AUDIO-VISUAL TEMPORAL ORDER JUDGMENTS IN AGING

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By

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Abstract

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Audio-visual temporal processing, and integration of auditory and visual information, is necessary for perceiving the world around us. Although previous research has indicated a slowing of temporal processing in older adults for unisensory stimuli, little work has examined the role of aging on multisensory temporal processing. The goal of this thesis is to use temporal-order judgment (TOJ) tasks to investigate age-related changes in audio-visual temporal processing.

Overall, our results indicate that older adults do not demonstrate impairments on simple audio-visual TOJs, but they do exhibit deficits on more complex TOJ tasks. We also found no influence of spatial cues on TOJs for younger or older adults. Finally, we found age differences in complex TOJ tasks could not be explained by changes in the ability of older adults to detect a gap between sequential visual stimuli.

The work in the thesis suggests that although there may be slowing in audio-visual temporal processing in complex situations, there are circumstances where audio-visual temporal processing is spared. By categorizing multisensory processing deficits in the elderly, we can aim to improve quality of life by preventing fails and perpetuating social interactions.

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Declaration of Academic Achievement

This thesis consists of six chapters. The first chapter is a general introduction chapter and the last chapter is a general discussion chapter. In between, there are four content chapters written in journal article format. I was primary researcher on all chapters, and in such, was responsible for coming up with new research ideas, programming experiments, analyzing data and preparing manuscripts.

Chapter 2 was written in collaboration with another graduate student in our department, Chris M. Fiacconi, and my supervisors, Patrick J. Bennett and Allison B. Sekuler; it has been accepted for publication in the Journal of Experimental Aging Research. Chapter 3 and Chapter 5 were written in collaboration with my supervisors. Chapter 4 was written in collaboration with my undergraduate student, Paul Sirek, and my supervisors. Chapter 3, Chapter 4, and Chapter 5 will be submitted to an undetermined journal article.

Chapter 1

General Introduction

1.1 Audio-Visual Integration

Multisensory integration is important in order for us to interact with the world around us. We are constantly encountering stimuli which have sensory information from multiple sensory modalities. If we cannot bind this sensory information into one percept, we will not perceive our world as a unitary whole.

Of particular importance is audio-visual integration because the majority of the stimuli we encounter on a daily basis contain auditory and visual information. For example, one of the most important social interactions we partake in is language production and comprehension. Understanding language takes coordination of both auditory and visual information (Erber, 1975). It has been shown that a variety of visual factors contribute to the understanding of speech (Keith, 1956). Furthermore, interpreting facial expressions and body language is important for interpreting social interaction (Graf, Cosatto, Strom, and Huang, 2002).

Evidence for enhanced processing for audio-visual information presented in a multimodal fashion, as opposed to uni-modal presentation comes from event-related potential (ERP) studies. For example, Teder-Sälejärvi, McDonald, Di Russo, and Hillyard (2002) showed that the neural response to audio-visual stimuli is greater than the response to either auditory or visual alone and to the sum of the two unisensory responses. Furthermore, reaction times to audio-visual stimuli are faster than reaction times to unisensory stimuli, indicating that we process audio-visual information quicker and more accurately.

Both spatial and temporal factors determine if auditory and visual information will be integrated into a single, multisensory percept (Spence, 2007). Specifically, auditory and visual stimuli are integrated into one percept when they are located at approximately the same location and occur at approximately the same time. However, studies have shown that if the two stimuli are temporally close to each other, the auditory information will be pulled towards the visual information, a phenomenon known as visual ventriloquism (Slutsky and Recanzone, 2001). Although integration is maximal when there is spatial and temporal correspondence between stimuli, there is some latitude to the temporal and spatial interval between the auditory and visual stimuli in order for them to be integrated (Teder-Sälejärvi et al., 2002).

1.2 Audio-Visual Temporal Order Judgments

One way to study audio-visual integration is by utilizing a temporal order judgment (TOJ) task. In this task, subjects are presented with auditory and visual stimuli that are separated by temporal intervals that vary in duration, and must judge which stimulus was presented first. This task provides information about the temporal resolution of audio-visual sensory processing.

Audio-visual temporal order judgments have been studied extensively in normal populations. As early as 1961, Hirsh and Sherrick performed a temporal order judgment task involving an auditory click and a visual light. They found that their subjects needed approximately 20 ms to reach a threshold of 75% accuracy. Several years later, (Gengel and Hirsh, 1970) found that multiple presentations, practice and feedback can, in certain circumstances, improve performance on this task. Furthermore, performance on TOJ tasks can be influenced by stimulus duration (Boenke, Deliano, and Ohl, 2009), stimulus complexity, and experimental method (van Eijk, Kohlrausch, Juola, and van de Par, 2008).

More recently, Zampini, Shore, and Spence (2003a) examined the effects of spatial cues on audio-visual temporal order judgments. Often in these types of tasks, the auditory and visual stimuli are presented from different locations. For example, the visual stimulus might be presented on a display located in front of the subject, whereas the auditory stimulus is presented over headphones. In this situation, sensory modality is confounded with stimulus location, and therefore location cues might affect temporal order judgments. To determine if such cues affect performance in TOJ tasks, Zampini et al. administered an audio-visual TOJ task that included conditions in which auditory and visual stimuli originated from the same or different locations. Using the method of constant stimuli, in which the SOA between auditory and visual stimuli was varied across trials, Zampini et al. estimated the psychometric function that related the SOA to the percentage of times subjects responded that the visual (or auditory) stimulus was presented first. From this curve, Zampini et al. calculated the just noticeable difference (JND) and the point of subjective simultaneity (PSS). The JND is an index of sensitivity to the difference between auditory and visual stimulus onset times, and is calculated by subtracting the SOAs that correspond to the 75% and 25% points on the psychometric function. The PSS corresponds to the 50% point on the psychometric function, and represents the SOA at which an individual judges the auditory and visual stimuli to occur simultaneously (See Figure 1.1). Zampini et al. found that the PSS was larger (i.e., the visual stimulus had to be further ahead of the auditory stimulus) when the auditory and visual stimulus came from different locations. More importantly, the JND was smaller (i.e., sensitivity to the SOA was better) when the auditory and visual stimuli were presented from different locations. These results indicate that TOJs are significantly influenced by spatial cues, and that performance may be improved when stimuli are spatially discordant.

Zampini, Shore, and Spence (2003b), further investigated spatial cues in audio-visual TOJs. Using the same method, they measured JND and PSS while varying spatial cues. They found that when stimuli were spatially separate, but along the midline (i.e., with headphones or a loudspeaker and lights presented above and below fixation), there were no differences in either JND or PSS. Similarly, when stimuli were spatially separate, but both to the left or right of central fixation, there were no differences in either JND or PSS. However, when stimuli were spatially separate across the midline, participants were significantly better when stimuli were presented from different locations. This demonstrates that the advantage caused by spatial redundancy may be generated by spatial redundancy within a hemisphere.

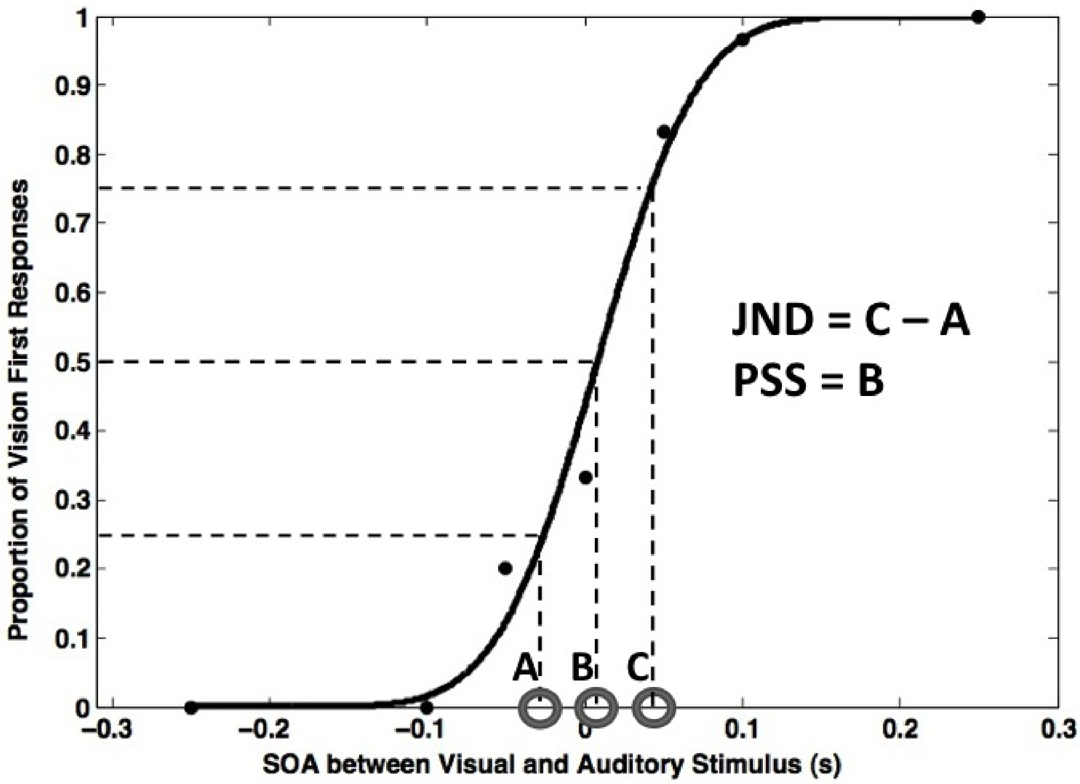

Figure 1.1: An example of how JND and PSS are calculated from a psychometric curve. The proportion of vision first responses is plotted on the y-axis and the SOA between the visual and auditory stimulus is plotted on the x-axis. PSS is taken as the 50% correct SOA (B), and JND is calculated as the 25% SOA (A) subtracted from the 75% SOA (C).

1.3 Aging and Multisensory Processing

It has been shown that there is a general slowing of temporal processing as we age (Fitzgibbons and Gordon-Salant, 1996; Salthouse, 1996). It is reasonable to suspect, therefore, that audio-visual integration will be impaired by aging. Audio-visual integration is important for speech perception, which is a vital component of many aspects of social interaction, which has been linked to happiness and quality of life in elderly adults (Lee and Ishii-Kuntz, 1987). Furthermore, multisensory integration is important for perceiving the world, and may play an important role in maintaining balance and avoiding falls (Setti, Burke, Kenny, and Newell, 2011a). In fact, Setti et al. reported that falls in the elderly may be caused by inefficient multisensory processing. For these reasons, it is important to study audio-visual multisensory processing in aging.

1.3.1 Unisensory TOJs

Unisensory TOJs have been explored in several modalities in aging. For example, Busey, Craig, Clark, and Humes (2010) measured TOJ thresholds in a series of visual tasks involving strings of two or four letters presented at the same or different locations. Older adults had significantly larger visual thresholds, showing decreased visual temporal resolution. Furthermore, individuals performed better when the visual stimuli were presented from different locations, and older adults were slower at reporting the location of visual stimuli.

Reduced temporal resolution has also been demonstrated in the auditory domain. Fitzgibbons and Gordon-Salant (1998) compared older and younger adults on discrimination and identification tasks of temporal processing. Older adults performed worse than younger adults in the discrimination task with complex tonal sequences and in the identification task at smaller tone durations.

Craig, Rhodes, Busey, Kewley-Port, and Humes (2010) measured TOJ thresholds in the tactile domain with vibratory stimuli administered to the hands. A group of older and a group of younger participants judged the temporal order of either two or four tactile stimuli presented to the same finger or different fingers (i.e., corresponding fingers on the two hands). Older adults had larger thresholds than the younger adults, and this difference was the largest for the four tactile stimuli condition.

1.3.2 Multisensory TOJs

With previous research demonstrating deficits on unisensory TOJs for older adults, it is reasonable to expect that older adults would also show deficits on multisensory TOJs. However, few studies have examined this issue. Poliakoff, Shore, Lowe, and Spence (2006) measured the effects of aging on visuo-tactile TOJs. Using the same method as Zampini et al., Poliakoff et al. measured JND and PSS on a visuo-tactile TOJ with stimuli presented on either the left or the right of central fixation. Therefore, on any given trial, stimuli could be presented at the same or different locations. Not surprisingly, Poliakoff et al. found that the JND was smaller when stimuli were presented from different locations. Furthermore, older adults had significantly longer JNDs than younger adults. This indicates that not only are all participants less precise when stimuli are presented in the same location, older adults are less precise overall. Virsu, Lahti-Nuuttila, and Laasonen (2003) measured both audio-tactile and visuo-tactile thresholds in 20-59 year-old adults and found that thresholds in both tasks increased with age.

Only two studies have have examined the effects of aging on audio-visual TOJs, Virsu et al. (2003) measured audio-visual TOJ thresholds in normal readers and dyslexic readers between 20 and 59 years of age. The auditory stimulus was an 8 ms 4 KHz square waves presented through a loudspeaker; the visual stimulus was an 8 ms flash of light emitted from an LED. Although the visual stimulus was presented at central fixation, it is unclear whether or not the auditory stimuli was presented in the same location as the visual stimulus. The SOA was varied by a staircase method to find the SOA required to produce 84% correct responses. Thresholds became significantly larger across the lifespan, indicating a decline in audio-visual temporal processing as we age.

In a more recent study, Setti et al. (2011b) administered an audio-visual TOJ concurrent with electro-encephalography (EEG) to measure ERPs. The stimuli – a white disc presented at the fixation point and a pure tone presented over headphones – were separated by a temporal interval of 70 or 270 ms with either the visual stimulus or the auditory stimulus being presented first. For response accuracy, there was a significant interaction between SOA and age group: there was no difference between groups at the 70 ms SOA, but accuracy was significantly lower in older adults at the 270 ms SOA. The amplitudes of the P1 component of the visual ERP and the N1 component of the auditory ERP mirrored the behavioural results: the amplitudes of both components were significantly larger in younger adults in the 270 ms SOA condition but not the 70 ms SOA condition. Setti et al. interpreted their results as showing that the temporal window of multisensory integration is wider in older adults. Auditory and visual stimuli separated by an SOA of 70 ms fall within the temporal window of integration of both groups. Consequently, the auditory and visual stimuli are integrated into a single multisensory percept, and younger and older adults failed to accurately judge the temporal order of the two stimuli. On the other hand, auditory and visual stimuli separated by 270 ms fall outside the temporal window of integration for younger, but not older, adults. Therefore, Setti et al. argued, younger subjects, but not older subjects, are able to distinguish the temporal order of the auditory and visual stimuli.

1.4 Outline of Current Studies

The purpose of this thesis is to examine the effects of aging on audio-visual temporal order judgments.

The experiments described in Chapter 2 examine the effects of aging and spatial cues on simple audio-visual temporal order judgments. Our audio-visual task required subjects to determine the temporal order of a single pair of visual and auditory stimuli. In the first experiment, the speakers were positioned such that the auditory and visual stimuli were perceived to be in similar locations. In the second experiment, the speakers were located to the left or right of the visual stimulus. JND and PSS were analyzed to assess the effects of age and stimulus position.

Chapter 3 examines more complex audio-visual temporal order judgments. These TOJs are deemed more complex because they contain multiple audio-visual stimuli within a given trial. For example, in one of the experiments, there are two visual stimuli separated by a varying temporal interval, and one auditory stimulus always simultaneous with the first or second visual stimulus. The task will follow a two-alternative forced choice (2AFC) procedure, in which participants must respond which visual stimulus the tone occurred with. Threshold and standard deviation (SD) values will be calculated from curve-fitting procedures. Two other similar tasks will be conducted as well to determine whether or not older adults demonstrate a deficit on more complex audio-visual TOJs.

Chapter 4 aims to extend results found in Chapter 2. We again use a simple audio-visual TOJ task as used in Chaper 2; however, we vary spatial cues by using headphones versus speakers. Furthermore, in an attempt to replicate Setti et al., we increase the temporal offset between the two stimuli and utilize their same visual stimulus.

In Chapter 3 we will discuss more complex audio-visual TOJ tasks. As mentioned previously, one of the experiments involves two visual stimuli separated by a varying temporal interval. In order to determine if older adults are able to distinguish that there are two stimuli occurring, and they are not blurring the two visual stimuli together in time, in Chapter 5, we administer several gap detection tasks to groups of older and younger adults. In the gap detection task, the same visual stimulus as the previous chapters is used; however, there is either one visual stimulus or two visual stimuli separated by a varying temporal interval. The object of this task is to determine whether or not there is one visual stimulus or two visual stimuli. Furthermore, we ran participants in the original 2AFC TOJ task to determine if there is a relationship between performance on the two tasks.

In the final chapter, I will summarize my results, discuss the impact this line of research has had on audio-visual research and aging, and indicate directions for future research.

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Chapter 2

The Influence of Aging on Audio-Visual Temporal Order Judgments

Abstract

The perception of naturalistic events depends on the ability to integrate perceptual information from multiple sensory systems. Currently, little is known about how multisensory integration is affected by normal aging. We conducted two experiments to investigate audio-visual temporal processing in younger (18-29 years) and older (70+ years) adults. In both experiments, participants were presented with a brief visual stimulus and a brief auditory stimulus separated by various temporal offsets, and participants judged which stimulus was presented first. In Experiment 1, the auditory and visual stimuli were presented from the same perceived location, while in Experiment 2 they were presented from different locations. We found no effect of stimulus location, and no evidence of age-related declines in performance in either experiment.

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2.1 Introduction

Sensitivity to the temporal structure of multimodal events is vital to human perception and cognition. Face to face verbal communication, for example, involves the dynamic coordination of auditory and visual information (Sumby and Pollack, 1954) An important goal for researchers interested in perception is to gain a better understanding of how the brain achieves this efficient coordination between sensory modalities.

Numerous studies have focused on the temporal coordination of within-modality sensory information in both younger and older adults (Hirsh and Sherrick, 1961; Zampini, Shore, and Spence, 2003a; Rutschmann and Link, 1964; Busey, Craig, Clark, and Humes, 2010; Kim and Mayer, 1994). Given that aging is associated with a general decline in processing speed (Salthouse, 1996), it is not surprising to learn that temporal resolution in a variety of tasks and sensory modalities is reduced in older adults. For example, age-related temporal slowing has been demonstrated throughout the visual system from simple measures such as foveal flicker sensitivity (Kim and Mayer, 1994) to more complex measures such as temporal order judgments (Busey et al., 2010). Indeed, Busey et al. (2010), found that older adults performed significantly worse than younger adults in a series of temporal order judgment (TOJ) tasks that required participants to report the order of sequentially presented letters. Age-related temporal slowing has also been found in other modalities including audition (e.g., Wingfield, Poon, Lombardi, and Lowe, 1985; Fitzgibbons and Gordon-Salant, 1998) and touch (Humes, Busey, Craig, and Kewley-Port, 2009; Craig, Rhodes, Busey, Kewley-Port, and Humes, 2010).

Although age-related changes in within-modality temporal processing have been documented previously, relatively little is known about how aging affects crossmodal temporal resolution. Understanding the relationship between aging and crossmodal integration can have important real-world applications. For instance, recent evidence suggests that age-related declines in crossmodal temporal resolution are associated with an increased incidence of falls in the elderly (Setti, Finnigan, Sobolewski, McLaren, Robertson, Reilly, Kenny, and Newell, 2011). Research into this topic has been limited, but some relevant findings have been reported. Poliakoff, Shore, Lowe, and Spence (2006) examined how aging impacts the integration of visuotactile information using a cross-modal TOJ task. Old and young participants indicated whether a brief vibrotactile stimulus or a brief visual stimulus was presented first. These authors found that the just noticeable difference (JND) was 30 ms larger in older adults than younger adults. Furthermore, Virsu, Lahti-Nuuttila, and Laasonen (2003) measured audio-visual TOJ thresholds in four age groups (20-29, 30-39, 40-49, 50-59 years) and found that thresholds increased with age, suggesting that aging impairs audio-visual temporal sensitivity.

An important aspect of Virsu et al.'s experimental design is that the visual and auditory stimuli were presented in different spatial locations. Previous work (Poliakoff, Shore, Lowe, and Spence, 2006; Zampini, Shore, and Spence, 2003a,b) has demonstrated that performance of younger subjects in multisensory TOJ experiments is substantially better when the two stimuli to be judged are presented from different locations compared to when they are presented from the same location. It is thought that this improvement in performance occurs because participants can use spatial cues in addition to temporal information to make their order judgments - in other words, spatial information is redundant with temporal order information. Therefore it is possible that the age differences found by Virsu et al. reflect age differences in the ability of participants to take advantage of redundant spatial cues. Furthermore, Virsu et al. only tested participants up to 59 years of age, leaving open the question of whether the obtained age-related declines are even greater in elderly participants.

For these reasons, we think it remains an open question as to whether aging affects the precision of audio-visual temporal order judgments. We therefore attempted to clarify this issue by testing both younger and older participants in an audio-visual TOJ task while addressing both of the previously mentioned concerns. In Experiment 1, we presented the auditory and visual stimuli from the same location to ensure that any age-related differences in performance could be attributed to a decline in temporal sensitivity rather than reflecting problems with integrating spatial cues (see Zampini et al., 2003a,b) In Experiment 2, we presented the auditory and visual stimuli from different locations in an attempt to replicate Virsu et al. A comparison across Experiments 1a and 1b would allow us to conclude that any discrepancy in the results between the two experiments could be attributed to spatial factors. Additionally, our group of older participants were all at least 70 years of age. Testing participants in this age range allowed us to obtain a clearer picture of how multisensory temporal processing changes with age, and whether there are any additional deficits beyond 59 years of age.

2.2 EXPERIMENT 1

2.3 Methods

2.3.1 Participants

Twenty-three younger adults (18-29 years, M = 22.1) and 21 older adults (70-82 years, M = 73.9) participated in Experiment 1. All participants completed vision and general health questionnaires to screen for visual pathology, such as cataracts, macular degeneration, glaucoma, and amblyopia. Older participants also completed the Montreal Cognitive Assessment (Nasreddine et al., 2005; M = 29) and the Mini-Mental State Examination (Folstein, Folstein, and McHugh, 1975; M = 27.09). All participants had normal or corrected-to-normal near (Old: M = .98; Young: M = 1.46) and far (Old: M = .97; Young: M = 1.38) Snellen (decimal) acuity. Participants were paid (10$/hour) for their participation.

2.3.2 Stimulus and Appartus

The experiment was programmed using Matlab (version 7.9.0) and the Psychophysics Toolbox (version 3.0.8; Brainard, 1997; Pelli, 1997) running on an Apple PowerMac computer. The visual stimulus was a Gaussian-damped, 1 cpd, horizontal sinusoidal gratings set to a contrast of 0.8. One standard deviation of the Gaussian envelope subtended 0.233 deg of visual angle. The stimuli were displayed on a 20-inch Sony Trinitron monitor with a resolution of 1280 x 1024 pixels and a frame rate of 100 Hz. The nominal duration of the visual stimulus was 1 video frame, or 10 milliseconds (ms), although the actual duration was 2-3 ms (Elze, 2010). The auditory stimulus was 10 cycles of a 1 KHz tone. Auditory stimuli were presented over two speakers that were centered on locations that were 34 cm to the left and right of the center of the visual display. Sound intensity, which was measured with a B&K 2239 sound meter, was 76 dB SPL[1]. The participants viewed the visual display binocularly from a viewing distance of 114

[1]In a pilot experiment designed to assess the influence of the auditory tone intensity on TOJ performance, we manipulated the tone intensity over a wide range of different supra-threshold intensities. The resulting PSS and JND values obtained at each level of intensity were largely the same. In other words, the intensity of the auditory tone did not seem to impact performance in our task.

cm; a chin/forehead rest was used to stabilize viewing position. The visual display was the only source of illumination in the testing room. The speakers were set within a black border that surrounding the visual display, and the front of each speaker was covered by a thin black curtain, and therefore the speakers were not visible during testing.

2.3.3 Procedure

Upon entering the laboratory, task instructions were administered and a short practice block was run to ensure that the participants understood how to perform the task. Participants were instructed to fixate on a small, high-contrast dot presented in the center of the display. At the start of each trial, the fixation dot flickered for 300 ms to attract attention, remained visible for another 500 ms, and then was extinguished. The visual stimulus was presented approximately 800 ms after the offset of the fixation point; a 50 ms random temporal jitter was used to ensure that the visual stimulus did not occur at a fixed interval relative to fixation offset. The onset of the auditory stimulus, relative to the onset of the visual stimulus, was varied across trials using the method of constant stimuli. The stimulus onset asynchrony (SOA) was -250, -100, -50, 0, 50, 100, or 250 ms, where negative values indicate that the auditory stimulus was presented first. The timing of the two stimuli were carefully calibrated, so that the onsets of the auditory and visual stimuli were indeed simultaneous in the 0 ms SOA condition. Participants judged whether the auditory or visual stimulus was presented first by pressing a key on a computer keyboard. A diagram reminding them of which key corresponds to "auditory first" or "visual first" was laid out on the table in front of them. Participants were under no time constraint to respond, but they were told that responses typically occurred within 5s. The fixation dot reappeared 500 ms after a response was given, and the next trial automatically began. No response feedback was given to participants. Each participant performed the entire task twice for a total time of approximately 45 minutes.

2.4 Results

A JND and point of subjective simultaneity (PSS) were obtained for each participant by fitting a cumulative normal function to the proportion of "vision first" responses across SOAs. The JND and PSS were defined, respectively, as the standard deviation and mean of the best-fitting cumulative normal. Figure 2.1 shows the data and best-fitting cumulative normal from a single younger participant. The mean PSS was 11 ms in younger participants and 12 ms in older participants (see Figure 2.2 for a boxplot of PSS values), a difference that was not significant ($t(42) = .07$, $p = .94$, 95% CI mean difference [-30, 28]). The fact that the PSS values were positive means that the visual stimulus had to precede the auditory stimulus in order for the two to be perceived as simultaneous. The mean JND was 160 and 177 ms in younger and older participants, respectively (see Figure 2.3 for a boxplot of JND values). A t-test indicated that the JND did not differ significantly between groups ($t(42) = .70$, $p = .49$, 95% CI mean difference [-31, 63]).

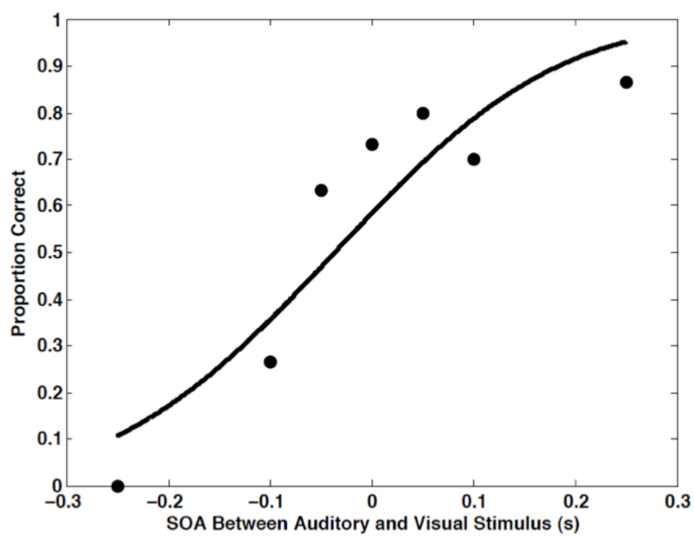

Figure 2.1: The figure shows data collected from a single younger participant for Experiment 1. Onset from the visual stimulus to the auditory stimulus in seconds is plotted on the x-axis and proportion of vision first responses is plotted on the y-axis. The smooth curve is the best-fitting cumulative normal fit to the data.

Virsu et al. (2003) used 8 ms auditory and visual stimuli to measure audio-visual thresholds, defined as the SOA required to yield 84% correct responses. For participants 20-29 years of age, the mean JND was 174 ms (see Figure 1 in Virsu et al., 2003), a value that does not differ significantly from the JND of 160 ms obtained in the current experiment ($t(22) = -0.75$, $p = 0.46$). For participants 50-59 years of age, Virsu et al. (2003) obtained a mean JND of 273 ms, which is significantly greater than the JND of 177 ms obtained from older participants in the current experiment ($t(20) = -6.59$, $p < .001$, 2-tailed).

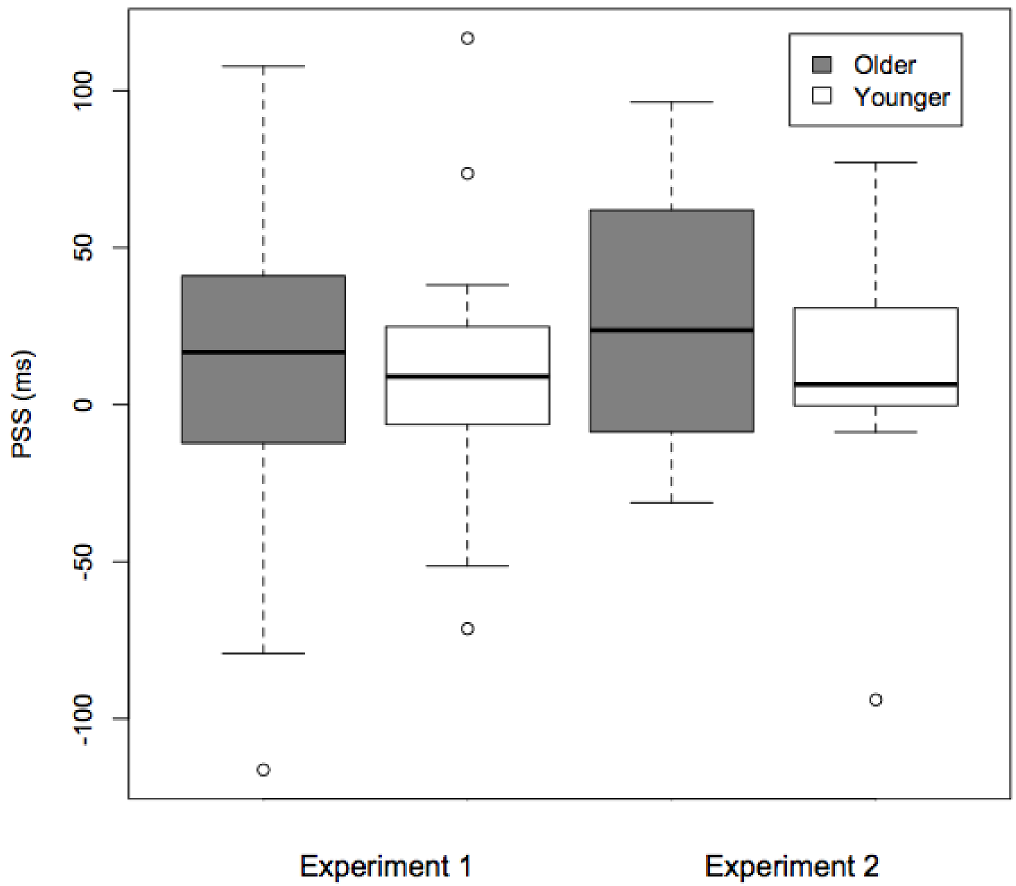

Figure 2.2: Boxplots depicting PSS values for each group in Experiments 1 and 2. The black horizontal lines in each plot represent the median. The rectangular box extends out to the 25th and 75th percentiles (inter-quartile range; IQR), while the dotted line extends to 1.5 times the IQR. The open circles represent those data points that lie beyond 1.5*IQR.

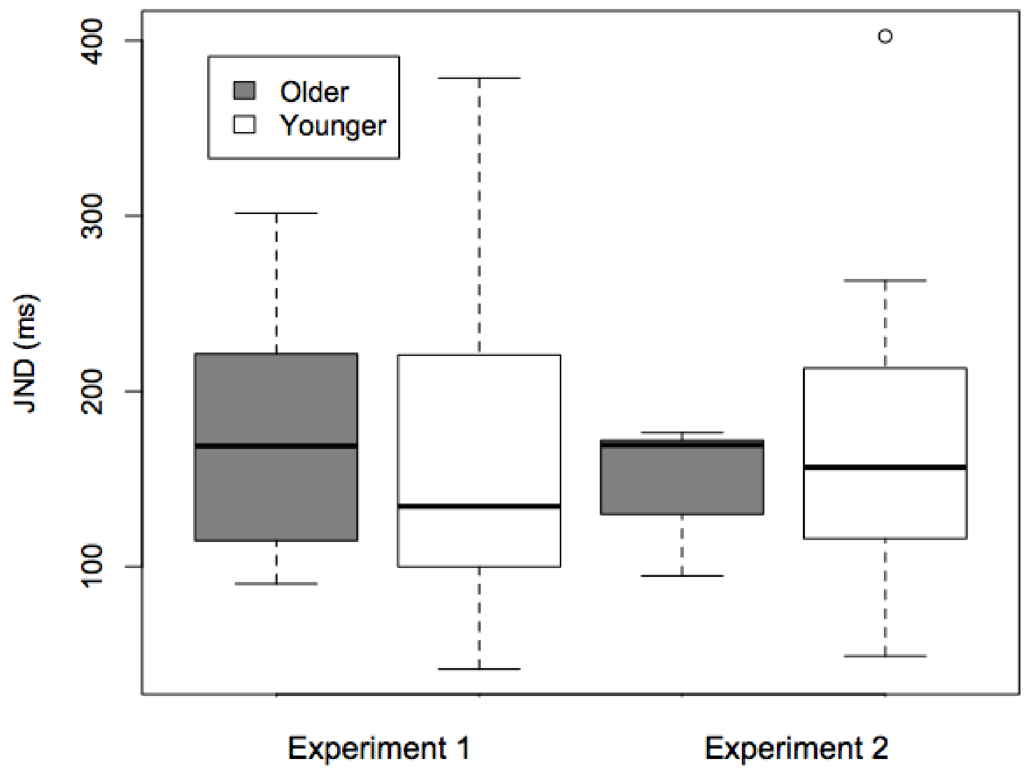

Figure 2.3: Boxplots depicting JND values for each group in Experiments 1 and 2. The black horizontal lines in each plot represent the median. The rectangular box extends out to the 25th and 75th percentiles (inter-quartile range; IQR), while the dotted line extends to 1.5 times the IQR. The open circles represent those data points that lie beyond 1.5*IQR.

2.5 EXPERIMENT 2

Experiment 1 found no evidence for an age difference in audio-visual temporal order judgments, a result that differs from the findings of Virsu et al. (2003). More specifically, JNDs from younger participants did not differ significantly from the values reported by Virsu et al., but JNDs from our older participants were significantly lower than JNDs found by Virsu et al. in 50 year old participants. As noted previously, Virsu et al. presented the visual and auditory stimuli in different locations, and therefore the age difference obtained in that study may reflect an age difference in the ability to use spatial cues to make temporal order judgments. Experiment 2 tested this idea by presenting the visual and auditory stimuli in different locations.

2.6 Methods

2.6.1 Participants

Twelve younger adults (21-31 years, $M = 25.5$) and 12 older adults (70-82 years, $M = 75.2$) participated in Experiment 2. All participants completed vision and general health questionnaires to screen for visual pathology, such as cataracts, macular degeneration, glaucoma, and amblyopia. Older adults completed two measures of cognitive function: the Montreal Cognitive Assessment (Nasreddine et al., 2005; $M = 27.2$) and the Mini-Mental State Examination (Folstein et al., 1975; $M = 28.8$). All participants had normal or corrected-to-normal near (Old: $M = .95$; Young: $M = 1.47$) and far (Old: $M = 1.02$; Young: $M = 1.47$) Snellen (decimal) acuity. Participants were paid (10$/hour) for their participation.

2.6.2 Stimulus and Appartus

The stimuli and apparatus were the same as Experiment 1, with one exception. In the current experiment, each participant completed the experiment with the two speakers both placed 92 cm to the left of the center of the visual display in one block of trials, and 92 cm to the right of the center of the visual display in the other block of trials. The order of left/right speaker placement was counter-balanced across participants.

2.6.3 Procedure

The experimental procedure was the same as in Experiment 1.

2.7 Results

The procedure for data analysis was identical to Experiment 1 with the following exception. Overall PSS and JND values were obtained for each participant by averaging the PSS and JND values obtained in each block (speakers left/right) of trials. Figures 2.2 and 2.3 depict boxplots for the PSS and JND for each condition, respectively. Similar to Experiment 1a, the mean PSS values for both groups were positive, indicating that the visual stimulus had to be presented prior to the auditory stimulus to be perceived as simultaneous. The mean PSS values were 10 ms and 25 ms for younger and older adults, respectively. The mean JND values were 175 ms and 153 ms for younger and older adults, respectively. As was found in Experiment 1, the PSS ($t(22) = .92$, $p = .37$, 95% CI mean difference [-49, 19]) and JND ($t(22) = .78$, $p = .45$, 95% CI mean difference [-83, 39]) did not differ between age groups. To directly assess whether presenting the two stimuli from the same vs. different spatial locations had an effect on performance, we conducted separate 2 (Experiment) x 2 (Age) factorial ANOVAs for JND and PSS values. For JND scores, our analysis revealed no main effects of either Experiment ($F < 1$), or Age ($F < 1$), and no interaction between these variables ($F(1, 64) = 1.01$, $p = .32$). Similarly, for PSS scores, there were no main effects of Experiment ($F < 1$), or Age ($F < 1$), and no significant Experiment x Age interaction ($F < 1$).

To increase power and increase the sensitivity of our tests of an age difference, we combined the data from Experiments 1 and 2, creating groups of 33 older and 35 younger participants, and re-evaluated the group differences and 95% confidence intervals. For PSS scores, the mean age difference collapsed across both experiments was 6 ms (95% CI = [-15,27]). For JNDs, the mean age difference collapsed across both experiments was 3 ms (95% CI = [-33, 38]). Virsu et al. (2003) found that the mean JND in 50-59 year olds was 98 ms greater than the mean JND in 20-29 year olds. To calculate the power of our t-test to detect this age difference, we used the combined data to estimate the population standard deviation of the JND error distribution; our estimate of 75 ms is essentially the same as the value of 73 ms found by Virsu et al. for 20-29 year olds[2]. Based on this estimate of error, and assuming sample sizes of 33 participants per group, the power to detect a 98 ms increase in JND in older participants is 0.99. Even if the expected age difference is reduced by 50% to 49 ms, the power is still 0.84.

Collapsing across age groups, we also computed the 95% confidence interval around the mean difference between Experiments 1 and 2 for both PSS and JND scores. For PSS scores, the mean difference between Experiments 1 and 2 was 6 ms (95% CI = [-15, 27]). For JND scores, the mean difference between Experiments 1 and 2 was 4 ms (95% CI = [-32, 40]). Based on our sample sizes (44 in Experiment 1 and 24 in Experiment 2) and our estimate of the standard deviation of the JND population error distribution (74 ms), the JND difference required to obtain a power of 0.8 was 54 ms.

2.8 General Discussion

Our goal in this paper was to examine how the ability to accurately perceive the temporal order of audio-visual stimuli changes with age. To answer this question, younger and older adults performed an audio-visual TOJ task. Experiments 1 and 2 found no evidence to suggest that audio-visual temporal order sensitivity declines with age. In addition, a comparison of Experiments 1 and 2 found no evidence to suggest that performance for either age group depended on whether the auditory and visual stimuli were presented from the same or different locations.

These results are surprising given the findings of previous work. Virsu et al. (2003) found that audio-visual temporal sensitivity declined significantly with age, at least when the two stimuli were presented from different locations. In Experiment 2, we attempted a more direct replication of Virsu et al. by presenting the auditory and visual stimuli from different locations. Based on the null effect of age observed in Experiment 2, it is unlikely that the discrepancy between our results and those of Virsu et al. in terms of age differences in temporal sensitivity reflect age differences in the ability to use spatial cues to aid performance. A closer examination of the data revealed that the two studies obtained similar JNDs with younger participants, but that JNDs in older participants were much lower in the current study than in Virsu et al. This difference may reflect the different procedures used in the two studies. Our experiment used the method of

[2]The value was estimated from the sample sizes and error bars in Virsu et al.'s Figure 1.

constant stimuli: each SOA was presented multiple times in a random order. In contrast, Virsu et al. used a staircase procedure that varied SOA across trials to estimate the SOA producing 84% correct performance. As pointed out by Poliakoff et al. (2006), a staircase procedure might not be ideal for measuring performance in a TOJ task. If for instance the visual stimulus must be presented 20 ms before the auditory stimulus in order for them to be perceived as simultaneous, a staircase procedure could introduce a systematic bias in threshold estimates. If the visual stimulus on a given trial is presented 20 ms before the auditory stimulus, this would produce a subjective percept of simultaneity, and accuracy would likely be at chance. However, if on a given trial the auditory stimulus is presented 20 ms before the auditory stimulus, this would result in a subjective percept of the auditory stimulus occurring 40 ms before the visual stimulus and lead to performance much greater than chance. Therefore, estimates of SOA thresholds would be inflated. Such inflated thresholds could account for the age difference observed by Virsu et al. if it were assumed that older adults had a larger PSS than younger adults. Our data were consistent with this account (see Figure 2.3), although the age differences in PSS were not statistically significant.

More recently, Setti et al. (2011) also reported an age-related deficit in an audio-visual TOJ task. Setti et al. measured TOJ accuracy in both younger and older adults at SOAs of 70 ms, and 270 ms. Accuracy for both age groups did not differ when the SOA was 70 ms, but older adults were less accurate than younger adults at the 270 ms SOA. The authors interpreted this finding by suggesting that older adults have a larger "window-of-integration" than younger adults and consequently were unable to accurately discriminate the order of the two stimuli. This account is broadly consistent with other findings suggesting that older adults larger window-of-integration may actually lead to enhanced multisensory integration (Laurienti, Burdette, Maldjian, and Wallace, 2006) in some contexts. Although we were unable to find an age difference in our TOJ task, our results are not directly comparable to those of Setti et al. because we did not test TOJ accuracy with a SOA of 270 ms. Nonetheless, it is worth mentioning that a possible explanation for these seemingly discrepant findings has to with the nature of the auditory and visual stimuli used by those authors. In our experiments, the auditory stimulus was presented through loudspeakers, whereas Setti et al. presented the auditory stimulus through headphones. Furthermore, the visual stimulus in the Setti et al. experiments was a 16 ms white disc presented against a black background and was therefore likely of higher contrast than the gabor pattern used in the current study.

Another aspect of our results worth mentioning is the absence of an effect of spatial location on measures of JND or PSS. Some previous studies have clearly demonstrated greater temporal sensitivity (as indexed by smaller JNDs) when two multisensory stimuli are presented from different locations compared to the same location (Zampini et al., 2003a,b; Poliakoff et al., 2006). To account for this finding, Zampini et al. (2003a) suggested that presenting two stimuli from different locations introduces spatial cues that are redundant with the temporal order of presentation. Thus, in discriminating the order of two stimuli separated in time, participants can rely not solely on the temporal precision of their sensory systems, but also on which spatial location was stimulated first as an additional cue. Contrary to these findings, we found no evidence across Experiments 1 and 2 that the presence of spatial cues had any effect on performance.

Again, methodological differences may provide some insight into this puzzle. In the experiments reported by Zampini et al. (2003a), the stimuli were presented from multiple locations. They placed two loudspeakers on either side of a central fixation light, and an additional light was placed directly in front of each loudspeaker. Thus, on any given trial, the auditory stimulus could be presented from the left or right of the fixation light, as could the visual stimulus. Therefore, uncertainty was present as to which location(s) would be stimulated on each trial. In contrast, the auditory and visual stimuli in Experiment 2 were always presented in the same two different locations on each trial. It is possible that uncertainty as to which locations will be stimulated on a trial-to-trial basis might encourage participants to make good use of redundant spatial cues and therefore lead to smaller JNDs. Perhaps of most importance, a closer look at the literature revealed that Zampini et al. (2003b) found a reliable benefit for redundant spatial cues only when the auditory and visual stimuli were presented from different locations that crossed the body midline. In Experiment 2 of the current paper (and in the experiments reported by Virsu et al. (2003) and Setti et al. (2011), the visual stimulus was presented directly in front of the participant, and the auditory stimulus was presented either to the left or right. Thus, the two stimuli did not cross the body midline. In this respect, the null result of spatial location reported here is consistent with the data reported by Zampini et al. Future studies should investigate how age may interact with different methods of stimulus presentation.

In comparing the magnitude of the JNDs obtained in our experiments with those reported by others, it is clear that the JNDs reported here fall somewhere in between those found in prior work. As mentioned previously, the JNDs obtained in the current experiments in younger participants were similar to the JNDs reported by Virsu et al. (2003). Furthermore, based on the psychometric functions measured in our experiments, younger adults in Experiment 1 made 65% correct responses when the stimulus SOA was 70 ms, which is slightly better than the 59% correct obtained by Setti et al. (2011) with that SOA. Hence, the performance of our younger participants was comparable to the performance measured in some previous studies. However, the JNDs measured in the current experiments also were considerably larger than those found in some previous studies (Hirsh and Sherrick, 1961; Zampini et al., 2003a). Part of this difference is due to the fact that we defined our JND as one standard deviation (which corresponds to the SOA needed to change vision-first responses from 50% to approximately 84%) of the fitted cumulative normal, whereas other studies have defined the JND as the SOA needed to increase response accuracy from 50% to 75% correct. This difference in criterion then, would result in larger JNDs in our experiments. Although recalculating the JND from our sample using the 75% correct criterion reduced the mean JND to 108 ms for younger adults in Experiment 1, this value still is larger than JNDs of 20-40 ms reported by Hirsh and Sherrick (1961) and Zampini et al. (2003a).

Taken as a whole, the literature to date is characterized by a large degree of variability in overall performance across many studies. A careful analysis of the methodological differences between these studies might provide a potential explanation for this variability. As alluded to above, we note that the stimulus characteristics vary widely across studies. For example, the visual stimulus used by Zampini et al. (2003a) consisted of a red LED that illuminated for 9 ms in a darkened room. Such a stimulus is of particularly high contrast and contains a wide range of spatial frequencies. Similarly, the auditory stimulus was a 9 ms presentation of white noise that contains all temporal frequencies. Such conditions might be particularly optimal for temporal order discrimination due to the wider range of stimulus information available. Also, the studies that obtained very small audio-visual JNDs (Hirsh and Sherrick, 1961; Zampini et al., 2003a) have presented the visual stimuli in the peripheral visual field, whereas studies that obtained larger JNDs e.g., the current study, Virsu et al. (2003), and Setti et al. (2011) presented visual stimuli at a central fixation point. We propose that a systematic investigation of stimulus characteristics might serve as a fruitful avenue for future research that seeks to explain the highly variable range of performance in audio-visual TOJ tasks.

Irrespective of these issues, our experiments strongly suggest that older adults ability to accurately discriminate the temporal order of two audio-visual stimuli is not compromised in comparison to younger adults. Although other studies (Poliakoff et al., 2006) have shown that temporal sensitivity to visuo-tactile information is impaired with age, our results suggest that this impairment does not necessarily generalize to other multisensory domains (specifically audio-visual information). Future research will be needed to better understand the precise mechanisms by which multisensory perception changes with normal aging.

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Chapter 3

Temporal Order Judgment Deficits with Aging on More Complex Audio-Visual Tasks

Abstract

The effects of aging on temporal order judgments (TOJs) have not been investigated. We therefore conducted three experiments that measured TOJs using more complex audio-visual stimuli in groups of younger (18-34 years) and older (+70 years) adults. On all three tasks, older adults performed significantly worse than the younger adults. Therefore, we can conclude that older adults have slower audio-visual temporal processing on more complex tasks.

Keywords

temporal order judgments, audio-visual integration, aging

3.1 Introduction

Real-world events almost always consist of sensory stimulation from more than one sensory modality, and the integration of this sensory information is important for everyday tasks. Often, stimuli involve both auditory and visual events that must be coordinated in time. For example, speech perception is dependent upon the integration of both auditory and visual information (Alsius, Navarra, Campbell, and Soto-Faraco, 2005).

Studies have shown that aging is associated with a reduced speed of processing (Stephen, Knoefel, Adair, Hart, and Aine, 2010) and efficiency (Setti, Burke, Kenny, and Newell, 2011a) of audio-visual integration. However, few studies have specifically examined audio-visual temporal order judgments (TOJs) in aging, and the results of these studies have been mixed. Virsu, Lahti-Nuuttila, and Laasonen (2003) tested adults between the ages of 20-59 years on an audio-visual TOJ task and found that discrimination thresholds increased across the lifespan. Setti et al. (2011b) compared a group of younger adults and a group of older adults on a simple audio-visual TOJ task with stimulus-onset asynchronies (SOAs) of 70 ms and 270 ms and found that older adults were less accurate than younger adults in the 270 ms condition, but not the 70 ms condition. Setti et al. suggest that auditory and visual stimuli separated by 270 ms still fall within older adults' temporal window-of-integration, causing them to perceive a single event rather than two. However, Fiacconi, Harvey, Sekuler, and Bennett (In press), using the same task as Setti et al. with a wider range of SOAs and different stimuli, found no evidence for a decline in audio-visual temporal processing with age.

Importantly, all previous studies investigating audio-visual TOJs in aging have used simple audio-visual tasks involving only one auditory stimulus and one visual stimulus. Studies have shown that increasing task complexity can increase age differences. For example, Einstein, Holland, McDaniel, and Guynn (1992) administered a short-term memory task to a group of older and younger adults with conditions where there was either one target or multiple targets in the recognition phase. Although they failed to find a short-term memory deficit in older adults in the single target condition, there was a significant deficit in the multiple target condition because adding targets caused the performance of older, but not younger, subjects to decrease significantly. Effects of complexity on age differences also have been found in perceptual experiments. For example, Fitzgibbons and Gordon-Salant (1995) found that age differences in duration discrimination was far greater for complex tonal patterns than simple ones. More recently, Craig, Rhodes, Busey, Kewley-Port, and Humes (2010) conducted a study on the effects of stimulus complexity and aging in a tactile TOJ task. Similar to the results of Fitzgibbons and Gordon-Salant, temporal thresholds were larger for older adults, but larger age differences were found with the most complex tactile patterns.

Setti et al. (2011a) postulated that improper multisensory temporal discrimination may be responsible for the frequency of falls in the elderly. A more complex TOJ task may relate better to real-life situations, and demonstrate more accurate deficits in temporal processing in older adults. Therefore, by studying more complex tasks, we can gain a better understanding of deficits that lead to falls in seniors and focus on prevention. For these reasons, and because complex audio-visual TOJs have not been previously examined in older adults, the present paper aims to investigate the effect of aging on several more complex audio-visual TOJs. We suspect that we will find an age-related decline in discrimination capabilities for these more complex, multiple stimuli, audio-visual TOJ tasks.

In Experiment 1, we increased the complexity of a simple audio-visual TOJ by adding a second auditory stimulus. A visual stimulus was presented simultaneous with one of the auditory stimuli, and participants were asked to determine which auditory stimuli the visual stimulus was presented with. Experiment 2 was the same as Experiment 1, except there were two visual stimuli and one auditory stimulus. Consequently, we can determine whether the results will generalize to multiple events in other modalities, as well as replicate our results from Experiment 1. One important difference between these experiments and previous audio-visual TOJ tasks is that there is always a simultaneous event occurring. To determine if the results were due to complexity or the presence of a simultaneous event, we conducted a third experiment where the visual stimulus was varied so that it did not always occur simultaneously with one of the auditory stimuli.

3.2 EXPERIMENT 1

3.3 Methods

3.3.1 Participants

Twenty-two younger adults (13 male, 18-29 years old, $M = 22.3$) and 21 older adults (10 male, 70-82 years old, $M = 73.9$) volunteered to participate Experiment 1. All participants had normal or corrected-to-normal vision measured by Snellen decimal acuity (Old: near $M = 0.98$, far $M = 0.97$; Young: near $M = 1.47$, far $M = 1.40$). The older adults did not suffer from any cognitive impairment as assessed by the Montreal Cognitive Assessment (Nasreddine et al., 2005; $M = 26.6$) and the Mini-Mental State Examination (Folstein, Folstein, and McHugh, 1975; $M = 29$). Participants received compensation of $10/hour for their participation in the experiment.

3.3.2 Stimulus and Appartus

The visual stimulus was a horizontal, 1 cpd Gabor pattern with a contrast of 0.8. The auditory stimulus was a 1 KHz pure tone with an intensity of 76 dB SPL as measured by a B&K 2239 soundmeter. A 20-inch Sony Trinitron Monitor with a resolution of 1280 x 1024 pixels situated at a 114 cm viewing distance was used to present the visual stimuli. The frame rate was 100 Hz. The auditory stimulus was presented over two speakers located 34 cm to the left and right of visual fixation. The speakers were not visible to the participant. The experiment was programmed using Matlab Version 7.9.0 and Psychophysics Toolbox version 3.0.8 (Brainard, 1997; Pelli, 1997) and was run on an Apple PowerMac computer. The only source of illumination in the room was that of the visual display.

3.3.3 Procedure

The procedure for an individual trial in Experiment 1 is depicted in Figure 3.1. Participants were given instructions and performed a short practice block to ensure they understood the task. Participants fixated on a small, centered, high contrast dot that

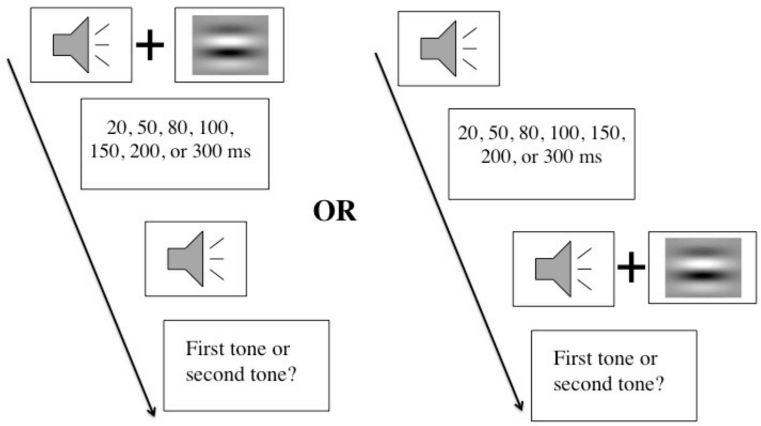


Figure 3.1: Experimental procedure for Experiment 1.

flickered for 300 ms, remained on the screen for an additional 500 ms, and then disappeared. Approximately 800 ms after the fixation dot disappeared, an auditory stimulus was presented for 10 ms. After a randomized inter-stimulus interval (ISI) of 20, 50, 80, 100, 150, 200 or 300 ms, a second auditory stimulus was presented for 10 ms. A single visual stimulus (duration = 10 ms) was presented simultaneously with either the first or second tone. Participants reported whether the visual stimulus was presented with the first or second tone by pressing one of two keys on a standard computer keyboard. Participants were under no time limit and received no feedback. The next trial started automatically 500 ms after a response was made. The task took approximately 25 minutes to complete.

Several older participants could not perform the task and therefore were asked to return to the lab to complete the task with ISIs of 80, 100, 150, 200, 300, 500, 750, or 1000 ms. All participants were able to perform the task with these new ISIs.

3.4 Results

A cumulative normal curve was fit to a plot of each participants proportion of correct responses for each ISI. A threshold and standard deviation (SD) value were calculated for each participant. Threshold was estimated as the mean of the curve (i.e., 75% correct responses). Due to the data being skewed, a square-root transform was applied to threshold and SD. One younger adult was removed from the analysis because they had a negative threshold value. Figure 3.3 shows examples of individual curves fit for an older participant who could not perform the task, an older participant who performed the task well, and a younger participant. As you can see, while some older adults are completely incapable of performing the task at the original ISIs, others perform the task just as well as younger participants.

Boxplots of thresholds and SDs are plotted in Figure 3.2. Thresholds in older adults (M_O = 182.54 ms) were significantly larger than thresholds in younger adults (M_Y = 54.18 ms; $t(26) = 3.26$, $p = .003$). Older adults (M_O = 237.81 ms) also had significantly larger SDs than younger adults (M_Y = 64.94 ms; $t(23) = 3.99$, $p = .001$).

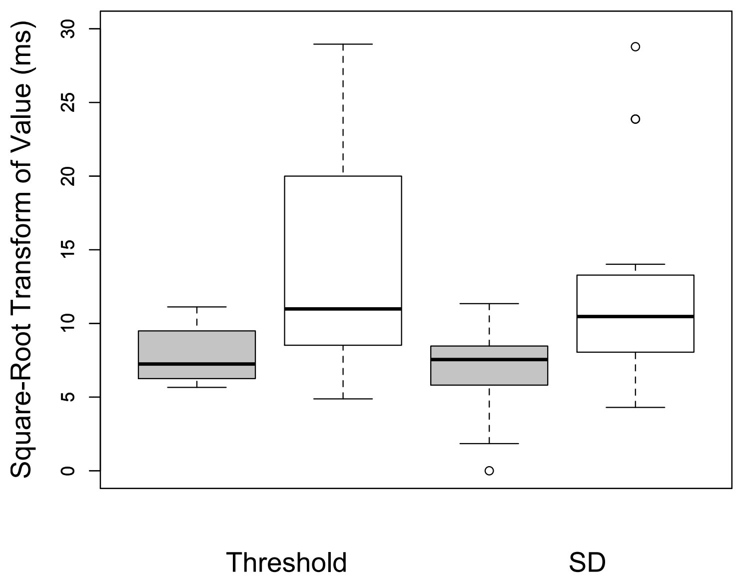


Figure 3.2: Boxplots showing threshold and standard deviation values by group for Experiment 1. The light grey boxes represent the younger adults and the white boxes represent the older adults.

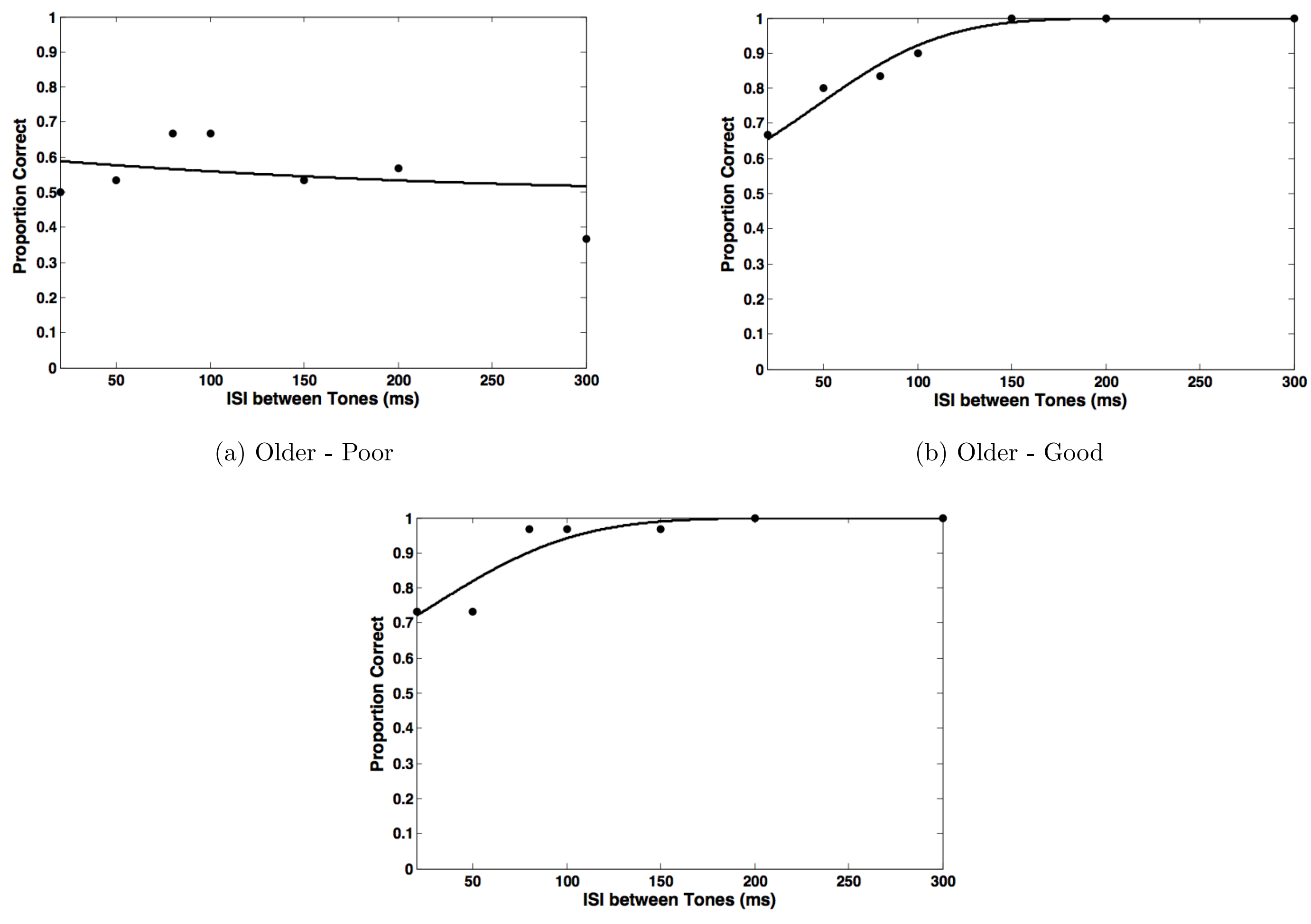


Figure 3.3: Examples of curve-fitting graphs for three individual participants for Experiment 1. The first panel shows an older participant who is unable to perform the task, the second panel shows an older participant who performs the task well, and the third panel shows a younger participant. For each graph, the ISI between the two tones is plotted on the x-axis and the proportion of correct responses is plotted on the y-axis. The curve represents the best-fitting cumulative normal.

3.5 EXPERIMENT 2

To determine if the age-related decline exhibited in the previous experiment can be generalized to when multiple events are occurring in another modality, we ran the same experiment with two visual events and a simultaneous auditory event.

3.6 Methods

3.6.1 Participants

Twenty-six younger adults (13 male, 19-34 years old, $M = 24.5$) and twelve older adults (4 male, 72-80 years old, $M = 76.7$) volunteered to participate Experiment 2. All participants had normal or corrected-to-normal vision measured by Snellen decimal acuity (Old: near $M = 0.99$, far $M = 1.03$; Young: near $M = 1.49$, far $M = 1.30$). The older adults did not suffer from any cognitive impairment as assessed by the Montreal Cognitive Assessment (Nasreddine et al., 2005; $M = 25.5$) and the Mini-Mental State Examination (Folstein et al., 1975; $M = 28.6$). Participants received compensation of $10/hour for their participation in the experiment.

3.6.2 Stimulus and Appartus

The stimuli and apparatus were identical to that of Experiment 1.

3.6.3 Procedure

The procedure for an individual trial in Experiment 2 is depicted in Figure 3.4. The experimental procedure was the same as Experiment 1, with two exceptions.

Firstly, each trial contained one auditory stimulus and two visual stimuli separated by a variable ISI. The auditory stimulus was presented simultaneously with either the first or second visual stimulus, and participants determined which visual stimulus the auditory stimulus was presented with by pressing one of two keys on a standard computer keyboard.

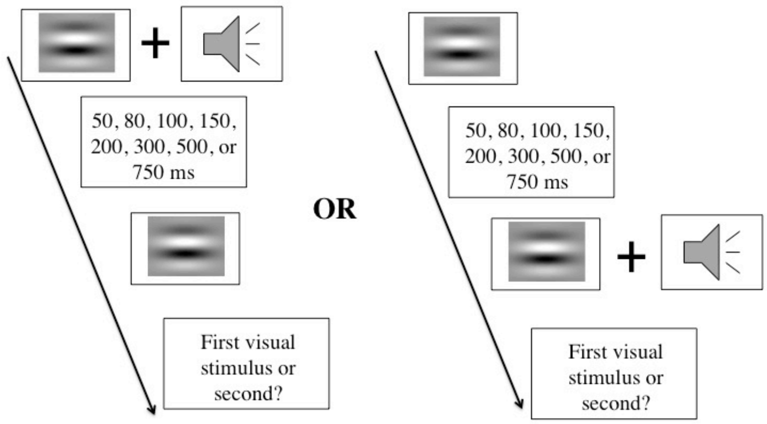


Figure 3.4: Experimental procedure for Experiment 2.

Secondly, the experiment used two sets of ISIs: a hard condition with ISIs of 50, 80, 100, 150, 200, 300, 500, or 750 ms, and an easy condition with ISIs of 80, 100, 150, 200, 300, 500, 750, or 1000 ms. Fourteen younger adults performed the task with the hard condition and twelve younger adults performed the task with the easy condition. All older adults performed the easy condition.

3.7 Results

The same procedure as Experiment 1 was used to calculated thresholds and SDs. One younger adult in each of the conditions was removed due to having a negative threshold.

Figure 3.5 shows thresholds and SDs for each group. Older adults ($M_O = 719.53$ ms) had significantly larger thresholds than younger adults in both the easy ($M_{Y(easy)} = 126.98$ ms; $t(15) = 5.64$, $p < .001$) and hard ($M_{Y(hard)} = 168.98$ ms; $t(17) = 5.12$, $p < .001$) ISI conditions. There was no significant difference between thresholds obtained from younger adults in the two ISI conditions ($t(22) = 0.44$, $p = .667$). Similarly, SDs were significantly larger in older adults ($M_O = 562.97$ ms) than younger adults in the easy ($M_{Y(easy)} = 251.20$ ms; $t(18) = 3.76$, $p = .001$) and hard ($M_{Y(hard)} = 188.70$ ms; $t(17) = 4.49$, $p < .001$) ISI conditions. There was no significant difference between thresholds obtained from younger adults in the two ISI conditions ($t(20) = -0.73$, $p =$

.472).

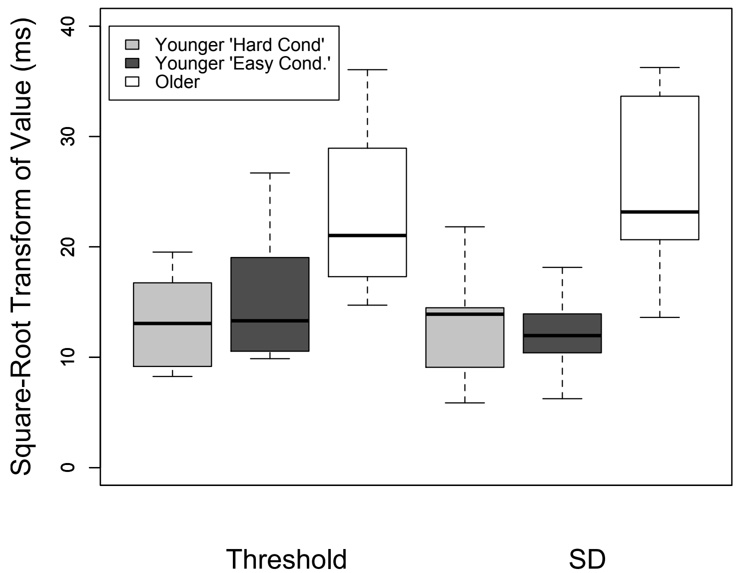


Figure 3.5: Boxplots showing threshold and standard deviation values by group for Experiment 2. The light grey boxes represent the younger adults who completed the hard condition, the dark grey boxes represent the younger adults who completed the easy condition and the white boxes represent the older adults.

3.8 EXPERIMENT 3

An important difference between the studies described in Chapter 2, which found no evidence of an age difference in audio-visual TOJs, and Experiments 1 and 2 is that stimuli in the current studies always contained a simultaneous audio-visual event. Therefore, the deficit found in these more complex tasks may be due to an inability to process *simultaneous* auditory and visual stimuli. To test this hypothesis, in Experiment 3, we varied the visual stimulus so that it was not always simultaneous with an auditory event.

3.9 Methods

3.9.1 Participants

Twenty-four younger adults (13 male, 19-32 years old, M = 23.2) and twelve older adults (4 male, 72-82 years old, M = 76.9) volunteered to participate Experiment 3. All participants had normal or corrected-to-normal vision measured by Snellen decimal acuity (Old: near M = 1.00, far M = 1.03; Young: near M = 1.40, far M = 1.23). The older adults did not suffer from cognitive impairment as assessed by the Montreal Cognitive Assessment (Nasreddine et al., 2005; M = 25.8) and the Mini-Mental State Examination (Folstein et al., 1975; M = 28.5). Participants received compensation of $10/hour for their participation in the experiment.

3.9.2 Stimulus and Appartus

The stimuli and apparatus were identical to that of Experiment 1.

3.9.3 Procedure

The procedure for an individual trial in Experiment 3 is depicted in Figure 3.6. The experimental procedure was essentially the same as Experiment 1; however, the visual stimulus was now varied so that it was not always simultaneous with one of the two tones. Participants determined which visual stimulus the auditory stimulus was closer to by pressing one of two keys on a standard computer keyboard. The stimulus duration for both auditory stimuli and the visual stimulus was 10 ms.

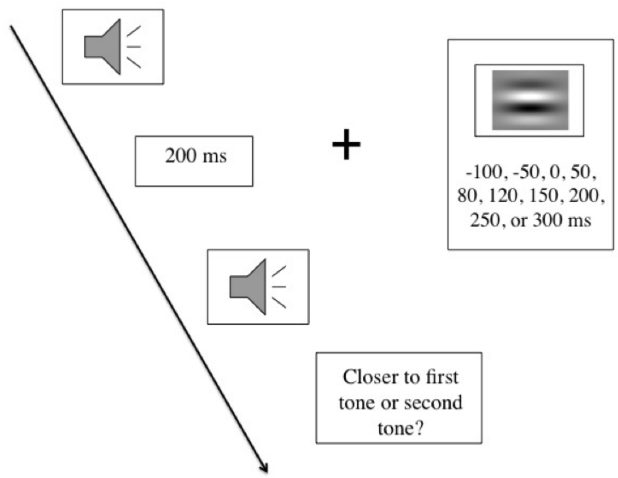


Figure 3.6: Experimental procedure for Experiment 3.

In the hard condition, the ISI – i.e., the interval between the two tones – was 200 ms and the stimulus onset asynchronies (SOA) – i.e., the interval between the onset of the first auditory stimulus and the onset of the visual stimulus – was -100, -50, 0, 50, 80, 120, 150, 200, 250, and 300 ms. In the easy condition, the ISI was 400 ms and the SOAs were -200, -100, 0, 100, 150, 250, 300, 400, 500, and 600 ms. The SOAs correspond to the temporal offset from the first tone. Negative SOAs indicate that the onset of the visual stimulus was prior to the onset of the first tone; an SOA of 0 indicates that the visual stimulus was simultaneous with the first tone. An SOA of 200 ms in the hard condition, or 400 ms in the easy condition, indicates that the visual stimulus was presented simultaneously with the second tone. Finally, SOAs greater than the ISI indicate that the onset of the visual stimulus occurred after the onset of the second tone. Twelve younger adults performed the task with the hard condition and twelve younger adults performed the task with the easy condition. All older participants performed the task with the easy condition.

3.10 Results

A point of subjective equality (PSE) and SD value were calculated for each participant from a cumulative normal that was fit to a plot of each participants' proportion of "first tone" responses at each SOA. PSE was defined as the ISI subtracted from the mean of the curve (i.e., 50% "first tone" responses). Subsequently, we can equate PSE between the conditions, defining it as the offset from the mid-point between the ISI. Zero indicates no bias, negative values indicate a bias towards the first tone, and positive values indicate a bias towards the second tone. Similarly, SD was divided by the ISI to equate the values between the conditions.

All older adults could perform the task at the easy condition SOAs. However, as was found in Experiments 1 and 2, some older adults were incapable of performing the task at any SOA, but others performed the task just as well as younger participants. Figure 3.9 shows examples of curves fit to data obtained in the hard ISI condition from an older subject who could not complete the task, a typical older subject who performed well, and a typical younger subject.

A boxplot of PSE is shown in Figure 3.7, and a boxplot of SD is shown in Figure 3.8. In the hard condition, the mean PSE for younger adults was -0.65 ms, and in the easy condition, the mean PSE for younger adults was 22.16 ms. Neither of these values differed significantly from 0 ms that would be expected from an unbiased observer (hard: $t(11) = -0.11$, $p = .917$; easy: $t(11) = 1.53$, $p = .155$). However, the mean PSE for older adults was but was 39.32, which did differ significantly from 0 ms ($t(11) = 2.55$, $p = .027$). Therefore, older adults were more biased towards the second tone than younger adults.

Older adults had significantly larger SDs than both the hard condition younger adults ($M_O = 0.565$; $M_{Y(hard)} = 0.303$ ms; $t(15) = 2.47$, $p = .026$), and the easy condition younger adults ($M_{Y(easy)} = 0.267$ ms; $t(14) = 2.90$, $p = .012$). There was no difference between the easy condition younger adults and the hard condition younger adults ($t(21) = -0.64$, $p = .529$).

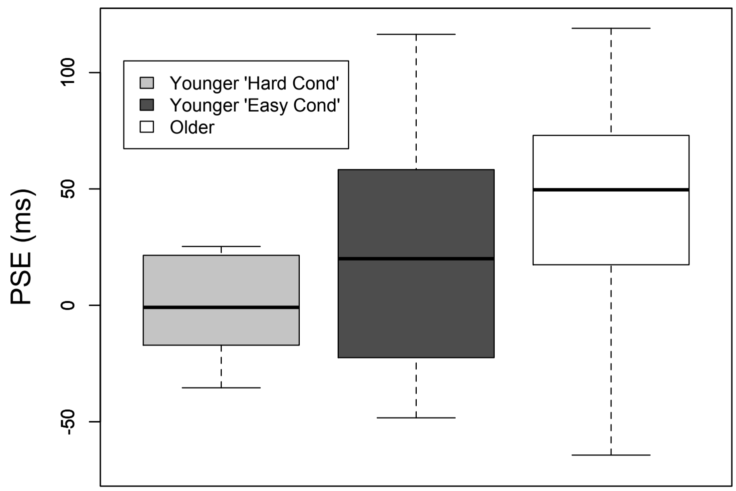


Figure 3.7: Boxplots showing PSE values by group for Experiment 3. The light grey boxes represent the younger adults who performed the hard condition, the dark grey boxes represent the younger adults who performed the easy condition, and the white boxes represent the older adults.

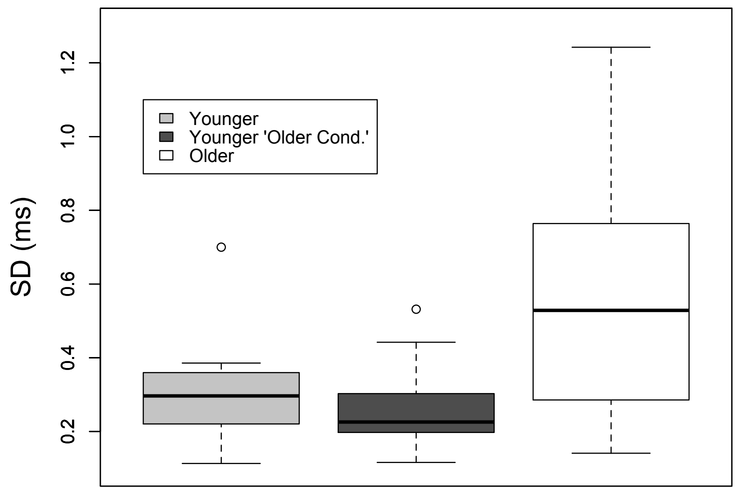
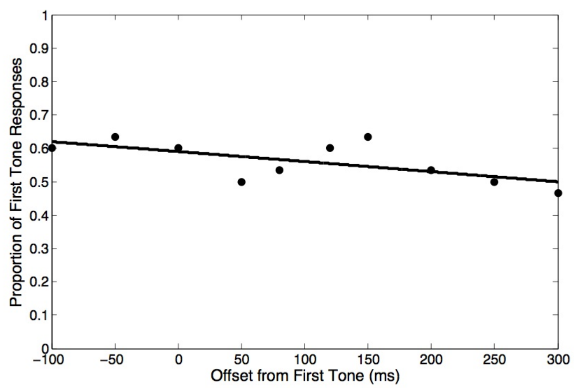
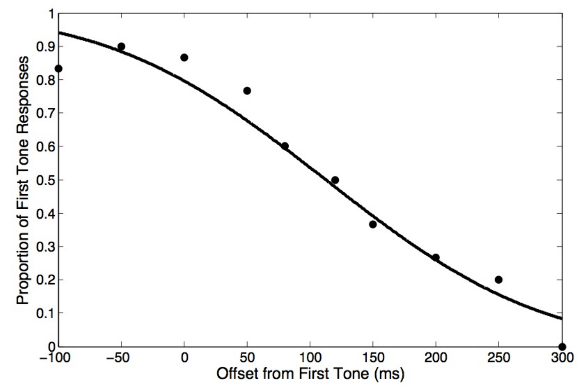


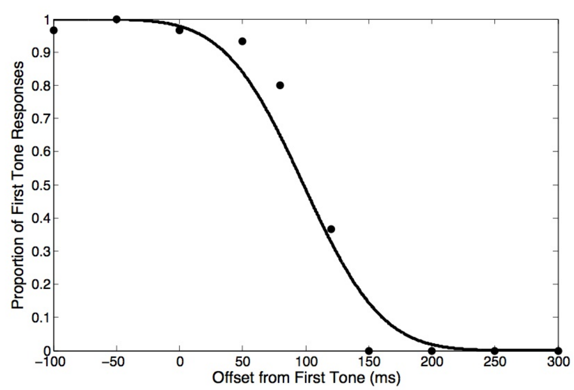
Figure 3.8: Boxplots showing standard deviation values by group for Experiment 3. The light grey boxes represent the younger adults who performed the hard condition, the dark grey boxes represent the younger adults who performed the easy condition, and the white boxes represent the older adults.



(a) Older - Poor



(b) Older - Good



(c) Younger

Figure 3.9: Examples of curve-fitting graphs for three individual participants for Experiment 3. The first panel shows an older participant who was unable to perform the task, the second panel shows an older participant who performs the task well, and third panel shows a younger participant. For each graph, the offset from the first tone is plotted on the x-axis and the proportion of first tone responses is plotted on the y-axis. The curve represents the best-fitting cumulative normal.

3.11 General Discussion

The goal of the current study was to assess if there are age-related deficits in temporal order judgment (TOJ) tasks that use audio-visual stimuli that are more complex than those that have been used in previous studies. This was accomplished by conducting three two-alternative forced choice tasks containing multiple auditory or visual events. In contrast to what we found in Chapter 2, the current experiments found that performance was poorer in older adults than younger adults. This remained consistent throughout the three experiments, and generalized to multiple events in the auditory or visual domain.

Experiments 2 and 3 included a second group of younger adults in a hard condition task to determine if younger subjects could be made to act like older subjects by changing the temporal parameters of the stimuli. We would predict that by making the ISI smaller, younger adults might find this task difficult, and show comparable performance to older adults in the easy condition. However, this was not the case for either experiment. Even with an ISI that was half the length of the easy condition ISI, the age difference did not disappear. However, younger adults may perform similar to older adults at even smaller ISIs; future research could investigate how small the ISI must be in order to equate the temporal resolution of older and younger adults.

By examining the boxplots for each experiment (i.e., Figure 3.2, Figure 3.5, Figure 3.8), we can see that older adults have much larger variance than the younger adults for both threshold and SD. Moreover, we can see from the curve-fitting examples (i.e., Figure 3.3 and Figure 3.9) that some older adults perform the task very well and others perform the task very poorly. It is not surprising that the older adults have a greater dispersion of data, as it has been previously demonstrated that there is greater variance in older adults' ability to perform various tasks (Shammi, Bosman, and Stuss, 1998; Hultsch, MacDonald, and Dixon, 2002).

Experiment 3 was conducted to assess whether the deficit apparent in the first two experiments was a consequence of complexity or the presence of a simultaneous event. Since the same pattern of results was observed in Experiment 3 as in Experiment 2, we can conclude that the deficit demonstrated is not caused by there always being a simultaneous event.

For Experiment 3, the point of subjective equality (PSE) values are very close to the true middle point between the two auditory stimuli. Therefore, in general, people are very good at estimating the midpoint between two stimuli. For the easy condition task, both older and younger adults had PSE values that were slightly off from the middle point, shifted towards the second tone. Although there does not seem to be an obvious explanation for this pattern of results, it may be that an increased gap between stimuli introduces more uncertainty and causes people to be biased towards the second tone. Although there have not been previous studies assessing variability in estimating the midpoint of a duration, support for this idea is provided by Ivry and Hazeltine (1995) who demonstrated that variability in estimations of duration increased as the duration of the temporal interval increased. While both younger and older adults were slightly shifted towards the second tone in the easy condition, it is only older adults whose estimations were significantly different from the midpoint. This is likely due to their general deficit in temporal processing on the task which would influence their estimation of the midpoint.

Our results are consistent with the idea that temporal processing slows as we age (Fitzgibbons and Gordon-Salant, 1996; Busey, Craig, Clark, and Humes, 2010), as well as results from previous studies showing impairments in audio-visual TOJs with aging (Virsu et al., 2003; Setti et al., 2011b). However, the studies in Chapter 2 found no evidence of an age-related decline in performance on a simple audio-visual TOJ task. It is important to note that this study was conducted using the same stimuli and experimental setup as those used in Chapter 2. The major difference between the experiments in Chapters 2 and 3 is that the experiments in the current chapter used audio-visual events consisting of three, not two, stimuli. As mentioned previously, studies have shown that increasing complexity can increase age differences on a task (Einstein et al., 1992; Fitzgibbons and Gordon-Salant, 1995). This is seemingly the case when comparing the experiments in Chapters 2 and 3.

Setti et al. (2011b) posit that older adults have a larger temporal window-of-integration, and therefore may integrate two events presented closely in time instead of perceiving them as separate stimuli. With multiple stimuli, there will be multiple overlapping windows-of-integration, making it very difficult for older adults to dissociate the individual stimuli. This can explain why such large age-related deficits are revealed on TOJ tasks involving multiple stimuli.

Research has shown that older adults can compensate for deficits on tasks by recruiting additional brain areas to help complete the task. For example, Gutchess et al. (2005) had older participants and younger participants complete a memory task while recording functional magnetic resonance imaging (fMRI). Although there was no difference in behavioural performance on the memory task, the fMRI showed that older adults recruited additional brain areas compared to the younger adults to accomplish the task. It is possible that for the simple audio-visual TOJs, older adults are able to perform just as well as younger adults by utilizing additional brain areas to perform the task. However, when it comes to more complex tasks, this compensation is not sufficient enough to maintain their behavioural performance at the same level as the younger adults. It would be interesting to measure brain activity during a simple audio-visual TOJ to determine if compensation is occurring.

In conclusion, we provide evidence for deficits in audio-visual temporal processing in elderly adults above the age of 70, it least for more complex audio-visual tasks. Future research could focus on adopting even more complex audio-visual tasks that can relate to real-life situations. In this way, we can better categorize impairments that hinder the every day lives of the elderly and work on the prevention of falls that lead to injury.

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Chapter 4

The Effects of Spatial Cues on Age-Related Changes in Audio-Visual Temporal Order Judgments

4.1 Abstract

Previous research has reported that the accuracy of audio-visual temporal order judgments (TOJs) is reduced in older adults, but research in our lab has found no age effect. While other studies presented the stimuli from different locations, we presented stimuli from the same perceived location. Redundant spatial cues improve TOJs in younger subjects (Zampini et al., 2003b), but do age differences in sensitivity to spatial cues affect age differences in TOJs? TOJs were measured in younger and older adults with the auditory stimulus presented from speakers and headphones. We found no effects of age or spatial cues. This replicates our previous finding, and suggests that the discrepancy between studies is not caused by age differences in the ability to use spatial cues.

Keywords

temporal order judgments, audio-visual integration, aging

4.2 Introduction

Temporal processing has been shown to decline with age (Salthouse, 1996). This has been demonstrated in temporal order judgment (TOJ) tasks in numerous unisensory studies of visual (Busey, Craig, Clark, and Humes, 2010), auditory(Strouse, Ashmead, Ohde, and Grantham, 1998), and tactile (Craig, Rhodes, Busey, Kewley-Port, and Humes, 2010) processing. A handful of studies have investigated multisensory TOJs in aging. For example, Poliakoff, Shore, Lowe, and Spence (2006) found that younger adults were more precise on a visuo-tactile TOJ task than older adults. To date, there are only three studies that have investigated audio-visual TOJs in aging and they have found mixed results.

A previous study from our lab administered an audio-visual TOJ task on samples of younger and older adults (Fiacconi, Harvey, Sekuler, and Bennett, In press). Participants were presented with a visual Gabor stimulus and a tone separated by stimulus onset asynchronies (SOAs) of 250, 100, 50, or 0 ms with either the visual stimulus or the auditory stimulus occurring first. Participants had to determine which stimulus occurred first. Two measures were analyzed: the just noticeable difference (JND) and the point of subjective simultaneity (PSS). The results revealed no age-related decline for either measure.

In another study, Virsu, Lahti-Nuuttila, and Laasonen (2003) examined audio-visual TOJs across the lifespan. The task utilized by Virsu et al. was the same as Fiacconi et al.; however, their stimuli were slightly different – square waves for their auditory stimuli and flashes of lights for their visual stimuli. Furthermore, they used a staircase procedure, an 84% threshold measure and presented their auditory stimuli through a loudspeaker. Virsu et al. found that TOJ thresholds increased throughout the lifespan.

More recently, Setti et al. (2011b) used a pure tone and a high contrast white disc to compare performance on audio-visual TOJs between younger and older adults. They presented SOAs of 70 ms and 270 ms and presented their auditory stimuli over headphones. Although no difference was found between groups at 70 ms, younger adults were significantly more accurate than older adults at 270 ms. Setti et al. claim that this is due to 70 ms being within both groups' temporal window-of-integration, but 270 ms being outside the temporal window-of-integration for younger adults only. Therefore, while younger adults are able to differentiate the two stimuli, older adults integrate the two stimuli into one percept.

The current experiment resolves to examine the differences between these three studies. The first major difference is the presentation of the auditory stimuli; all three studies use different methods. Several studies have emphasized the importance of spatial cues on these types of tasks (Zampini, Shore, and Spence, 2003a,b; Poliakoff et al., 2006). When the two stimuli do not occur from the same spatial location, participants can use redundant spatial cues to improve performance on the task (Zampini et al., 2003a,b; Poliakoff et al., 2006). It is possible that younger adults are better able to take advantage of these redundant spatial cues and this can account for the difference in performance between older and younger adults in Setti et al. and Virsu et al.'s studies. However, we previously investigated the effect of having the auditory stimulus occurring at a different location than the visual stimulus, and again found no age difference for either JND or PSS. More surprisingly, there was no increase in performance for either group when stimuli occurred at different locations (see Chapter 2). Presently, we will investigate the effect of using headphones to present the auditory stimuli to rectify the age effect found by Setti et al.

Another difference between the study by Setti et al. and Fiacconi et al. are the temporal intervals between stimuli:Setti et al. used SOAs of 70 ms and 270 ms, whereas Fiacconi et al. used SOAs ranging from 0-250 ms. It is possible that the deficit cannot be demonstrated at shorter SOAs; therefore, we will investigate longer SOAs by increasing our temporal interval to 270 ms and further.

Finally, the visual stimuli presented in the studies were different: Fiacconi et al. used Gabor patches, Setti et al. used a high contrast white disc and Virsu et al. used LED lights. To determine if differences in visual stimuli are driving the conflicting results between studies, we will attempt to replicate Setti et al. by adopting the same stimuli used in their study.

In Experiment 1, we will administer the same task as Chapter 2, except we will increase the range of SOAs and present our auditory stimuli through speakers and headphones. Experiment 2 will follow the same procedure as Experiment 1; however, we will use the same visual stimulus utilized by Setti et al. in their study.

4.3 EXPERIMENT 1

4.4 Methods

4.4.1 Participants

Seventeen younger adults (6 male, 18-32 years old, $M = 22.8$) and 16 older adults (9 male, 70-80 years old, $M = 74.7$) volunteered to participate Experiment 1. All participants had normal or corrected-to-normal vision measured by Snellen decimal acuity (Old: near $M = .96$, far $M = .96$; Young: near $M = 1.37$, far $M = 1.30$). The older adults did not suffer from any cognitive impairment as assessed by the Montreal Cognitive Assessment (Nasreddine et al., 2005; $M = 28.8$) and the Mini-Mental State Examination (Folstein, Folstein, and McHugh, 1975; $M = 25.9$). Participants received compensation of $10/hour for their participation in the experiment.

4.4.2 Stimulus and Apparatus

Stimuli and apparatus were almost identical to those used in Chapter 2, Experiment 1. The visual and auditory stimuli were now 20 ms instead of 10 ms. Auditory stimuli were presented through speakers that were identical to the set up of the previous experiment in Chapter 2, Experiment 1, but also through Sennheiser HDA 200 headphones at 64 dB SPL as measured by a Scosche sound meter.

4.4.3 Procedure

The procedure was similar to that of Chapter 2, Experiment 1. However, the current experiment contained slightly different timing and a longer set of stimulus-onset asynchronies (SOAs). A high contrast fixation dot flickered for 300 ms, remained on the screen for 500 ms, and then disappeared. After a random interval of 900-950 ms after the offset of the fixation point, the visual stimulus was presented. The SOAs were -330, -300, -270, -230, -150, -70, 0, 70, 150, 230, 270, 300, 330 ms, where negative values indicate that the auditory stimulus was presented before the visual stimulus. The fixation dot reappeared 600 ms after a response was given, and the next trial began automatically. Each participant performed two counter-balanced blocks of the task: one through speakers and one through headphones. The task took approximately 45 minutes to complete.

4.5 Results

A just noticeable difference (JND) and point of subjective simultaneity (PSS) were obtained for each participant separately for each type of auditory presentation type by fitting a cumulative normal function to the proportion of "vision first" responses across SOA. JND was defined as the standard deviation and PSS was defined as the mean of the best-fitting cumulative normal. Figure 4.1 shows the data and best-fitting cumulative normal from a single younger participant.

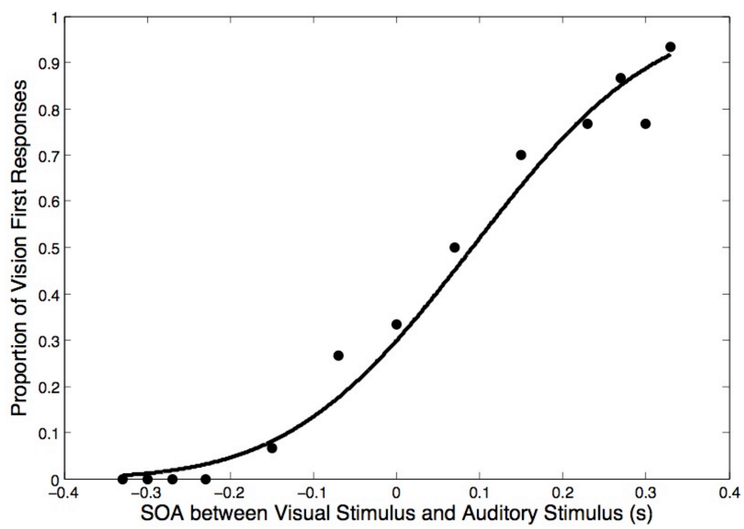

Figure 4.1: An example of a curve-fitting graph for a younger individual for Experiment 1. The SOA between the auditory and visual stimuli is plotted on the x-axis and the proportion of vision first responses is plotted on the y-axis. The curve represents the best-fitting cumulative normal.

A 2 (auditory presentation) X 2 (group) split-plot ANOVA was conducted on JND and PSS. There were no significant main effects of auditory presentation ($F(1, 29) = 3.03$, $p = .092$) or group ($F(1, 29) = 0.08$, $p = .782$), or a significant interaction ($F(1, 29) = 0.02$, $p = .885$) for PSS. There were no significant main effects of auditory presentation ($F(1, 29) = 3.33$, $p = .078$) or group ($F(1, 29) = 1.93$, $p = .176$), or a significant interaction ($F(1, 29) = 1.76$, $p = .195$) for JND. See Figure 4.2 for a boxplot of PSS and Figure 4.3 for a boxplot of JND by auditory presentation and group.

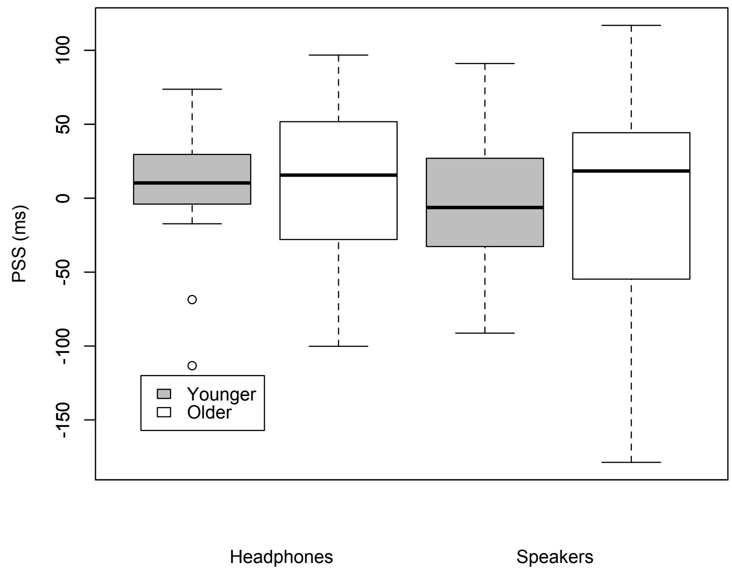

Figure 4.2: Boxplots showing PSS for each group by auditory presentation for Experiment 1. The grey boxes represent the younger adults and the white boxes represent the older adults.

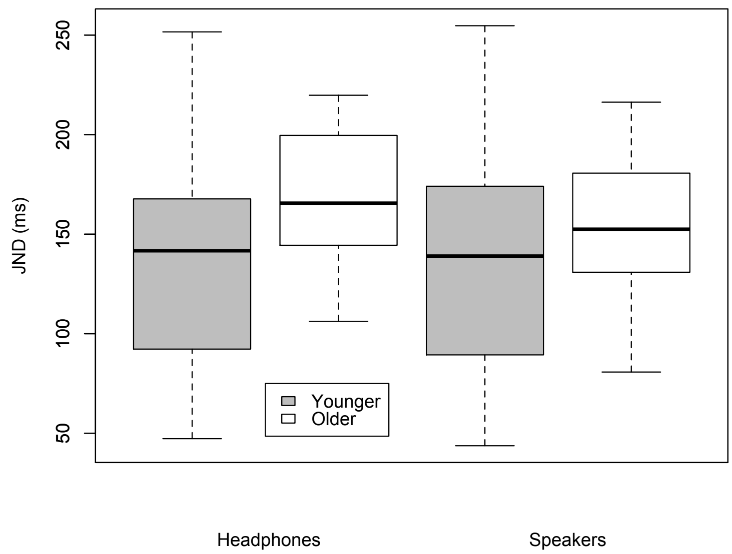

Figure 4.3: Boxplots showing JND for each group by auditory presentation for Experiment 1. The grey boxes represent the younger adults and the white boxes represent the older adults.

4.6 EXPERIMENT 2

In a final attempt to replicate Setti et al.'s results, we repeated the experiment with an identical visual stimulus to the one used in their study.

4.7 Methods

4.7.1 Participants

Thirteen younger adults (6 male, 19-32 years old, M = 22.5) and sixteen older adults (8 male, 70-83 years old, M = 73.8) volunteered to participate Experiment 2. All participants had normal or corrected-to-normal vision measured by Snellen decimal acuity (Old: near M = 1.02, far M = 1.04; Young: near M = 1.54, far M = 1.38). The older adults did not suffer from any cognitive impairment as assessed by the Montreal Cognitive Assessment (Nasreddine et al., 2005; M = 25.5) and the Mini-Mental State

Examination (Folstein et al., 1975; $M = 28.6$). Participants received compensation of \$10/hour for their participation in the experiment.

4.7.2 Stimulus and Apparatus

The stimuli and apparatus were identical to Experiment 1 with the exception of the visual stimulus. The visual stimulus was a 1.3 cpd, white disc set at a very high contrast. Instructions and stimuli were now presented against a black screen.

4.7.3 Procedure

The experimental procedure was identical to that of Experiment 1.

4.8 Results

PSS and JND values were calculated as they were in Experiment 1 and the same analyses were conducted.

There were no significant main effects of auditory presentation ($F(1, 30) = 1.43$, $p = .241$) or group ($F(1, 30) = 0.35$, $p = .558$), or a significant interaction ($F(1, 30) = 0.57$, $p = .456$) for PSS. There were no significant main effects of either auditory presentation ($F(1, 30) = 0.01$, $p = .926$) or group ($F(1, 30) = 0.46$,$p = .503$), or a significant interaction ($F(1, 30) = 1.39$, $p = .248$) for JND. See Figure 4.4 for a boxplot of PSS and Figure 4.5 for a boxplot of JND by auditory presentation and group.

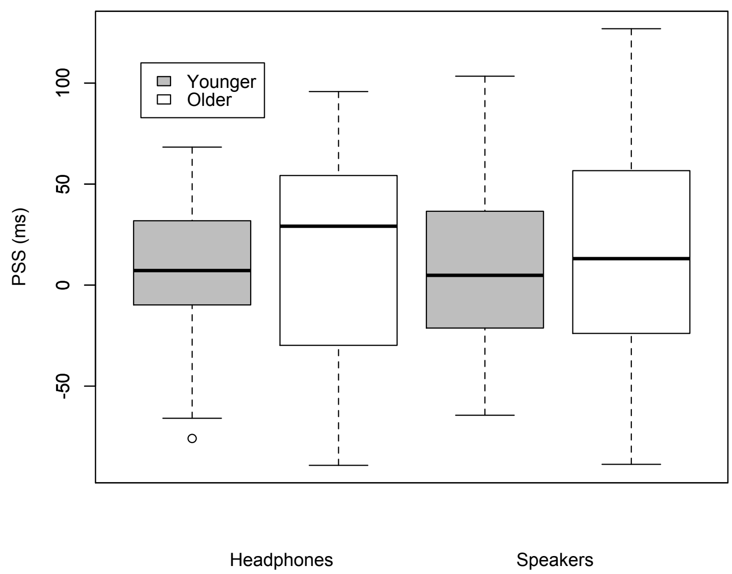

Figure 4.4: Boxplots showing PSS for each group by auditory presentation for Experiment 2. The light grey boxes represent the younger adults and the white boxes represent the older adults.

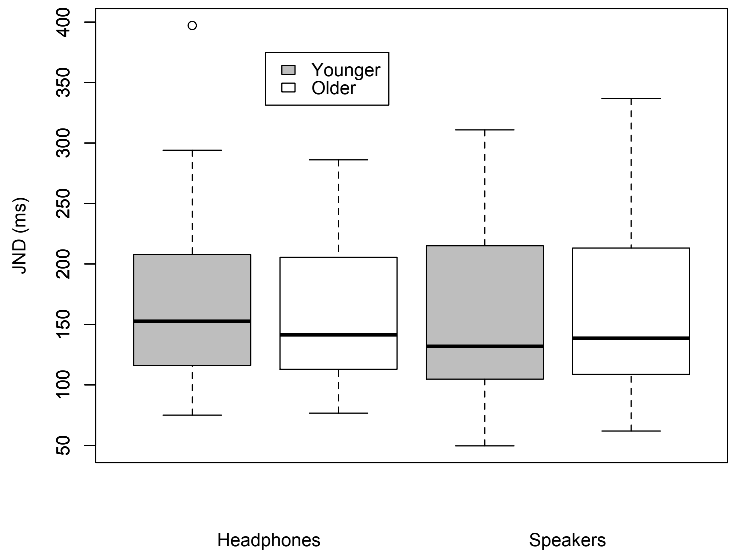

Figure 4.5: Boxplots showing JND for each group by auditory presentation for Experiment 2. The light grey boxes represent the younger adults and the white boxes represent the older adults.

4.9 General Discussion

Presently, we replicated our previous finding of no age-related decline in audio-visual processing (Fiacconi et al., In press). This finding stays stable despite increasing the range of stimulus onset asynchronies (SOAs), presenting our auditory stimuli over headphones, or changing our visual stimulus. Despite these adjustments, we continue to find comparable performance between older and younger adults for both the just noticeable difference (JND) and the point of subjective simultaneity (PSS). This indicates that audio-visual temporal processing does not decline with age.

We fail to replicate the results of Setti et al. (2011b) and Virsu et al. (2003), who do find a decline in the ability to perform audio-visual TOJs in older adults. However, there are still some things to consider methodologically when comparing Fiacconi et al. to Virsu et al. and Setti et al. First of all, the methods used to administer stimuli were different; we used the method of constant stimuli, whereas, Virsu et al. used a staircase method. In Chapter 2, we point out that using a staircase method might systematically bias threshold values to be greater than their true values. Therefore, using different methods may result in different values being estimated to measure performance. Furthermore, we measured JND and PSS, whereas Virsu et al. measured threshold and Setti et al. measured accuracy. Perhaps the discrepancies in findings are a result of different measures used to categorize performance.

Another possible explanation for the difference in results could be due to a dissimilarity in participant populations. The seniors that participate in studies in our lab have completed multiple experiments, and therefore are well practiced in psychophysical experiments. Furthermore, these seniors return to the lab to participate in further experiments. They enjoy being involved in experiments, and therefore are highly motivated. Seniors are also given very extensive instructions and practice trials. Our research assistant makes sure that the seniors fully understand how to perform the task before allowing them to complete the experiment.

It seems that overall, both younger and older adults perform better on our task than they do on similar tasks in other labs. Many of our younger adults reach almost 100% accuracy around 250 ms. In contrast, accuracies reported by Setti et al. seem to be somewhat lower. For example, at 270 ms, younger adults are only at 91% accuracy. This is somewhat puzzling considering that the two tasks are essentially identical. However, we presented a range of SOAs, whereas Setti et al. only presented SOAs of 70 ms and 270 ms. It is likely that people are better able to judge temporal order when they are given a range of SOAs to compare with each other.

Another unexpected finding is that there was no difference between using headphones and speakers. Even if the use of speakers did not account for the discrepancy between Fiacconi et al. and Setti et al., we would predict that both groups would perform better when using headphones because of several studies which have demonstrated that people make better temporal order judgments when the two stimuli occur in different locations (Zampini et al., 2003a,b; Poliakoff et al., 2006). Participants can take advantage of the redundant spatial cues: instead of solely judging “Which modality came first?”, they can also judge “Which spatial location came first?” to improve their performance. However, studies that have examined the role of spatial cues in TOJs have had the auditory and visual cues coming for either side on any given trial, whereas, in our study, the auditory stimulus always came from the same location. It is likely that the uncertainty of which side the cue will come from is what drives the increase in performance via spatial cues.

In conclusion, older adults over the do not decline in their audio-visual temporal order processing, which we have demonstrated multiple times with a variety of experimental manipulations. Future research should focus on looking into differences in task administration and uncertainty in spatial cues.

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Chapter 5

The Effect of Aging on Audio-Visual Temporal Order Judgments and Visual Gap Detection

5.1 Abstract

Auditory gap detection deteriorates with age, but less is known about the effects of aging on visual gap detection. We therefore measured performance on several visual gap detection tasks and an audio-visual temporal order judgment (TOJ) task in younger (19-33 years) and older (70+ years) adults. Sensitivity (d') in the gap detection task was lower and threshold in the TOJ task was higher in older adults. However, by a temporal interval of approximately 110 ms, older adults reached the same level of performance of younger adults on the gap detection task. Furthermore, performance measures in the two tasks were correlated for younger adults only. Our findings indicate that aging diminishes sensitivity to visual stimuli presented closely together in time, but that this deficit does not constrain performance on our audio-visual TOJ task.

Keywords

temporal order judgments, audio-visual integration, aging, gap detection

5.2 Introduction

Gap detection has been used to study temporal processing for many years. In fact, Plomp (1964) measured auditory gap detection thresholds as early as 1964. A gap detection experiment varies the temporal interval between two stimuli in order to determine the minimum interval to discern that there are two events. If this interval is too small, the events will be perceived as one event. Therefore, we can use gap detection to measure the temporal limits and resolution of our perceptual system.

Numerous studies have estimated auditory gap detection thresholds. Studies have measured gap detection thresholds with tones (Bertoli, Smurzynski, and Probst, 2002; Heinrich and Schneider, 2006) and noise bursts (Fitzgibbons and Wightman, 1982; Florentine et al., 1999), examined the effects of varying stimulus frequency (Fitzgibbons and Wightman, 1982; Florentine, Buus, and Geng, 1999), measured cortical activity (Eggermont, 2000), and compared thresholds obtained with the method of constant stimuli (Harris, Eckert, Ahlstrom, and Dubno (2010), Florentine et al. (1999); Harris et al. (2010)) and staircase procedures (Bertoli, Smurzynski, and Probst, 2002; Humes, Busey, Craig, and Kewley-Port, 2009; Snell, 1997).

Fewer studies have examined visual gap detection thresholds. In one study, Uttal and Hieronymus (1970) looked at spatial and temporal factors that influence visual gap detection. They found that gap detection thresholds were approximately 20 ms, significantly higher than auditory thresholds. Furthermore, participants performed better when the visual stimuli were presented from the same spatial location. In a more recent study, Humes, Busey, Craig, and Kewley-Port (2009) also found that visual gap detection thresholds (∼25 ms) were greater than auditory gap detection thresholds (∼10 ms).

Several auditory gap detection experiments have found age-related deficits. For example, Snell (1997) found that older adults have higher auditory gap detection thresholds across a variety of frequencies, intensities, and background conditions. In a more recent study, Harris et al. (2010) found that older adults had significantly higher thresholds than younger adults. Furthermore, age differences was larger in more complex conditions in which subjects were uncertain about the onset of the gap. Lister, Besing, and Koehnke (2002) found a similar result – i.e., larger age differences in more complex conditions – with another gap detection task which varied complexity by having the same or different stimuli on either side of the gap.

A task that is similar to a visual gap detection task is an attentional blink task; which requires subjects to identify targets presented in rapid succession. If two targets are presented temporally close together, it is difficult to identify the second target (Georgiou-Karistianis et al., 2007). Several studies have found that the magnitude of the attentional blink is larger in older adults (Georgiou-Karistianis et al., 2007; Maciokas and Crognale, 2003; Lahar et al., 2001). Given the results of this body of work, it would not be surprising to reveal age-related deficits in visual gap detection.

Amberson, Atkeson, Pollack, and Malatesta (1979) measured visual gap detection thresholds with flashes of lights across the lifespan (20-79 years). Their results indicated that adults above the age of 70 had significantly higher gap detection thresholds than all younger ages. More recently, Humes et al. (2009) conducted a study examining visual, tactile, and auditory gap detection thresholds in a group of younger (18-31 years) and older (60-88 years) adults. In all modalities, thresholds were significantly elevated in older adults.

In a previous study in Chapter 3, we compared older and younger adults on an audio-visual 2AFC temporal order judgment (TOJ) task. In this experiment, there were two visual stimuli separated by an inter-stimulus interval (ISI) between 50-1000 ms. On each trial, a pure tone was presented simultaneously with one of the visual stimuli, and the subject's task was to determine if it was the first or second one. Thresholds, defined as the ISI that yielded 75% correct responses, were significantly higher in older adults. It is possible that older adults were less able to perform this task due to increased neural blurring of the two visual stimuli. To test this idea, the experiments in the current chapter will measure gap detection thresholds with the same visual stimuli used in previous experiments.

5.3 EXPERIMENT 1a

5.4 Methods

5.4.1 Participants

Twelve older adults (M = 75.58, 70-81 years old) and 12 younger adults (M = 22.08, 18-32 years old) participants participated in Experiment 1a. All participants had normal or corrected-to-normal vision as measured by far (Old M = 1.00; Young M = 1.39) and near (Old M = 1.05; Young M = 1.55) Snellen decimal acuity. All older adults had normal cognitive abilities as tested by the Montreal Cognitive Assessment (Nasreddine et al. (2005); M = 26.27) and the Mini-Mental State Examination (Folstein, Folstein, and McHugh (1975); M = 28.33). Participants received $10/hour for their participation in the experiment.

5.4.2 Stimulus and Apparatus

The visual stimulus was a horizontal, 1 cpd, Gaussian-damped Gabor patch at 0.8 contrast. Visual stimuli were presented centrally on a 20-inch Sony Trinitron monitor with a resolution of 1280 x 1024 and a frame rate of 100 Hz. The duration of the visual stimulus was 10 ms. The experiment was programmed using Matlab Version 7.9.0 and Psychophysics Toolbox Version 3.0.8 (Brainard, 1997; Pelli, 1997), and presented on an Apple PowerMac computer. Participants viewed the computer screen from a distance of 114 cm with a chin rest to stabilize their head. The only source of illumination in the room was that of the visual display.

5.4.3 Procedure

On each trial, a high-contrast fixation dot appeared on the screen, flashed for 300 ms, stayed on the screen for 500 ms, then disappeared. After a random interval between 800 and 850 ms, two successive visual stimuli were presented, separated by a variable inter-stimulus interval (ISI). On no-gap trials, the ISI was 0 ms. On gap trials, the ISI was 20, 30, 40, 50, 60, 70 or 80 ms. There were 60 no-gap trials, as well as 60 trials for each gap condition. Participants were informed the 15% of the trials would be no-gap trials. Participants were asked to determine whether or not there had been one visual stimulus by pressing one of two buttons on a standard computer keyboard. Participants received feedback in the form of two different tones as the whether the got a given trial correct or incorrect. The next trial started automatically approximately 500 ms after the response. The task took approximately 30 minutes to complete.

5.5 Results

A d' value was calculated for each gap length for each participant by taking the z-transform of the hit rate – the proportion of times a participant responded gap when there was a gap, and the false alarm rate – the proportion of times a participant responded gap when there was no-gap. The z-transform of the false alarm rate was subtracted from the z-transform of the hit rate to give d'. The bias was calculated as the false alarm rate.

A t test revealed that older adults had significantly higher biases than younger adults, indicating that they responded gap more often than younger adults when there was no gap. Average d''s are plotted as a function of gap length in Figure 5.1. Values of d' were analyzed with a 2 (group) X 7 (gap length) split-plot ANOVA. The analysis revealed a significant main effect of group ($F(1, 22)$ = 14.46, $p < .001$), and gap length ($F(6, 132)$ = 72.96, $p < .001$). More importantly, a significant interaction between group and gap length was found, ($F(6, 132)$ = 17.46, $p < .001$). To analyze the interaction, t tests were used to compare the two groups at each gap length. Older adults had significantly lower d's for the 40, 50, 60, 70, and 80 ms gap lengths, but not for the 20 or 30 ms gap lengths (see Table 5.1). Although both groups performed poorly at the 20 and 30 ms gap lengths, older adults had lower discrimination than younger adults at gap lengths of 40 ms and above.

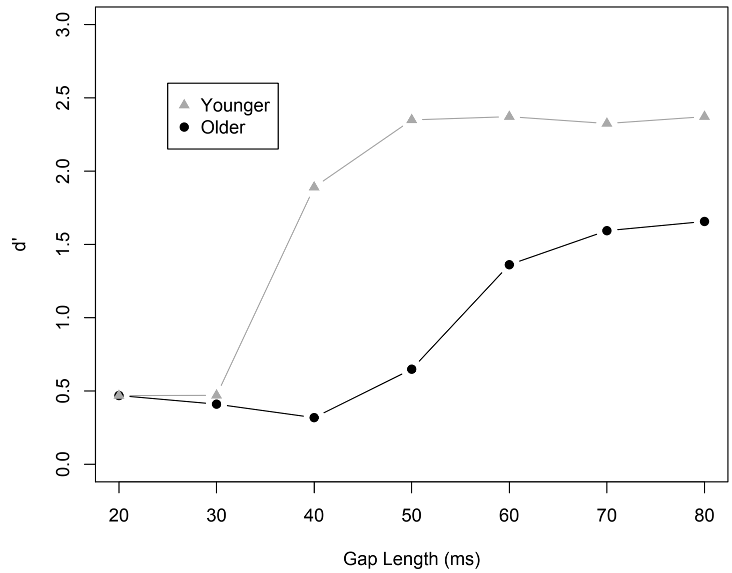

Figure 5.1: d' values by group across gap length. Gap length in ms is plotted on the x-axis and d' is plotted along the y-axis. The black circles represent the older adults and the grey triangles represent the younger adults.

Table 5.1: Statistics for Experiment 1a

Measure	t-value	df	p-value	M Old	M Young
d' 20 ms	0.00	17	.999	0.469	0.469
d' 30 ms	-0.22	18	.830	0.410	0.470
d' 40 ms	-5.31	16	$<$ .001	0.318	1.890
d' 50 ms	-7.51	21	$<$ .001	0.649	2.350
d' 60 ms	-4.45	21	$<$ .001	1.361	2.372
d' 70 ms	-2.93	21	.008	1.593	2.325
d' 80 ms	-3.36	20	.003	1.657	2.372
Bias	2.40	20	.027	0.662	0.487

Note: d' is calculated by subtracting the false alarm rate from the hit rate, and the bias is taken as the false alarm rate. M represents the mean and df represents the degrees of freedom.

5.6 EXPERIMENT 1b

To determine d' values stay stable over time, we brought the same group of participants back to the lab to perform the gap detection experiment a second time.

5.7 Methods

5.7.1 Participants

Eleven older adults ($M = 75.09$, 70-80 years old) and 11 younger adults ($M = 22.45$, 18-32 years old) participated in Experiment 1b. All participants had participated in Experiment 1a; 1 participant from each group was not able to be contacted and therefore did not participate in Experiment 1b. All participants had normal or corrected-to-normal vision as measured by far (Old $M = 1.00$; Young $M = 1.39$) and near (Old $M = 1.05$; Young $M = 1.56$) Snellen decimal acuity. All older adults had normal cognitive abilities as tested by the Montreal Cognitive Assessment (Nasreddine et al. (2005); $M = 26$) and the Mini-Mental State Examination (Folstein et al. (1975); $M = 28.27$). Participants received $10/hour for their participation in the experiment.

5.7.2 Stimulus and Apparatus

The stimuli and apparatus were identical to Experiment 1a.

5.7.3 Procedure

The procedure was identical to Experiment 1a with one exception. Since both older and younger participants were able to detect the gap reliably at 80 ms in Experiment 1a, the gap length of 80 ms was excluded from the study.

5.8 Results

d' and bias were calculated as they were in Experiment 1a, and the same analyses were conducted. The data, shown in Table 5.2, were analyzed the same way as in previous experiments.

The results were consistent with Experiment 1a: there were significant main effects of group $F(1, 20) = 14.96$, $p < .001$, and gap length $F(5, 100) = 41.57$, $p < .001$. More importantly, a significant interaction between group and gap length was found, $F(5, 100) = 12.67$, $p < .001$. t tests were used to compare the two groups at each gap length. Older adults had significantly lower d's for the 40, 50, 60, and 70 ms gap lengths, but not for the 20 or 30 ms gap lengths. A t test revealed that older adults had significantly higher biases than younger adults. Finally, d' values at each gap length in Experiment 1b were significantly correlated with d' values at each gap in Experiment 1a (see Table 5.2), indicating that this measure stays stable over time.

Table 5.2: Statistics for Experiment 1b

Measure	t-value	df	p-value	M Old	M Young	r-value	p-value
d' 20 ms	-1.42	18	.178	0.458	1.070	0.677	$< .001$
d' 30 ms	-1.41	20	.174	0.301	0.820	0.651	.001
d' 40 ms	-5.78	19	$< .001$	0.169	2.229	0.847	$< .001$
d' 50 ms	-6.00	20	$< .001$	0.689	2.567	0.919	$< .001$
d' 60 ms	-3.30	20	.003	1.270	2.448	0.827	$< .001$
d' 70 ms	-3.83	20	.001	1.285	2.543	0.781	$< .001$
Bias	3.22	17	.005	0.695	0.432	0.916	$< .001$

Note: d' is calculated by subtracting the false alarm rate from the hit rate, and the bias is taken as the false alarm rate. The correlation is between d' in Experiment 1b and Experiment 1a; the last p-value shows the significance of the correlation. M represents the mean and df represents the degrees of freedom.

5.9 EXPERIMENT 1c

To determine if the observed age differences were sensitive to response bias, we conducted a new experiment that contained three times the number of no-gap trials than the previous two experiments.

5.10 Methods

5.10.1 Participants

Ten older adults ($M = 75.1$, 70-81 years old) and 10 younger adults ($M = 23.2$, 19-33 years old) participated in Experiment 1c. All participants participated in Experiment 1b; we were unable to contact one participant from each group, and therefore they did not participate in Experiment 1c. All participants had normal or corrected-to-normal vision as measured by far (Old $M = 1.03$; Young $M = 1.38$) and near (Old $M = 1.08$; Young $M = 1.60$) Snellen decimal acuity. All older adults had normal cognitive abilities as tested by the Montreal Cognitive Assessment (Nasreddine et al. (2005); $M = 26$) and the Mini-Mental State Examination (Folstein et al. (1975); $M = 28.3$). Participants received $10/hour for their participation in the Experiment.

5.10.2 Stimulus and Apparatus

The stimuli and apparatus were identical to Experiment 1a.

5.10.3 Procedure

The procedure was identical to that of Experiment 1b except the number of no-gap trials was increased from 60 to 180 no-gap trials. The task took approximately 45 minutes to complete. Participants were informed that approximately 30% of the trials would be no-gap trials.

5.11 Results

d' and bias were calculated as they were in Experiment 1a. The data, shown in Table 5.3, were analyzed the same way as in previous experiments.

The d' results were consistent with those obtained in Experiments 1a and 1b: there were significant main effects of group ($F(1, 18) = 20.25$, $p < .001$), and gap length ($F(5, 90) = 36.04$, $p < .001$), and a significant interaction between group and gap length, ($F(5, 90) = 5.73$, $p < .001$). t tests showed that older adults had significantly lower d's for the 40, 50, 60, and 70 ms gap lengths, but not for the 20 or 30 ms gap length. Furthermore, as was found in the previous experiments, a t test revealed that adults had significantly higher biases than younger adults. Finally, d' values at each gap in Experiment 1c were significantly correlated with d' values at each gap in Experiment 1a, indicating that performance does not vary based on the proportion of no-gap trials. Importantly, bias in Experiment 1c was significantly correlated with bias in Experiment 1a, indicating that bias does not change based on the proportion of no-gap trials.

Table 5.3: Statistics for Experiment 1c

Measure	t-value	df	p-value	Old M	Young M	r-value	p-value
d' 20 ms	-1.05	17	.310	0.389	0.877	0.864	$< .001$
d' 30 ms	-1.85	15	.084	0.224	0.925	0.804	$< .001$
d' 40 ms	-7.40	16	$< .001$	0.184	2.392	0.896	$< .001$
d' 50 ms	-4.41	16	$< .001$	1.175	2.694	0.831	$< .001$
d' 60 ms	-4.01	15	.001	1.635	2.802	0.733	$< .001$
d' 70 ms	-3.11	16	.007	1.865	2.799	0.604	.004
Bias	2.83	17	.011	0.524	0.321	0.557	.011

Note: d' values were calculated by subtracting the z-transform of the false alarm rate from the hit rate, and bias is taken as the false alarm rate. The correlation is between d' in Experiment 1a and Experiment 1c; the last p-value shows the significance of the correlation. M represents the mean and df represents the degrees of freedom.

5.12 EXPERIMENT 2

To determine if there is a relationship between gap detection and TOJs, which have previously found an age-related decline, we ran the same group of participants in an audio-visual 2AFC TOJ task and correlated threshold with d' on the gap detection task.

5.13 Methods

5.13.1 Participants

Eleven older adults ($M = 75.09$, 70-80 years old) and 11 younger ($M = 22.45$, 18-32 years old) adults participated in Experiment 2. All participants had also participated in Experiment 1b. All participants had normal or corrected-to-normal vision as measured by far (Old $M = 1.00$; Young $M = 1.39$) and near (Old $M = 1.05$; Young $M = 1.56$) Snellen decimal acuity. All older adults had normal cognitive abilities as tested by the Montreal Cognitive Assessment (Nasreddine et al. (2005); $M = 26$) and the Mini-Mental State Examination (Folstein et al. (1975); $M = 28.27$). Participants received $10/hour for their participation in the experiment.

5.13.2 Stimulus and Apparatus

The visual stimuli and apparatus were identical to Experiment 1a. However, this experiment included a 1 KHz tone that was played over two speakers placed 34 cm to the left and right of central fixation of the visual display. The speakers were covered with a black curtain, and therefore were not visible to the participant. The auditory stimulus was a 10 ms pure tone with an intensity of 76 dB SPL as measured by a B&K 2239 sound meter.

5.13.3 Procedure

On each trial, a high-contrast fixation dot appeared on the screen, flashed for 300 ms, stayed on the screen for 500 ms, then disappeared. After a random delay of 800-850 ms, the two visual stimuli were presented successively, separated by an ISI of of 50, 80, 100, 150, 200, 300, 500, 750, or 1000 ms. An auditory stimuli was presented simultaneously with either the first or second visual stimulus. Participants reported whether the auditory stimulus occurred with the first visual stimulus or the second visual stimulus by pressing one of two keys on a standard computer keyboard. Participants received no feedback, and the next trial started automatically 500 ms after a response. The ISI was selected randomly on each trial, with the constraint that each ISI was presented 30 times. The task took approximately 30 minutes to complete.

5.14 Results

A cumulative normal curve was fit to a plot of each participants proportion of correct responses for each ISI. A threshold and standard deviation (SD) value were calculated for each participant. Threshold was estimated as the mean of the curve (i.e., 75% correct responses). Figure 5.2 shows an example of an individual curve fit for a typical younger participant. One younger participant and one older participant was removed from the analysis due to having negative threshold values. Boxplots of thresholds and SDs are shown in Figure 5.3.

Older adults ($M = 335.81$ ms) had significantly larger thresholds than younger adults ($M = 200.11$ ms), $t(14) = 2.50$, $p = .025$. Older adults ($M = 356.54$ ms) had significantly larger SDs than younger adults ($M = 213.48$ ms), $t(18) = 3.20$, $p = .005$. These results indicate that older adults perform poorly on the task compared to younger adults.

We also evaluated the correlation between threshold in Experiment 2 and d' in Experiment 1b. Figure 5.4 illustrates the relationship between these two measures for a 40 ms gap. Overall, the correlation was significant for all gaps except for 30 and 60 ms (see Table 5.4). However, when we split up the data by group, the measures in the older group were not correlated at any gap duration. In the younger group, the correlations were close to significance for three of the gap lengths, and r-values for younger adults closely resembled the r-values for the overall correlation. Since there were only eleven younger participants, the lack of significance is most likely driven by a lack of power. Therefore, performance on the gap detection task is not related to performance on the TOJ task for older adults, but as d’ increases, threshold decreases for younger adults.

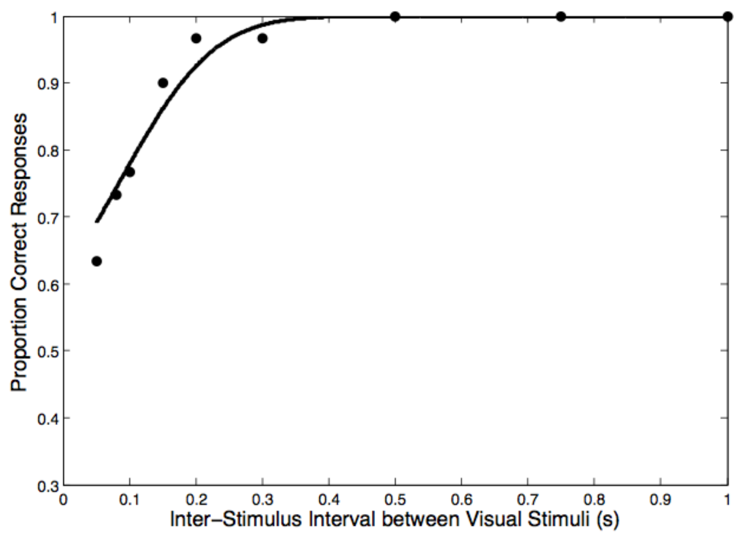

Figure 5.2: An example of a curve-fitting graph for a younger individual for Experiment 2. The ISI between the two visual stimuli is plotted on the x-axis and the proportion of correct responses is plotted on the y-axis. The curve represents the best-fitting cumulative normal.

Table 5.4: Statistics for Experiment 2

Measure	r-value Total	p Total	r-value Old	p Old	r-value Young	p Young
d' 20 ms	-.46	.043	.10	.772	-.46	.183
d' 30 ms	-.38	.100	.13	.729	-.37	.290
d' 40 ms	-.60	.006	.31	.381	-.66	.038
d' 50 ms	-.48	.034	.51	.131	-.57	.085
d' 60 ms	-.41	.076	.48	.162	-.45	.192
d' 70 ms	-.46	.039	.32	.368	-.58	.082

Note: Correlation is between d' in Experiment 1b and threshold in Experiment 2. p represents p-value.

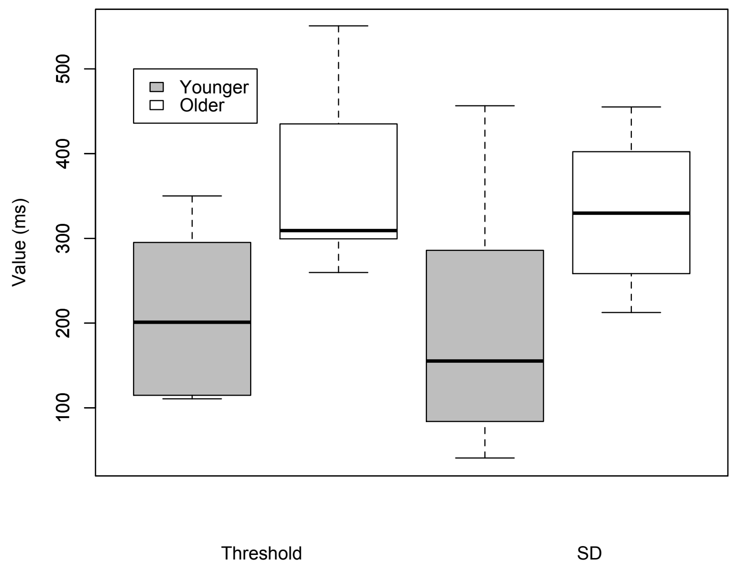

Figure 5.3: Boxplots of threshold and SD by group for Experiment 2. The grey boxes represent the younger adults and the white boxes represent the older adults.

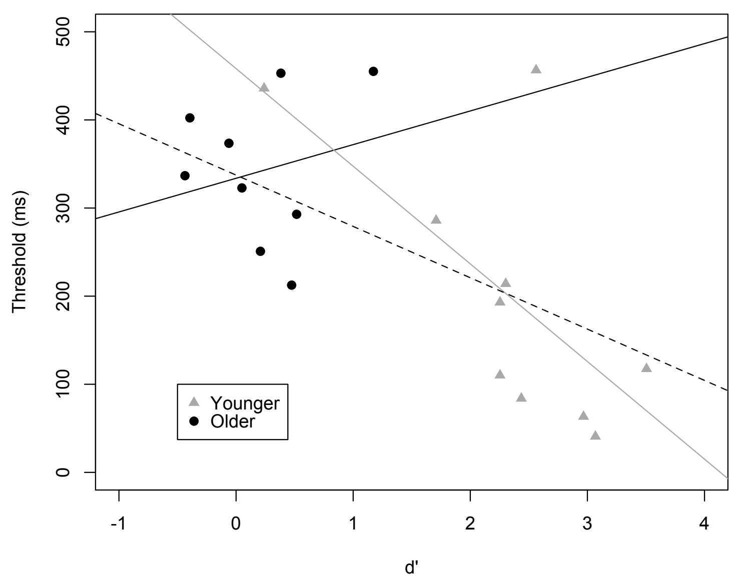

Figure 5.4: The correlation between d' on Experiment 1b and threshold on Experiment 2 by group at a gap length of 40 ms. Threshold in ms is plotted on the y-axis and d' is plotted on the x-axis. The black circles and line represent the older adults, and the grey triangles and line represent the younger adults. The dashed black line represents the overall correlation.

5.15 EXPERIMENT 3

To determine if the performance of older and younger adults in a gap detection task is equivalent when the gap duration is longer, we conducted a experiment that used gap durations of up to 140 ms. Furthermore, we aim to determine if older adults can detect gap lengths similar to the ISIs used in our TOJ task.

5.16 Methods

5.16.1 Participants

Twelve older adults (M = 76.25, 70-81 years old) and 12 younger adults (M = 20.91, 19-23 years old) participated in Experiment 3. All participants were naïve participants who had not previously participated in Experiment 1a-c or 2. All participants had normal or corrected-to-normal vision as measured by far (Old M = 0.93; Young M = 1.29) and near (Old M = 0.89; Young M = 1.29) Snellen decimal acuity. All older adults had normal cognitive abilities as tested by the Montreal Cognitive Assessment (Nasreddine et al. (2005); M = 25.17) and the Mini-Mental State Examination (Folstein et al. (1975); M = 28.83). Participants received $10/hour for their participation in the Experiment.

5.16.2 Stimulus and Apparatus

The stimuli and apparatus were identical to that of Experiment 1a.

5.16.3 Procedure

The procedure was identical to that of Experiment 1a. However, four blocks of trials were used with used gap lengths of 50, 80, 110, or 140 ms. Each block contained 75 gap trials and 75 no-gap trials, and the order of blocks was counterbalanced among participants. Each block took approximately 15 minutes to complete, and therefore the total experiment lasted one hour. Participants were given feedback after each trial and were allowed to take short breaks between blocks.

5.17 Results

d' and bias were calculated as they were in Experiment 1a, and the same analysis was conducted. See Figure 5.5 for d' values across gap length by group and Figure 5.6 for bias across gap length by group.

The analysis of d' found significant main effects of group ($F(1, 22) = 10.35$, $p < .001$) and gap length ($F(3, 66) = 40.86$, $p < .001$), as well as a significant interaction between group and gap length ($F(3, 66) = 5.89$, $p < .001$). Follow-up t tests revealed that older adults had significantly lower d''s in the 50, 80, and 110 ms gap lengths, but not in the 140 ms gap length (see Table 5.5). These results indicate that older and younger adults had similar sensitivity for gaps of 140 ms.

For bias, the main effect of group was not significant ($F(1, 22) = 1.84$, $p = .188$), but the main effect of gap length ($F(3, 66) = 3.43$, $p = .022$) and the group x gap length interaction ($F(3, 66) = 2.82$, $p = .046$) were significant. To evaluate the interaction, group differences in bias were evaluated with t tests at each gap length: older adults had a significantly higher bias only in the 50 ms condition.

Table 5.5: Statistics for Experiment 3

Measure	t-value	df	p-value	M Old	M Young
d' 50 ms	-5.65	22	$< .001$	1.217	3.041
d' 80 ms	-2.46	22	.022	2.827	3.828
d' 110 ms	-2.21	20	.038	3.230	4.090
d' 140 ms	-1.33	18	.201	3.364	3.901
Bias 50 ms	3.83	19	.001	0.248	0.104
Bias 80 ms	1.52	17	.147	0.112	0.057
Bias 110 ms	-0.57	12	.576	0.083	0.130
Bias 140 ms	0.34	21	.737	0.086	0.075

Note: d' is calculated by subtracting the false alarm rate from the hit rate, and the bias is taken as the false alarm rate. M represents the mean and df represents the degrees of freedom.

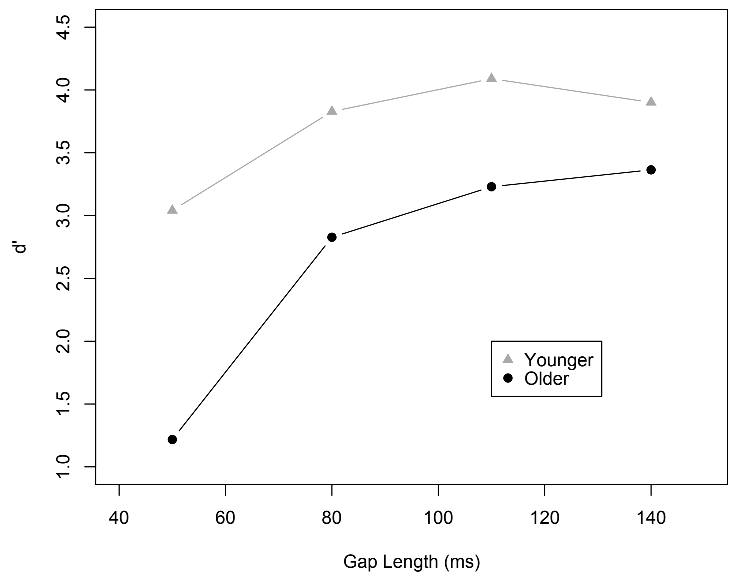

Figure 5.5: d' values by group across each gap length. Gap length in ms is plotted on the x-axis and d' is plotted along the y-axis. The black circles represent the older adults and the grey triangles represent the younger adults

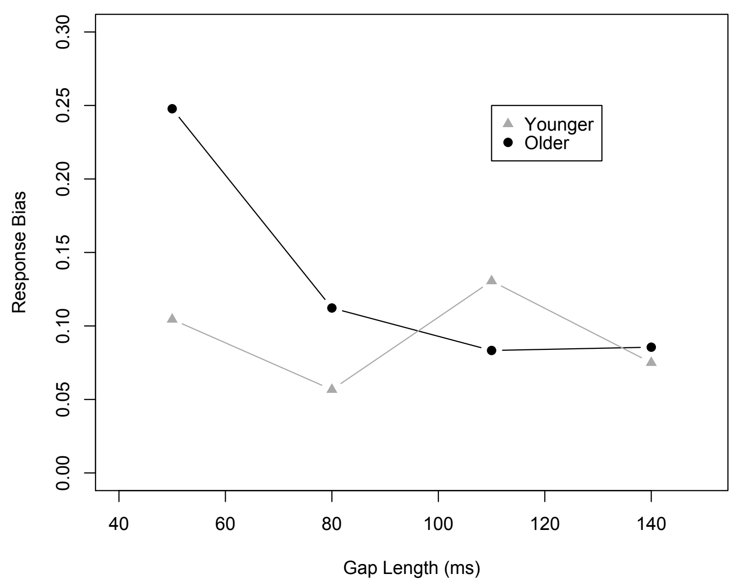

Figure 5.6: Bias by group across each gap length. Gap length in ms is plotted on the x-axis and bias is plotted along the y-axis. The black circles represent the older adults and the grey triangles represent the younger adults.

5.18 General Discussion

The experiments in this chapter explored the effects of aging on visual gap detection. We found that older adults have lower sensitivity on visual gap detection tasks than younger adults. In Experiments 1a-c, for example, sensitivity in younger adults was very high (i.e., $d' \approx 2$) for gap durations as low as 40 ms, whereas sensitivity in older adults did not attain this level even with gap durations of 70-80 ms. Even in Experiment 3, which found higher sensitivity than Experiments 1a-c, average d' for a gap duration of 50 ms was 3.0 and 1.2 for, respectively, younger and older subjects. In addition, d' was correlated between the gap detection experiments, indicating that the measure stays relatively stable and was unaffected by increasing the proportion of no-gap trials. Experiment 2 replicated the results obtained in Chapter 3 and found that older adults had significantly higher thresholds than younger adults on an audio-visual 2AFC TOJ task, and that performance on the gap detection was somewhat correlated with performance on the TOJ task for younger adults, but not for older adults. Therefore, although older adults show deficits on visual gap detection at smaller ISIs, they are very accurate in situations that use gap lengths that are comparable to the ISIs used in our TOJ task. Therefore, they are not constrained by the blurring of visual stimuli on the TOJ task.

Older adults are able to achieve the same performance as younger adults when gap lengths are over 110 ms. This is almost three times the gap length that younger adults require to obtain similar d' values. Therefore, we can conclude that older adults are impaired on visual gap detection tasks. This is consistent with previous research showing higher gap detection thresholds in older adults compared to younger adults (Amberson et al., 1979; Humes et al., 2009). In the current experiments, younger adults demonstrated high performance with gap durations of 40 ms, which is higher than the thresholds of ∼20 ms reported by both Uttal and Hieronymus and Humes et al.. However, early studies of visual flicker fusion have found thresholds of 35 ms (Basler, 1911) and 70 ms (Lindsley and Lansing, 1956). Furthermore, Amberson et al. found thresholds of ∼65 ms in younger adults. Therefore, it appears that gap detection thresholds are highly variable depending on stimuli, method of presentation and task conditions. While Amberson et al. and Humes et al. find that older adults have approximately 1.5 times the gap detection threshold as younger adults, our ratio is much higher – approximately 2.75 times. However, both Amberson et al. and Humes et al. presented flashing lights as visual stimuli rather than visual stimuli presented on a computer screen. Future research could investigate the effect of different types of visual stimuli on gap detection thresholds.

As mentioned in the introduction, studies have shown an increased attentional blink for older adults (Georgiou-Karistianis et al., 2007; Lahar et al., 2001; Maciokas and Crognale, 2003). Since an attentional blink task also involves rapid presentation of visual stimuli, our results are consistent with these findings. This line of research is done in the context of attention, and age differences on this task are explained by fewer attentional resources for older adults. More specifically, Georgiou-Karistianis et al. (2007) claim that older adults are unable to disengage their attention from the previous target. It is highly possible that the deficit in visual gap detection can also be explained by a reduction in attentional resources; older adults may be unable to disengage their attention from the first visual stimulus and therefore cannot perceive the second visual stimulus.

We have demonstrated that d' values stay stable over time within an individual. Participants performed the gap detection task three times, and d' values were significantly correlated with d' values that were obtained in the original gap detection experiment. Moreover, when the proportion of no-gap trials was increased, this did not shift participants' biases, and d' remained correlated with the original values. Therefore, changing the relative ratio of gap to no-gap trials does not influence performance on this task.

In Chapter 3, we found a significant effect of age on thresholds in a complex audio-visual temporal order judgment task. This task consists of two visual stimuli separated by a varying temporal interval with a pure tone always simultaneous with the first or second visual stimulus. We repeated this task in the current study with a new group of participants, and replicated our results. Are older adults performing poorly on this task because they are unable to detect a gap between the visual stimuli? In other words, is it the temporal blurring of the two visual stimuli that is constraining their performance on the TOJ task? Based on the findings from the current experiment, we can conclude that this is not the case. Although we show that older adults have a deficit on visual gap detection, it is unlikely that this is solely driving their deficit on the TOJ task. Blurring of the two visual stimuli is certainly contributing to their poor performance, especially at lower ISIs of 50-110 ms. However, we have demonstrated that above 110 ms, older adults perform equally as well as younger adults, and the TOJ task has ISIs ranging from 50-1000 ms. Detecting the gap should not constrain performance beyond a temporal interval of 110 ms. Further evidence for this is indicated by the lack of correlation for the older adults between the gap detection task and the TOJ task. Since performance on the two tasks is unrelated, it is unlikely that the deficit on the TOJ task is a result of the deficit in gap detection.

Older adults had significantly higher biases than younger adults, except at higher gap lengths when their performance was comparable to that of younger adults. This is not surprising given their poor performance on the task. Younger adults are more certain as to whether or not there is a gap; therefore, they are less likely to make a false alarm. If older adults are uncertain, there is fusion of the two visual stimuli, and they will be more likely to respond that there is no-gap when there is indeed a gap.

Although we have demonstrated deficits in temporal processing as we age on visual gap detection, we do not provide insight into how temporal factors interact with spatial factors. Several studies have indicated that spatial location is extremely important for gap detection tasks and temporal order judgment tasks (Zampini, Shore, and Spence, 2003a,b; Poliakoff, Shore, Lowe, and Spence, 2006; Uttal and Hieronymus, 1970). Therefore, future studies should focus on investigating the influence of both temporal and spatial factors on these types of tasks. Stimuli in everyday life contain both spatial and temporal factors; therefore, this will provide a better representation of multi-sensory temporal processing in the elderly in a real-life capacity.

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Chapter 6

Discussion

6.1 Results Summary

In Chapter 2, we assessed the effects of spatial cues and aging on audio-visual TOJs using simple stimuli. We found that the point of subjective simultaneity (PSS) and the just noticeable difference (JND) did not differ between age groups. Furthermore, we found no effect of spatial cues for either JND or PSS. The results suggested that there is no decline in audio-visual temporal processing in seniors above the age of 70. Furthermore, having the auditory stimulus originate from a different location than the visual stimulus, it least when there is no uncertainty as to which side the auditory cue will come from, does not improve performance on this task.

Chapter 3 assessed audio-visual TOJs using more complex stimuli consisting of three stimuli: two in one modality (e.g., two auditory stimuli or two visual stimuli) and a third stimulus in the other modality. Unlike what was found in Chapter 2, the experiments in Chapter 3 found significant differences between older and younger adults.

The experiments in Chapter 4 were similar to the experiments in Chapter 2, except that the effects of spatial cues were investigated by comparing TOJs obtained with auditory stimuli presented over headphones versus over speakers. Furthermore, we increased the SOAs to 330 ms, and in the last experiment, utilized the same visual stimuli as Setti et al. As in Chapter 2, we found no age-related changes in either JND or PSS, and no effects of spatial cues.

In Chapter 5, we evaluated the influence of aging on visual gap detection. Older adults demonstrate impairments on visual gap detection; it takes almost three times the temporal interval for older adults to reach the level of performance of younger adults. Threshold on the complex TOJ task was correlated with d' on the visual gap detection task for younger adults only. Although certainly a contributing factor, it is unlikely that performance on the complex TOJ task is constrained by a deficit in visual gap detection.

6.2 Impact on Research

A major contribution we have made to this body of research is the investigation of complex TOJs in aging. To date, the experiments in this thesis are the only studies that have directly assessed how the effects of aging on audio-visual TOJs depend on stimulus complexity. By examining more complex audio-visual TOJs, we can more closely mimic stimuli which seniors encounter in real-life; therefore, we can aim to categorize how multisensory processing influences their day-to-day lives.

Another major contribution we have made to temporal order judgment research is the investigation of spatial cues. Under certain circumstances, it appears that the separation of spatial cues does not influence performance on these types of tasks. This can be beneficial in future studies when determining experimental setup. Combined with the work of Zampini et al. (2003a,b), the current experiments suggest that spatial cues do not significantly influence audio-visual TOJs, provided that the stimuli are presented in the same hemifield.

Although previous studies have investigated audio-visual TOJs in aging (Setti et al., 2011b; Virsu et al., 2003), we are the first to use psychometric functions to study age differences on an audio-visual temporal processing task. Furthermore, we are the first to use JND and PSS to categorize age-related deficits in audio-visual temporal processing. This allows a comparison between audio-visual processing and previous studies of multisensory processing in aging that have used these measures (e.g., Poliakoff et al., 2006).

In addition, we have contributed to the body of work on gap detection and aging. We are the first to analyze sensitivity using signal detection theory in gap detection while investigating age differences. This provides a better picture of how gap detection abilities change between groups across varying temporal intervals. We also demonstrate that at a certain point, older adults can be made to behave like younger adults if they are given a large enough temporal interval. Furthermore, we directly compare two different tasks of temporal processing, and demonstrate that, it least for younger adults, there is a relationship between the two tasks.

Audio-visual temporal processing is important for several real-life applications in the elderly. As mentioned previously, Setti et al. (2011a) have indicated that inefficient multisensory processing may contribute to falls in the elderly. Preventing falls and reducing injury can improve the quality of life in seniors. In fact, Fuller (2000) has shown that not only are falls the leading cause of death in the elderly, but that injuries from falls lead to a decrease in quality of life and life expectancy.

Finally, maintenance of social relationships is extremely important for quality of life in the elderly. Doyle and Forehand (1984) demonstrated that loneliness is one of the greatest indicators of poor life satisfaction in the elderly, and Chen (2001) showed that social interaction is a key element in maintaining high levels of life satisfaction in older adults. If unable to properly integrate auditory and visual speech information, older adults may be unable to maintain strong relationships.

6.3 Ideas for Future Research

Some questions still remain about the impact of spatial cues on audio-visual TOJs, especially when considering aging. In our experiments, auditory and visual stimuli occurred from a fixed location and were not presented to opposite hemispheres. There was no uncertainty about the locations of the auditory and visual stimuli. The effects of uncertainty have been investigated in young adults (Zampini et al., 2003b), but not in older adults. It would be interesting to investigate uncertainty and presentation to separate hemifields, as in the study by Zampini et al., to determine if these manipulations differentially influence older and younger adults. Based on the visuo-tactile experiment conducted by Poliakoff et al. (2006), it may be that younger adults are better able than older adults to take advantage of redundant spatial cues when there is uncertainty as to which side the stimuli will come from.

Another possible line of future research would be to continue to investigate more complex audio-visual TOJs in aging. For example, one could look at the impact of having more than three stimuli involved in a TOJ task. Furthermore, more complex tasks that relate better to everyday life could be employed to help to characterize how improper multisensory processing leads to falls in the elderly. Perhaps eventually a naturalistic task involving multisensory processing and movement could be employed. By better categorizing the deficits, we can aim to help older adults live with inefficient multisensory processing and aim to prevent falls in the elderly.

As mentioned before, social interactions are extremely important for maintaining the well-being of older adults and helping them to live longer (Fuller, 2000). Language perception is extremely important for social interactions, and involves the coordination of auditory and visual information (Erber, 1975). Although research has previously been conducted on audio-visual TOJs in language for younger adults (Vatakis, Navarra, Soto-Faraco, and Spence, 2007; Macaluso, George, Dolan, Spence, and Driver, 2004), research has not been previously conducted on seniors. In the study by Vatakis et al., auditory and visual speech and music stimuli were presented at varying SOAs, and adults had to judge whether the visual information or the auditory information came first. It would be interesting to conduct a similar study, but comparing younger and older adults to determine if older adults are impaired on temporal audio-visual processing of language. This would also generalize to a more complex audio-visual temporal order judgment task that relates to everyday life.

It would be interesting to look at EEG or functional magnetic resonance imaging (fMRI) with the original TOJ experiment in Chapter 2. As mentioned in Chapter 4, older adults can often compensate on tasks by recruiting additional brain areas to help maintain their performance at the level of younger adults (Gutchess et al., 2005). It is possible that the reason older adults are performing the same as younger adults is that they are compensating for their processing deficit by recruiting additional brain areas. Therefore, ERPs could be analyzed to determine if deficits are reflected in the ERP components rather than the behavioural data. Furthermore, fMRI could provide insight into whether additional brain areas are being recruited and which particular areas are being recruited to allow older adults to perform the TOJ task.

We have been the first lab to investigate more complex audio-visual TOJs in aging. Since we find such large age effects for this task, it would be interesting to investigate this same task in the visual and auditory unisensory domain. Many studies have looked at unisensory temporal order judgments; however, not in more complex TOJ tasks. It would be interesting to look at whether or not the age effects are the same or greater than the audio-visual age difference. In the auditory domain, there could be two bursts of white noise separated by a varying temporal interval, and there could be a high frequency tone simultaneous with either the first or second noise burst. Therefore, participants would respond whether the tone came with the first noise burst or the second noise burst. In the visual domain, there could be a Gabor stimulus in each interval separated by a varying temporal interval. There could be a ring around either the first or second Gabor stimulus, and participants would have to respond which Gabor stimulus the ring came with.

Although we have investigated many differences between the three studies which have looked at audio-visual TOJs in aging, discrepancies still have not been explained. One methodological difference which we did not investigate is the method of presenting stimuli and measures used to estimate sensitivity on the tasks. Virsu et al. use a staircase method, Fiacconi et al. used the method of constant stimuli, and Setti et al. only presented two SOAs. The final piece of this puzzle may be resolved by examining age differences using these three different methods.

One last thing that could evaluated is spatial cues with gap detection. In the studies we conducted, the two visual stimuli were always at central fixation. It is possible that different results could be found when the visual stimuli are spatially separate. With this task, we could have one visual stimulus to the left and one visual stimulus to the right. Participants would respond whether or not the two visual stimuli were simultaneous or not. Uttal and Hieronymus (1970) found that participants are better at gap detection when visual stimuli occur at the same location than when they are spatially separate. However, this has not been previously investigated in aging, and it would be interesting to see if the same pattern of results are present in seniors.

6.4 Conclusion

More research must be conducted in order to fully understand how multisensory temporal processing changes as we age. The thesis provides an analysis of audio-visual temporal processing in older adults that indicates while certain task may be spared, deficits are apparent on more complex tasks. If we can specifically characterize the audio-visual deficits experienced by older adults, we can aim to improve their quality of life.

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