Audiovisual temporal discrimination is less efficient with aging: an event-related potential study

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We investigated the crossmodal temporal discrimination deficit characterizing older adults and its event-related potential (electroencephalogram) correlates using an audiovisual temporal order judgment task. Audiovisual stimuli were presented at stimulus onset asynchronies (SOA) of 70 or 270 ms. Older were less accurate than younger adults with an SOA of 270 ms but not 70 ms. With an SOA of 270 ms only, older adults had smaller posterior P1 and frontocentral N1 amplitudes for visual stimuli in auditory–visual trials and auditory stimuli in visual–auditory trials, respectively. These results suggest a deficit in cross-sensory processing with aging reflected at the behavioural and neural level, and suggest an impairment in switching between modalities even when the inputs are separated by long temporal intervals. *NeuroReport* 22:554–558 © 2011 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

Discriminating the temporal order of multiple stimuli becomes more difficult as we grow older [1–3]. Such deficits are not explained by sensory acuity, but instead suggest a deficit in processing within the central nervous system [4,5]. Temporal discrimination thresholds are traditionally used as an estimate of the size of the temporal window of integration [6]. A temporal window of integration is the interval during which stimuli from different modalities tend to be merged into a unitary percept [7]. For audiovisual stimuli, this is less than 100 ms in younger adults [8], but it is enlarged in older adults [9]. The window of auditory–visual integration may be as large as 270 ms in older adults and its extension is thought to be associated with falling [10] and deficits in speech comprehension [11].

The aim of this study was to compare cerebral function associated with auditory–visual temporal discrimination processing in young and older adults using event-related potentials (ERPs). The task consisted of a temporal order judgment (TOJ) with stimulus onset asynchronies (SOAs) varying either within or outside the optimal temporal window of integration for young adults (SOAs of 70 or 270 ms, respectively). We were particularly interested in the visual P1 and auditory N1 components of the ERP, which have been linked to perceptual processing [12] and/or modulation of perceptual processing through attentional control [13–16]. These components have been found to differ between young and older adults [12,17]. In this study, we hypothesized that older adults would commit more TOJ errors than younger adults especially with an SOA of 270 ms. We also expected that the P1 and N1 would differ between young and older adults in parallel with TOJ accuracy at different SOAs.

Methods

Participants

Eighteen younger [six men; mean age = 24 years; standard deviation (SD) = 3.2] and 18 older adults (11 men; mean age = 71 years; SD = 5.4) volunteered to take part in the study. The older adults were recruited as part of a larger study on aging, Technology Research for Independent Living project (*http://www.trilcentre.org*). All older participants were reported to have good hearing (apart from two who reported a mild hearing impairment). Hearing was assessed with a Hughson–Westlake audiometer. All had normal or corrected-to-normal vision for their age group with a mean visual acuity of 0.08 (SD = 0.09; Binocular LogMar) and mean contrast sensitivity of 1.70 (SD = 0.07; Pelli-Robson chart). None of the participants suffered from a cognitive impairment (Mini Mental State Examination > 24) or psychiatric or neurological illness. Younger adults were undergraduate and postgraduate students from Trinity College Dublin, and were recruited

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through advertisement. The study was approved by the School of Psychology Research Ethics Committee, Trinity College Dublin and Ethics Committee of St. James's Hospital, Dublin and conformed to the Declaration of Helsinki. All participants gave written informed consent.

Stimuli and apparatus

The visual stimulus was a white disc with a luminance of 49 cd/m^2, which was presented against a black background (16-ms duration; visual angle of 1.3°). The visual stimuli were presented on a Gateway EV910 monitor (Gateway Inc., Irvine, California, USA) with a dimension of 21″, resolution of 1024 × 768 and a refresh rate of 75 Hz. Participants were seated in front of the computer monitor at a distance of 57 cm.

The auditory stimulus, which was delivered binaurally through headphones (Logitech USB headset; Logitech Americas Headquarters, Fremont, California, USA), was an auditory pure tone 'beep' with a frequency of 3.5 kHz of 10-ms duration and 1-ms rise/fall time and with a sound pressure level of 70 dB across all participants.

Procedure

At the beginning of each trial, participants were presented with a white fixation cross for 700 ms followed by a blank screen for 500 ms and then by either the visual (flash) or auditory stimulus (beep). After a SOA of either 70 or 270 ms, the second stimulus in the alternate modality (either auditory or visual) was delivered. The task was to indicate which stimulus was presented first by a key press (left or right arrow, counterbalanced). After a response was made, a 500 ms blank delay followed, and the following trial began with the fixation cross. The instructions emphasized response accuracy over speed. Participants completed four blocks of 44 trials each and could take a self-timed rest between blocks. Trial order was randomized within blocks.

Electroencephalogram acquisition and signal processing

Electroencephalogram (EEG) was acquired from a 64-channel montage [electrodes positioned according to the international 10/20 system [18], using the Biosemi Active Two system (*http://www.biosemi.com/products.htm*)] with active scalp electrodes, sampled at a rate of 512 Hz per channel and digitized with 19-bit resolution. An online vertex reference electrode was used. During EEG acquisition, eye movements and blinks were monitored through two bipolar channels: one with electrodes placed on the supraorbital ridge and below the left eye and the other with one electrode on the outer canthus of each eye.

EEG data were processed offline using EEGLAB (*http://sccn.ucsd.edu/eeglab/*). First, these data were visually inspected and bad channels interpolated using the nearest neighbours method. Data were then rereferenced to the common average reference. Epochs of length 1000 ms (512 data points) were extracted, beginning 200 ms before the onset of the first stimulus in a two-stimulus sequence, and were baseline corrected over the −200–0 ms interval. Epochs were rejected based on threshold criteria of ± 100 μV, to remove those epochs corrupted by eye-blink movement or other artefacts (average 10% in both groups). The remaining epochs were bandpass filtered from 1 to 30 Hz and the mean baseline was subtracted from −200 to 0 ms. For each condition, individual-average ERPs were then created for each participant and group-average ERPs were computed from these epochs. Analysis parameter intervals were chosen based on those used in past studies and corroborated by detailed visual and preliminary quantitative investigations of individual-average and grand-average ERP waveforms. P1 range mean amplitudes were then extracted from occipital electrodes (O1, O2, Oz, PO7, PO3, POz, PO4, PO8, P7, P5, P3, P1, Pz, P2, P4, P6, P8). The amplitude of the posterior P1 in response to the flash in the visual–auditory condition was computed for the 100–140 ms interval and averaged over the 17 occipitoparietal sites. The posterior P1 amplitude for the flash in the auditory–visual condition was likewise computed using one of two time intervals: for the SOAs of 70 or 270 ms, intervals of either 180–250 ms, or 380–450 ms were used, respectively. ERP mean amplitudes in the N1 range were extracted from the frontal electrodes (Fz, F1, F2, F3, F4, F5, F6, FCz, FC1, FC2, FC3, FC4, FC5, FC6). The amplitude of the N1 response to beeps in the auditory–visual condition was computed for the 80–160 ms interval and averaged over the 14 fronto-central electrodes. The amplitude of the N1 response to beeps in the visual–auditory condition was similarly computed for the 170–220 ms interval for the SOA of 70 ms and the 370–420 ms interval for the SOA of 270 ms.

Results

Behavioural results

The mean accuracy at judging crossmodal temporal order across younger adults was 75% (SD = 20%) and across older adults was 69% (SD = 20%). The proportion of accurate responses per condition was entered into an age group (older or younger) × initial stimulus modality (visual or auditory) × SOA-mixed (70 or 270 ms) analysis of variance (ANOVA). A main effect of SOA was found [$F(1,34) = 211.7$; $P < 0.001$]: participants' TOJs were more accurate when the SOA was 270 ms (mean = 86%; SD = 16%) than when it was 70 ms (mean = 58%; SD = 14%). Neither the effect of age [$F(1,34) = 3.6$, $P = 0.06$] nor modality of initial stimulus [$F(1,34) = 3.5$, $P = 0.06$] reached significance. However, the results suggested a trend for older to be overall less accurate than younger adults and a trend for participants to be more accurate when the auditory stimulus was presented first [a mean accuracy of 75% (SD = 20%) and 69% (SD = 20%) for the auditory–visual and visual–auditory conditions, respectively], in line with the temporal ventriloquism effect.

Importantly, the interaction between SOA and participant group was significant [$F(1,34) = 5.22$, $P < 0.05$]. Tukey post-hoc tests on this interaction revealed no difference in TOJ between younger (mean = 59%; SD = 13%) and older adults (mean = 58%; SD = 16%) with a short SOA of 70 ms ($P = 0.98$). However, younger participants were significantly more accurate than older participants when the SOA was 270 ms (mean = 91%; SD = 13% and mean = 81%; SD = 17%, respectively; *Post hoc*, $P < 0.05$). No other interaction reached significance.

Event-related potential results

We first analysed what we refer to as the 'control' conditions (auditory–visual and visual–auditory) by taking the ERP responses to the initial stimulus only. In the visual P1 component of the ERP for the visual–auditory conditions, we ran an age group (younger or older participants) × SOA (70 ms or 270 ms) ANOVA. The results showed a main effect of age in that older participants presented a smaller P1 amplitude than younger participants [$F(1,34) = 25.23$; $P < 0.001$; mean = 1.49; SD = 2.09 and mean = 5.43; SD = 2.82, respectively]. There was no effect of SOA [$F(1,34) = 2.95$, $P = 0.095$; SOA of 70 ms, mean = 3.21, SD = 3.17 and SOA of 270 ms, mean = 3.70, SD = 3.19] and no interaction found [$F(1,34) = 0.004$, $P = 0.95$] (see Supplemental Material 1, Fig. 2, Supplemental digital content 1, *http://links.lww.com/WNR/A132*).

In the age group × SOA ANOVA, which tested N1 amplitude differences in the auditory–visual condition (i.e. when the auditory stimulus was presented first), the results showed no main effect of group [$F(1,34) = 0.15$, $P = 0.69$; younger mean = -1.27, SD = 1.32 and older mean = −1.13, SD = 1], nor of SOA [$F(1,34) = 0.0004$, $P = 0.98$; SOA of 70 ms, mean = −1.21, SD = 1.20 and SOA = 270 ms, mean = −1.20, SD = 1.15], and no interaction [$F(1,34) = 0.15$, $P = 0.69$]. The results above, showing no difference between younger and older participants in the auditory ERP but lower amplitude in older adults in the visual ERP are in line with previous reports showing that visual ERPs are more susceptible to change with aging than auditory ERPs [19] (see Supplemental Material 1, Fig. 2, Supplemental digital content 1, *http://links.lww.com/WNR/A132*).

We then ran two separate ANOVAs on the amplitudes in the relevant components elicited to the second stimulus in each trial, one for each of the cross-sensory conditions (i.e. P1 to the visual stimulus in the auditory–visual condition and N1 to the auditory stimulus in the visual–auditory condition).

In the two (younger or older participants) × two (SOA, 70 or 270 ms) ANOVA on the visual P1 amplitudes, a main effect of participants' group was found [$F(1,34) = 10.74$, $P < 0.01$] with a significantly smaller amplitude of the P1 component in the older adults (mean = 0.68, SD = 1.92) relative to that elicited by younger adults (mean = 2.55, SD = 1.92). No main effect of SOA was found [$F(1,34) = 3.94$, $P = 0.56$]. There was an interaction between the age group and SOA [$F(1,34) = 7.69$, $P < 0.01$]. Planned comparisons showed that there was a difference in the P1 amplitude between younger and older participants at the SOA of 270 ms ($P < 0.001$), whereas no such difference was found at the SOA of 70 ms ($P = 0.2$; Fig. 1a). Of note, the apparently higher visual P1 amplitude for older participants at the SOA of 70 ms relative to the SOA of 270 ms is possibly a product of the previous processing of the auditory stimulus that elicited activation in frontoparietal areas with a corresponding inverted polarization at posterior sites. Therefore, the higher visual P1 for older participants with an SOA of 70 ms is not related to the processing of the visual stimulus.

The mixed two (younger or older participants) × two (SOA, 70 or 270 ms) ANOVA on the auditory N1 amplitudes revealed no main effect of age group (younger mean = −1.09, SD = 1.48; older mean = −1.02, SD = 1.03). Both the main effect of SOA [$F(1,34) = 6.33$, $P < 0.05$] and the interaction between SOA and group were significant [$F(1,34) = 7.99$, $P < 0.01$]. Planned comparisons showed that again the difference between younger and older participants appeared at the SOA of 270 ms ($P = 0.01$), but not at the shorter SOA of 70 ms ($P = 0.12$; Fig. 1b).

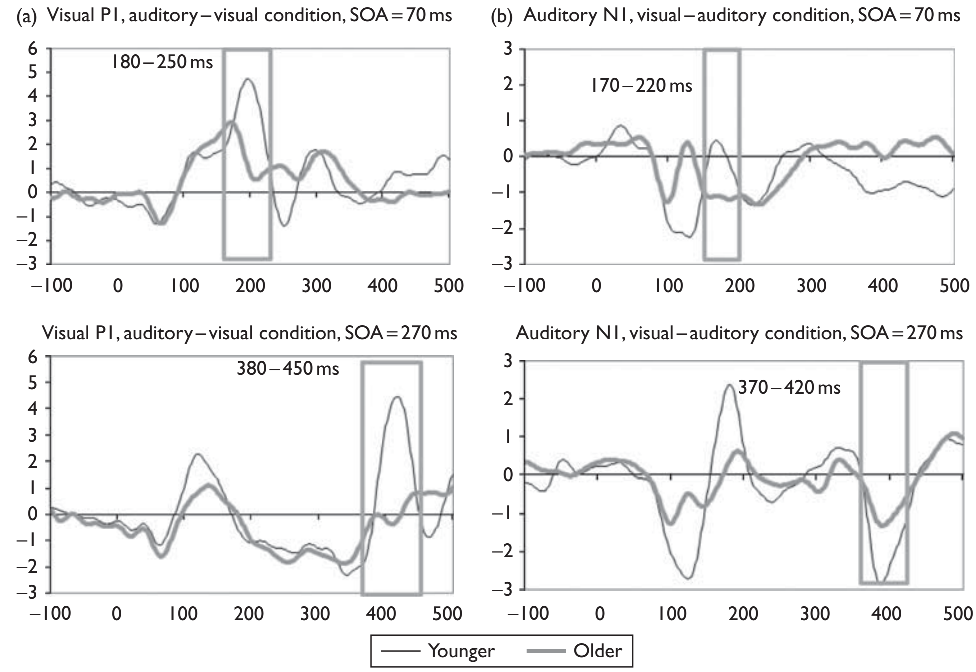
The topographical maps of the EEG activity in the visual P1 and auditory N1 time windows for the auditory–visual and visual–auditory conditions, respectively, when the SOA was 70 or 270 ms, showed larger activity in the occipital regions (P1) and in the frontal regions (N1) for younger participants, whereas activity is more distributed in older participants (see Supplemental Material, Figs 3 and 4, Supplemental digital content 2, *http://links.lww.com/WNR/A134* and Supplemental digital content 3, *http://links.lww.com/WNR/A135*).

Discussion

In summary, there was no effect of age on the TOJ accuracy at the SOA of 70 ms, whereas at the 270 ms SOA, older adults were less accurate than younger adults. Given that a 70 ms SOA is within the temporal window of audiovisual integration for young adults [8], the lack of an age effect is not unexpected. The accuracy decrement in older adults for the 270 ms SOA relative to younger adults is consistent with recent findings that older adults are susceptible to the sound-induced flash illusion even at such SOAs [10] and with evidence that they integrate cross-modal information to a greater degree than young adults, particularly when attention is divided across modalities [20–22].

ERP data paralleled these findings. In the ERP elicited by the second stimulus in each trial, amplitudes did not differ between the age groups with an SOA of 70 ms, which was not surprising given the accuracy data. In contrast, for an SOA of 270 ms, the posterior P1 amplitude

Fig. 1



Amplitudes in the P1 component and in the N1 component of the event-related potential (ERP) across older and younger adult groups in response to the visual 'flash' stimulus in the auditory–visual condition and to the auditory 'beep' stimulus in the visual–auditory condition, respectively. SOA, stimulus onset asynchronies.

(in response to 'flashes' in auditory–visual trials) was significantly smaller in older than in younger adults. Furthermore, at this SOA, the amplitude of the N1 (in response to 'beeps' in visual–auditory trials) was significantly smaller in older than younger adults. In the 'control' comparisons (of ERPs elicited by first stimuli in each trial), there was no age effect on the N1 component (to beeps), but the P1 amplitude (to flashes) was lower in older adults. Collectively, the ERP results indicate that it is processing of the second stimulus in a crossmodal TOJ trial, which is impaired in older adults specifically when the SOA is beyond the temporal window of multisensory integration of young adults, although possibly within the extended window of older adults [9].

Such impairment in older adults may be due to the protracted processing of the preceding stimulus. With a SOA of 270 ms, young adults may more effectively disengage from the first stimulus once perceived, and more efficiently redirect processing towards the second stimulus. Younger adults may also more effectively use the first stimulus in a trial (e.g. auditory) as a cue to disengage from and suppress (auditory) processing, and attend to and facilitate processing of the second stimulus, which is presented in the other modality (e.g. visual). Various investigators proposed that top–down modulation of sensory processing occurs during the P1/N1 intervals [13,17]. Moreover, Gazzaley *et al.* [23] report ERP data, which suggest a selective deficit in the suppression of visual processing in older adults, which may partly explain the current ERP results. The ability to switch between sensory modalities, that is, to suppress one modality to focus on the other, may become less efficient with aging (see Ref. [24]).

Of note, although the older participants in this study had good hearing and vision for their age group, it is possible that sensory acuity was not equated to that of younger adults. This may have produced a relative disadvantage for older adults in temporal order discrimination. However, this is unlikely to be the only reason for our results, as it does not explain the different results for each of the SOAs.

Importantly, Powers *et al.* [25] found that training participants on an audiovisual TOJ task leads to reduced temporal discrimination thresholds across auditory and visual asynchronous events. We are currently assessing the efficacy of a similar training procedure in older adults. If the temporal window within which crossmodal events are integrated can similarly be reduced, it would be of substantial interest to investigate the ERP correlates of such training, particularly in older adults whose inefficient multisensory processing appears to be linked to falls [10].

Conclusion

In conclusion, this study shows a deficit in behavioural performance in older adults when deciding which of the two crossmodal stimuli was presented first. In particular, their deficit was evident with a longer SOA (270 ms), but not a shorter SOA (70 ms). This behavioural deficit is associated with a reduced early visual (P1) and auditory (N1) amplitude in response to the second stimulus (in auditory–visual and visual–auditory conditions, respectively).

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