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Research article

The spatial reliability of task-irrelevant sounds modulates bimodal audiovisual integration: An event-related potential study

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HIGHLIGHTS

- Auditory spatial reliability affects audiovisual integration.
- We observed three ERPs related to the effect of auditory spatial reliability.
- Spatial linking within audiovisual information is enhanced by spatial reliability.
- Audiovisual spatial linking occurs at a relatively late stage of processing.

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ABSTRACT

The integration of multiple sensory inputs is essential for perception of the external world. The spatial factor is a fundamental property of multisensory audiovisual integration. Previous studies of the spatial constraints on bimodal audiovisual integration have mainly focused on the spatial congruity of audiovisual information. However, the effect of spatial reliability within audiovisual information on bimodal audiovisual integration remains unclear. In this study, we used event-related potentials (ERPs) to examine the effect of spatial reliability of task-irrelevant sounds on audiovisual integration. Three relevant ERP components emerged: the first at 140–200 ms over a wide central area, the second at 280–320 ms over the fronto-central area, and a third at 380–440 ms over the parieto-occipital area. Our results demonstrate that ERP amplitudes elicited by audiovisual stimuli with reliable spatial relationships are larger than those elicited by stimuli with inconsistent spatial relationships. In addition, we hypothesized that spatial reliability within an audiovisual stimulus enhances feedback projections to the primary visual cortex from multisensory integration regions. Overall, our findings suggest that the spatial linking of visual and auditory information depends on spatial reliability within an audiovisual stimulus and occurs at a relatively late stage of processing.

1. Introduction

Objects and events in the natural world have multimodal features that stimulate different human sensory organs. Despite the initial segregation of the sensory input, sensory information is ultimately integrated in the brain to form unified multisensory percepts [1,2]. This phenomenon is referred to as "multisensory integration."

Electrophysiological studies in animals have led to the formulation of three fundamental rules for multisensory integration: the spatial rule, the temporal rule, and the principle of inverse effectiveness. According to the spatial and temporal rules, deep layers of the superior colliculus contain multisensory neurons that exhibit multiplicative increases in firing rate when two stimuli of different modality are presented in close spatial and temporal proximity. If the two stimuli are not temporally aligned or spatially collocated, neural firing is greatly reduced or even inhibited [3,4]. Studies in humans have also shown that the near-simultaneous and proximal presentation of visual and auditory stimuli facilitate the integration of audiovisual stimuli into a multisensory perception [5,6]. However, a recent behavioral study suggested that reliable spatiotemporal relationships between visual and auditory stimuli rather than spatiotemporal congruity underlie audiovisual integration using a visual discrimination task [7]. Li et al. investigated the

Abbreviations: AV, audiovisual; EEG, electroencephalography; EOG, electrooculography; ERP, event-related potential; HR, hit rate; RT, response time; V, visual.

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effect of temporal reliability of sound on bimodal audiovisual integration and found that the neural mechanism of integration varied depending on whether the task-irrelevant sound provided reliable temporal information [8]. However, it remains unclear whether the spatial reliability of task-irrelevant sounds modulates bimodal audiovisual integration.

In present study, we designed two experiments to explore the effects of spatial reliability of sound on bimodal audiovisual integration. In one experiment, a task-irrelevant sound implicitly provided reliable spatial information for the discrimination of a simultaneously presented visual stimulus; in the other experiment, the task-irrelevant sound did not provide reliable spatial information. We provide a discussion comparing the integration processing audiovisual stimuli in the two experiments and discuss the effect of spatial reliability of sound on bimodal audiovisual integration.

2. Materials and methods

2.1. Participants

Sixteen university students (10 male students and 6 female students; mean age 22.6 [21–26] years) participated in the present study. All of the participants had normal or corrected-to-normal vision and hearing capabilities. After receiving a full explanation of the purpose and risks of the study, participants provided written informed consent for participation and were compensated with 100 RMB. The study was approved by the ethics committee of Changchun University of Science and Technology (CUST).

2.2. Stimuli

Visual (V) stimuli consisted of horizontal (standard V stimuli) and vertical (target V stimuli) Gabor gratings (3.2 × 3.2 cm, subtending a visual angle of approximately 2°; spatial frequency = 1.75 cycles/degree; Fig. 1a). We conducted a preliminary experiment in order to determine a single intermediate contrast level so that the accuracy for stimulus detection was approximately 80%. A 19-inch computer monitor was positioned 92 cm in front of the participants. V stimuli were presented peripherally for 40 ms at an angle of approximately 6° from a centrally presented fixation point on the monitor. V stimuli were accompanied by task-irrelevant white noise (70 dB, duration 40 ms, including 10-ms rise and fall periods), which was presented through two hidden speakers placed peripherally at an angle of approximately 6° from the fixation point on the monitor. Together, a given V stimulus and task-irrelevant white noise comprised an AV stimulus.

2.3. Procedure and tasks

The study was conducted in a dimly lit, sound-attenuated, and electrically shielded laboratory room at Changchun University of Science and Technology in China. Participants were seated on a comfortable chair and provided a chin rest for head fixation. Each participant took part in two experiments in a pseudorandom order.

2.3.1. Experiment 1

In this experiment, task-irrelevant white noise was always produced in same hemispace as the V stimulus (Fig. 1b). Because auditory stimuli had the same source location as V stimuli, task-irrelevant white noise implied the spatial location of the V stimulus and thus provided reliable spatial information for visual discrimination. A total of 512 standard AV stimuli (80%) and 128 target AV stimuli (20%) were presented. Each type of stimulus was presented in the left or right hemispace with equal probability.

2.3.2. Experiment 2

The spatial relationship of task-irrelevant white noise and the V stimulus within a given AV stimulus was varied in Experiment 2; the white noise was sometimes congruent with the V stimulus (located in the same hemispace as the V stimulus) and sometimes incongruent with the V stimulus (located in a different hemispace from the V stimulus) (Fig. 1c). Thus, auditory stimuli did not provide reliable spatial information for visual discrimination. A total of 512 standard AV stimuli (80%) and 128 target AV stimuli (20%) were presented. Spatially congruent AV stimuli accounted for 50% of the total AV stimuli, and were randomly presented in the left or right hemispace with equal probability. The remaining 50% of stimuli were as follows: 25% V_LA_R stimuli (V stimulus presented in the left hemispace and white noise presented in the right hemispace) and 25% V_RA_L stimuli (V stimulus presented in the right hemispace and sound presented in the left hemispace).

Each experiment was equally distributed across 4 sessions (160 trials each) lasting approximately 3 min each. Participants were permitted 5 min breaks between sessions. For each session, the participant was instructed to fix their eyes on the centrally presented fixation point and attend to V stimuli while ignoring all auditory stimuli. The participants were instructed to press the left button of a computer mouse when a target V stimulus appeared in the left hemispace, and to press the right button when a target V stimulus appeared in the right hemispace. The inter-stimulus interval (ISI) varied randomly between 750 ms and 1250 ms (mean ISI = 1000 ms), independent of subject response (Fig. 1a).

2.4. Apparatuses

Stimulus presentation was controlled by a personal computer using Presentation 0.71 software (Neurobehavioral Systems Inc, Albany, USA). An electroencephalography (EEG) system (SynAmps 2, Neuroscan Inc, Abbotsford, Australia) was used to collect EEG recordings from 64 electrodes mounted on an electrode cap. All signals were referenced to the left mastoid. Horizontal eye movements were measured by collecting electrooculography (EOG) data from a pair of horizontal EOG electrodes placed at the outer canthi of the left and right eyes. Vertical eye movements and eye blinks were detected by collecting EOG data from a pair of vertical EOG electrodes placed approximately 1 cm above and below the subject's left eye. Electrode impedance was maintained below 5 kΩ. Raw signals were digitized using a sample frequency of 1000 Hz and all data were stored digitally for off-line analysis. An ERP analysis was conducted using Scan4.5 software (Neuroscan Inc, Abbotsford, Australia).

2.5. Data analysis

Only spatially congruent AV stimuli were of interest in the analysis of Experiment 2. In order to ensure that the number of analyzed stimuli was the same in each experiment, half of the responses to standard AV stimuli and target AV stimuli presented in the left and right hemispaces were randomly extracted from Experiment 1 for analysis.

2.5.1. Behavioral data

Response times (RTs) and hit rates (HRs) for target stimuli were computed separately for each experiment. RTs and HRs were analyzed using a repeated-measures analysis of variance with experiment (Experiment 1 versus Experiment 2) and stimulus location (left hemispace versus right hemispaces) as subject factors.

2.5.2. ERP analysis

The ERPs elicited by standard AV stimuli were analyzed. EEG and EOG signals were amplified and filtered with a band-pass analog