to improve visual detection.

Each experiment consisted of 640 trials that were equally distributed in four sessions. The target stimulus frequency of each type was 20%. All stimuli were randomly presented, and each type of stimulus was presented in the left or right hemispace with equal probability. The inter-stimulus interval (ISI) varied randomly

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