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Impaired perceived timing of falls in the elderly

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ABSTRACT

Falls are the leading cause of injury-related deaths and hospitalizations, with older adults at an increased risk. As humans age, physical changes and health conditions make falls more likely. While we know how the body reflexively responds to prevent injury during a fall, we know little about how people perceive the fall itself. We previously found that young adults required a fall to precede a comparison sound stimulus by approximately 44 ms to perceive the two events as simultaneous. This may relate to common anecdotal reports suggesting that humans often describe distortions in their perception of time − time seems to slow down during a fall – with very little recollection of how and when the fall began. Here we examine whether fall perception changes with age. Young (19–25y) and older (61–72y) healthy adults made temporal order judgments identifying whether the onset of their fall or the onset of a comparison sound came first to measure the point of subjective simultaneity. Results show that fall perception is nearly twice as slow for older adults, where perturbation onset has to precede sound onset by ∼88 ms to appear coincident, compared to younger adults (∼44 ms). We suggest that such age-related differences in fall perception may relate to increased fall rates in older adults. We conclude that a better understanding of how younger versus older adults perceive falls may identify important factors for innovative fall prevention strategies and rehabilitative training exercises to improve fall awareness.

1. Introduction

Optimal perception of the world around us requires the central nervous system (CNS) to use multiple sources of sensory information from different sensory modalities. Doing so is important because sensory redundancy can improve the ability to extract meaningful signal from noise [1]. Integrating information from numerous sensory channels facilitates perception, cognition, and action of the self and of the environment by shaping an individual's behaviour to perform better in an environment that is constantly changing [1]. One such system that is integral to maintaining a healthy and active lifestyle throughout the lifespan is balance control. To prevent us from falling down, balance control uses multiple sensory systems, including auditory, visual, somatosensory, and vestibular [2], but may be adversely affected by how the CNS integrates information from numerous sensory channels [3,4].

Sensory information that is redundant in time provides critical information to the CNS with which it can determine what stimuli should be bound together. Synchrony often characterizes whether stimuli from different modalities should be perceived as belonging together or originating from separate and independent events or objects [5]. However, maintaining a perception of simultaneity can be difficult due to the propagation of different stimulus energies [6]. For example, we see lightning before hearing thunder due to the differences in the physical arrival time of the stimuli at the eye and ear [7], making it challenging for our perceptual systems to consistently and accurately perceive simultaneous events. Resultant transmission time for the information to reach the CNS [8], as well as different stimulus attributes characteristic of each event [9] can affect the perceived timing of sensory events. Furthermore, one's attention can influence the processing speed of incoming stimuli [10], yielding delays between sensory events that do not correspond with the physical timing of phenomena. While not an apparent problem in younger adult populations, studies involving older populations have found that older adults are physically and perceptually slower than younger adults with respect to eye movements [4], response time [3], and temporal order judgments (TOJ) [11]. These results indicate that poor early perceptual processing may lead to less coherent multisensory perception, which may contribute to an increase in fall or sway-like behaviours [2].

Given that falls pose a threat to one's survival, it would seem reasonable to assume that we would perceive the onset of a fall with great accuracy and minimal delay. However, while the CNS is able to rapidly generate compensatory postural reactions, we have recently shown that the perceived onset of a postural perturbation is slow [12]. Here we found that young adults require the onset of a fall to occur 44 ms prior to the onset of a sound in order to perceive the two stimuli as simultaneous. Interestingly this may relate to other reports of vestibular

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stimulation being perceptually slow [13–18], however, arguably a fall involves far more stimulation than vestibular input alone. It would seem then that during a fall the CNS may prioritize physiological responses such as postural reflexes over perceptual awareness by relying on other sensory modalities to confirm sensory onset, and thus delaying perception. As such, it may be far less important to contemplate the onset of a perturbation than to react and regain stability from an unexpected event.

Despite physiological and non-physiological factors involved in modulating perception (e.g., stimulus intensity) and action, the CNS is remarkably good at being able to reconstruct the actual timing of a multisensory event [19]. It has been suggested that a neural mechanism called 'simultaneity constancy' resynchronizes incoming asynchronous multisensory signals representing an event by combining signals from different senses that have varying processing times [20,21]. Such a mechanism is at least partially responsible for the ability to accurately perceive simultaneity of vestibular events [13] despite sensory and perceptual delays. Recent work has found that relative to younger adults, older adults tend to have larger "temporal binding windows" [4,22,23] within which sensory stimuli are judged as occurring simultaneously. This allows for relevant and irrelevant stimuli to be processed and also reduces the probability of successfully integrating multiple stimuli [3]. Setti and colleagues [23] found that older adults were more susceptible to sound-induced flash illusions at longer stimulus onset asynchronies (SOAs), reflecting inefficient processing of irrelevant stimuli in the CNS. Additionally, when older participants are presented with pairs of visual and vibrotactile stimuli to either hand and asked to make TOJs, they required more time and were less accurate than younger observers to correctly perceive the temporal order of events [22]. These results indicate that poor early perceptual processing may lead to less coherent multisensory perception. Furthermore older adults are unable to ignore multiple ambiguous sensory cues as they fall or sway significantly more under sensory conflict situations, which may lead to a loss of balance and posture [2].

While some researchers claim that multisensory integration degrades as a function of age, with increased response times and a wider distribution or range of response times for example [4,24 for a review], others have not found this to be the case. Laurienti and colleagues [3] found that as an individual gets older, their unisensory perception starts to deteriorate and they tend to rely more on integration of the senses. Thus, it is possible that older adults can benefit from having larger temporal binding windows, which may allow them to exploit redundant cues to form a reliable and coherent perception. For example, Spence and colleagues [5] demonstrated that exploiting spatially redundant cues increased the precision with which observers made speeded audio-visual and visuo-tactile TOJs.

To date, while there have been many studies that have explored the use of a lean-and-release perturbation system to indirectly elicit inertial cues in older adults, none have looked at the perceived timing of the postural perturbation. In the present study, we tested younger and older healthy adults hypothesizing that following unexpected perturbations, older adults will require the perturbation to occur earlier in time than younger adults to be perceived as simultaneous with a comparison sound stimulus.

2. Methods

2.1. Participants

Twelve healthy younger adults (19–25y; *M* = 22.0y, *SD* = 1.71y; 7 female) and eleven healthy older adults (61–72y; *M* = 67.0y, *SD* = 4.38y; 9 female), free of musculoskeletal, auditory, visual, vestibular, or other neurological disorders, were recruited to participate in this study. Participants gave their informed written consent to participate in the study and all older adults were recruited through the Waterloo Research in Aging Participant Pool. The study was approved through a University of Waterloo Research Ethics Committee, which complies with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

Fig. 1. Lean-and-release cable set-up for both younger and older adults. Participants were blindfolded and instructed to lean forward such that their body weight was supported by the cable from neutral stance. Perturbation onset time was calculated by a mounted load cell attached to the mechanical lift. Participants wore noise-cancelling headphones (Sennheiser PXE 450; 70 dB) while standing in a standardized foot position (heel centers 0.17 m apart, 14° between the long axes of the feet [26]). For each of the 110 trials (10 practice), participants judged whether the onset of the fall or a comparison sound (500 Hz 250 ms square wave burst; 77 dB) came first.

2.2. Protocol

Using a lean-and-release perturbation system [12,25,26] participants judged the temporal order of a fall and sound to determine the point of subjective simultaneity (PSS). Participants indicated whether they thought the fall or sound came first by button press. Participants were also required to cross their arms with each hand secured to the opposite shoulder. A restrictive Velcro strap was used to secure their arms from moving throughout the experiment (Fig. 1). Fig. 2 represents a schematic of the onset of the stimuli presented on each trial. We refer the reader to our previous study [12] for more details on the protocol and stimulus generation.

2.3. Data analysis

TOJ data acquired at various SOAs are plotted as a function of the percentage of trials in which either response was chosen. Here, negative SOAs represent that a fall occurred prior to the auditory stimulus. A two-parameter logistic function (Eq. (1)) was fit to the TOJ data using Sigma Plot 12.0 (Fig. 3), where *x0* refers to the PSS and *b* refers to the slope of the logistic curve that is proportional to the just noticeable difference (JND). The JND is indicative of the smallest change in interval that observers can reliably notice, thus it is a reflection of the participant's precision in their decision-making.

$$(1)\quad y = \frac{100}{1 + e^{-\frac{(x - x0)}{b}}}\%$$

Recorded TOJs were analyzed for correct trials only. Trials were deemed as an error if there was a response prior to the end of the trial, or if no response was given. Trial errors occurred on fewer than 3% of all trials and these trials were not repeated later in the experiment.