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Comparison for younger and older adults: Stimulus temporal asynchrony modulates audiovisual integration

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ABSTRACT

Recent research has shown that the magnitudes of responses to multisensory information are highly dependent on the stimulus structure. The temporal proximity of multiple signal inputs is a critical determinant for cross-modal integration. Here, we investigated the influence that temporal asynchrony has on audiovisual integration in both younger and older adults using event-related potentials (ERP). Our results showed that in the simultaneous audiovisual condition, except for the earliest integration (80–110 ms), which occurred in the occipital region for older adults was absent for younger adults, early integration was similar for the younger and older groups. Additionally, late integration was delayed in older adults (280–300 ms) compared to younger adults (210–240 ms). In audition-leading vision conditions, the earliest integration (80–110 ms) was absent in younger adults but did occur in older adults. Additionally, after increasing the temporal disparity from 50 ms to 100 ms, late integration was delayed in both younger (from 230 to 290 ms to 280–300 ms) and older (from 210 to 240 ms to 280–300 ms) adults. In the audition-lagging vision conditions, integration only occurred in the A100V condition for younger adults and in the A50V condition for older adults. The current results suggested that the audiovisual temporal integration pattern differed between the audition-leading and audition-lagging vision conditions and further revealed the varying effect of temporal asynchrony on audiovisual integration in younger and older adults.

1. Introduction

In life, people obtain dynamic effective information from the complex environment through multiple senses. Merging the multiple informative inputs aid us in making identifications and decisions more quickly and accurately, which is called multisensory integration (Laurienti et al., 2006; Meredith et al., 1987; Spence, 2011; Stein and Meredith, 1993; Stein, 2012). Imagine that a firecracker is set off: we integrate the visual sparkle and sound of the burst in our brain, which makes it difficult to perceive the arrival time difference. However, on a stormy day, we generally see the lightning first and then hear the thunderclap. Although the lightning and the thunderclap come from a common cause and occur simultaneously, a temporal asynchrony between the visual flash and the sound is perceived in our brain. The abovementioned life experiences indicate that the integration of information from multiple senses obeys the temporal principle, which declares that in a condition of slight temporal asynchrony, the maximum facilitation effect is induced by the greatest overlapping of the response trains evoked by the unisensory component stimuli (Stein, 2012).

Meredith and Stein, in their representative neurophysiological studies, measured the response features of an auditory-visual superior colliculus neuron in a cat to a temporally combined stimulation (Meredith et al., 1987; Stein and Meredith, 1993). They found a

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dramatic increase in the magnitude of response enhancement when decreasing the temporal asynchrony between auditory and visual stimuli. Frassinetti et al. (2002) first reported that the temporal rules governing multisensory integration at the neuronal level were also observed in a human study (Frassinetti et al., 2002). In this study, visual enhancement was evaluated using a signal detection measure (perceptual sensitivity, d′), and they found that visual enhancement existed when the visual stimulus was presented simultaneously with the auditory stimulus but disappeared if the auditory stimulus preceded the visual stimulus by 500 ms. To more clearly understand the temporal window of multisensory interaction, Bolognini et al. (2005) instructed participants to conduct a visual detection examination under visual selective attention (Bolognini et al., 2005) to systematically investigate the effect of stimuli onset asynchrony (SOA) on audiovisual integration. Using the same signal detection measure to evaluate visual enhancement, their results indicated that visual enhancement occurred when the auditory and visual stimuli were presented simultaneously but disappeared with larger temporal disparities between the stimuli, such as 100 ms, 200 ms, 300 ms, 400 ms, or 500 ms. Additionally, Yang et al. (2014) recently detected temporal audiovisual integration by comparing responses to audiovisual stimuli with results from a predicted model (race-model) based on unimodal auditory and visual stimuli, and their results revealed alterations of audiovisual integration ranging from elevation (temporal disparity conditions, 0 ms and 50 ms) to suppression (150 ms) (Laurienti et al., 2006; Yang et al., 2014).

Recently, frequent neuroimaging research has also been conducted to clarify the temporal effect on audiovisual integration, and this work has further confirmed that audiovisual integration is sensitive to temporal asynchrony between auditory and visual stimuli. After analysing oscillatory gamma-band responses (GBRs) using electroencephalography (EEG), Senkowski et al. (2007, 2007) reported robust multisensory interactions in simultaneous audiovisual conditions, and the integration effect was found in the occipital areas in auditory-preceding visual stimulus conditions but was absent in visual-preceding auditory conditions (Senkowski et al., 2007). The robust integration effect elicited by simultaneous audiovisual stimuli was further confirmed by Van Atteveldt et al. (2007) using functional magnetic resonance imaging (fMRI) (Van Atteveldt et al., 2007). Liu et al. (2011) provided event-related potentials (ERP) evidence for temporal audiovisual integration (Liu et al., 2011). In their study, the adapted video frames of naturalistic motion stimuli were used, and the multisensory stimuli had SOA values of −300 ms, 0 ms, or 300 ms. Their results revealed that multisensory integration occurred regardless of temporal asynchrony but was influenced by temporal asynchrony.

Studies on the perception of synchrony between auditory and visual modalities have indicated that there exists a range of temporal disparities within which humans are unable to discern the asynchrony, and this range is known as the temporal binding window (Dixon and Spitz, 1980; King, 2005; Munhall et al., 1996; Van Wassenhove et al., 2007). In the study by Liu et al. (2011), the authors focused on a larger temporal disparity (300 ms) in which participant perceived temporal asynchrony clearly. Therefore, it is reasonable to postulate that there was integration diversity between the synchrony and asynchrony conditions. However, when the audiovisual temporal disparity falls within the temporal binding window, it remains unclear whether and in what way audiovisual integration is altered as a function of the relative timing between auditory and visual stimuli. Although Bolognini et al. (2005) and Yang et al. (2014) investigated the effect of temporal asynchrony on audiovisual integration systematically, to date, no systematic study has been performed using event-related potentials (ERPs) (Bolognini et al., 2005; Yang et al., 2014).

Additionally, age-effect studies have revealed that the auditory threshold tends to increase, the visual acuity tends to decrease with ageing (Diederich et al., 2008; Laurienti et al., 2006), and this deterioration can be attributed to the poorer health status and decline of cognitive function in older adults (Freiherr et al., 2013). However, despite the ongoing deterioration of the sensory systems during ageing, there is still a large body of evidence for an increase in or maintenance of multisensory integration processing in older adults, which can aid older people in compensating for the often-destructive consequences of unisensory dysfunction (Freiherr et al., 2013; Laurienti et al., 2006; Peiffer et al., 2007). Using magnetoencephalography, Diaconescu et al. (2013) investigated the disparities in multisensory integration between younger and older adults and reported that despite the common sensory-specific regions in both younger and older adults, preferential activity in the posterior parietal and medial prefrontal areas between 150 ms and 300 ms after audiovisual stimuli onset was observed in older adults (Diaconescu et al., 2013). The authors proposed that the activity of these two brain regions was the basis for the integrated response in older adults (Diaconescu et al., 2013; Freiherr et al., 2013). However, with normal ageing, it becomes more difficult to discriminate simultaneity, temporal order and casual relationships among stimuli, leading to an increase in the width of the temporal binding window compared to that in younger adults (Bedard and Barnett-Cowan, 2016; Diederich and Colonius, 2015; Poliakoff et al., 2006; Setti et al., 2011; Setti et al., 2011). A particular interest of the current study was how audiovisual temporal integration processing varies with ageing. Based on prior studies we predict that the audiovisual integration for older adults was different from that for younger adults in all SOA conditions, and the audiovisual interaction pattern was different between auditory-leading and auditory-lagging visual conditions.

According to a study conducted by Giard and Peronnet on the ‘additive model’ for multisensory integration, we first added the ERPs evoked by unimodal auditory stimuli and unimodal visual stimuli together. The audiovisual integration was expressed as the difference between the additive ERPs and the ERPs evoked by bimodal audiovisual stimuli (Giard and Peronnet, 1999). To understand the differences in integration among the varying conditions, the spatiotemporal topographical differences were presented. The primary goal of the present study was to clarify the mechanism of audiovisual temporal integration and the effect of ageing on audiovisual temporal integration by recording EEG signals from both unisensory stimuli and audiovisual stimuli (in synchrony or asynchrony).

2. Materials and methods

A behavioural pre-study was conducted (Ren et al., 2017). The results showed that temporal asynchrony between auditory and visual stimuli significantly modulated audiovisual integration and that the alternative pattern was different between the younger and older groups. The focus of the present study was to analyse EEG evidence for temporal asynchrony modulating audiovisual integration in both younger and older groups.

2.1. Participants

Fifteen healthy younger volunteers (22–25 years, mean age ± SD, 23.00 ± 0.93) and 15 healthy older volunteers (61–76 years, mean age ± SD, 68.20 ± 4.60) were recruited as paid volunteers to participate in the study. All younger adults were undergraduate students of Okayama University, and the older adults were recruited randomly from the general community of Okayama City. All participants had normal hearing and normal or corrected-to-normal vision and were naive about the purpose of the experiment. Vision was examined by a Japanese Eye Chart, and audition was examined by a RION AUDIOMETER AA-71 (Rion Service Center, Japan). Participants were excluded if their mini-mental state examination (MMSE) scores were > 2.5 standard deviations (SD) from the mean for their age and education level (Bravo and Hébert, 1997). Moreover, participants who reported a history of cognitive disorder were also excluded. All participants provided written informed consent for the procedure, which was previously approved by the ethics committee of Okayama