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ELDERLY ADULTS DELAY PROPRIOCEPTIVE REWEIGHTING DURING THE ANTICIPATION OF COLLISION AVOIDANCE WHEN STANDING

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Abstract—The ability to reweight visual and proprioceptive information is critical for maintaining postural stability in a dynamic environment. In this study, we examined whether visual anticipation of collision avoidance (AV) while standing could facilitate the down-weighting of altered proprioception in young and elderly adults. Twelve young (24.91 ± 6.44 years) and 12 elderly (74.8 ± 6.42 years) participants stood upright for 180 s under two task conditions: (a) quiet stance (QS) and (b) standing while anticipating virtual objects to be avoided. In order to disrupt the accuracy of proprioceptive input participants were exposed to bilateral Achilles tendon vibration during the middle 60 s of standing in both tasks. Visual field dependence was assessed using the Rod and Frame Test (RFT). Elderly demonstrated significantly higher visual field dependence compared to the young participants. Analysis of the normalized Root Mean Square (RMS) of the Center of Pressure velocity (dCoP) revealed that young participants immediately reduced the sway velocity variability induced by tendon vibration during the anticipation of collision AV compared to the QS task. In the elderly, however, the modulating influence of visual anticipation was delayed and became significant only in the last two time intervals of the vibration phase. These results suggest that volitionally shifting reliance on vision when anticipating a collision AV event facilitates the down-weighting of altered proprioception. Elderly adults seem to be unable to dynamically exploit visual anticipation in order to down weight the altered proprioception possibly as a result of their more permanent up-weighting of the visual modality. Sensory reweighting seems to be a more time consuming process in aging which may have important clinical implications for falling.

Key words: balance, falls, aging, vision, proprioception, sensory reweighting.

INTRODUCTION

During closed loop control of posture, vision, lower limb proprioception and vestibular sensation each provide information on a unique aspect of the environment and one's orientation in it (Peterka, 2002). The contribution of the sensory modalities to the internal representation of the environment varies depending on the weight the CNS assigns to each modality. As environmental conditions change, the weight assigned to a particular modality may need to be adjusted (i.e. reweighted) depending on its estimated accuracy for the control of posture (Peterka and Loughlin, 2004). For example, the accuracy of proprioceptive input is reduced when standing on a sway- and reverse-sway-referenced support surface (Doumas and Krampe, 2010) or during bilateral application of Achilles tendon vibration (Eklund, 1972). Similarly, the accuracy of visual input is reduced by optic flow manipulations (O'Connor et al., 2008) or changes in visual stimuli motion (Jeka et al., 2006), both requiring the down-weighting of visual input. The transition from one weighting configuration to another leads to a temporary imbalance of weights which results in increased postural instability (Peterka and Loughlin, 2004). Through effective sensory reweighting, this instability is progressively reduced as a function of adaptation (Jeka et al., 2008).

In older adults, ambiguous environments requiring the reweighting of sensory inputs could increase the risk of falling (Hay et al., 1996; Teasdale and Simoneau, 2001). This is because normal aging delays the process of sensory reweighting resulting in prolonged postural instability when proprioceptive (Doumas and Krampe, 2010) and/or visual input is altered (Jeka et al., 2010). Particularly, both healthy and fall-prone older adults show a more persistent increase in postural sway when they are exposed to changes in optic flow (O'Connor et al., 2008) or visual motion stimulation (Jeka et al., 2010). An insufficient and delayed down-weighting of the inaccurate visual cues could be due to increased visual field dependence (Isableu et al., 1998). Visual field dependence is a measure of the reliance on visual

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Abbreviations: ANOVA, analysis of variance; AV, avoidance; C7, 7th cervical vertebra; dCoP, Center of Pressure velocity; ML, Medio–Lateral; MMSE, Mini Mental Status Examination; QS, quiet stance; RFT, Rod and Frame Test; RMS, Root Mean Square; ST, stabilization time; T1–T5, time intervals 1 to 5.

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cues for the perception of verticality (Reger et al., 2003). Increased visual field dependence suggests that older adults rely more on visual input for postural corrections, even when visual accuracy is compromised (Sundermier et al., 1996; Simoneau et al., 1999). As a result, they are unable to centrally suppress the unreliable visual cues in the presence of visual motion perturbations (O'Connor et al., 2008; Jeka et al., 2010). The ability to centrally suppress the inaccurate sensory input, called perceptual inhibition, correlates with the ability to shift attention between sensory modalities during balance-challenging tasks (Redfern et al., 2001, 2009). Thus, an age-induced overreliance on visual information may be disruptive for postural control due to the delayed down weighting of the inaccurate visual cues.

We have recently examined how the visual anticipation of randomly approaching objects to be avoided (i.e. collision avoidance (AV) modulates the process of visual reweighting in young and healthy elderly adults (Eikema et al., 2012). Down-weighting of visual input was evoked by either removal or periodic motion of the visual surround. Visual anticipation under conditions of visual ambiguity imposes an intra-sensory conflict. On one hand, the ambiguous visual environment requires the down-weighting of vision in order to maintain a stable posture. On the other, visual information needs to remain of high priority to successfully detect and avoid the randomly approaching objects. In quiet standing, visual reweighting was impaired only in older adults due to their greater visual field dependence. Visual anticipation impaired visual reweighting, i.e. increased sway in response to the visual perturbation, independently of age. This is because the anticipation of the visual, possibly balance-threatening events modulated the reweighting process by increasing the anchoring to vision (Ohno et al., 2004; Ishida et al., 2010). What is still not known however is whether the increased anchoring to vision evoked by anticipation of collision avoidance can modulate the down-weighting of a non-visual modality such as proprioception when its accuracy is compromised. In a recent study, Isableu et al. (2011) have shown that increasing proprioceptive reliance by active forward or backward body leaning helped participants to reduce or suppress the destabilizing effects of altered vision on body posture. Nevertheless, large inter-individual differences in benefiting from the increased proprioceptive reliance were noted.

In the current study, we investigated whether increasing volitional reliance on vision through the anticipation of collision avoidance events could facilitate the down-weighting of altered proprioceptive input in both young and elderly adults. Proprioception was perturbed by the bilateral application of Achilles tendon vibration during the middle 60 s of a 180-s stance trial. Vibration alters proprioceptive input of the triceps surae muscles resulting in a posterior postural shift during standing (Eklund, 1972). Specifically, we predicted that sway velocity variability evoked by Achilles tendon vibration would be reduced during anticipation compared to quiet standing in both age groups. Because normal aging slows the process of sensory reweighting we expected a greater facilitation of the proprioceptive reweighting due to visual anticipation in young compared to elderly adults.

EXPERIMENTAL PROCEDURES

Participants

Twelve young (five males, seven females; age 24.91 ± 6.44, mass 70.91 kg ± 13.93) and 12 elderly (six males, six females; age 74.8 ± 6.42, mass 78.44 kg ± 13.16) adults participated in the study. Participants were free of neurological and musculoskeletal impairments and had normal or corrected to normal vision. The elderly participants performed the Mini Mental Status Examination (MMSE) in order to ensure they possessed the cognitive capacity to understand the instructions and perform the tasks. The MMSE cut-off score was set at 22. In the current study all elderly participants scored in the 26–30 range of the MMSE. Participants were informed of the procedures and provided written consent. All experiments were performed with the approval of the local ethics committee on human research in accordance with the Declaration of Helsinki.

Apparatus

Postural sway was recorded using a 3-D force plate (Balance Plate 6501, Bertec Corporation, Columbus, USA) at a sampling rate of 105 Hz. Kinematics were captured using an electromagnetic tracking system (Nest of Birds, Ascension Inc., Burlington, USA). A single marker was placed on the 7th cervical vertebra (C7). The virtual visual surround and visual stimuli were delivered by a stereoscopic projection screen (Barco Baron 908, Barco N.V., Kuurne, Belgium, width 128 cm, height 102 cm) viewed through active shutter goggles (Crystal Eyes 3, Stereographics) at 55 Hz per shutter. The screen was located 200 cm from the participant providing a horizontal viewing angle of 38°. The virtual environment consisted of an empty room with walls, floor, and ceiling textured with an alternating light and dark grey bar pattern (Fig. 1a). Proprioception was altered using bilateral Achilles tendon vibration using a pair of tendon vibrators (VB115, Technoconcept, France).

Task and procedure

The participants performed the Rod and Frame Test (RFT) in order to determine the degree of visual field dependence (Reger et al., 2003), indicating the degree to which an individual relies on visual information for postural corrections (Isableu et al., 1998). During the task, a rod was visible inside a frame, which would be tilted +18°, 0° or −18°. Using a hand-held marker of the electromagnetic tracking system, the participant was repeatedly asked to rotate the bar while standing until it was estimated to be vertical. The angular deviation of the rod's final position from the actual vertical was recorded as error in degrees.

Prior to the experimental trials, participants were familiarized with the visual collision AV task. The visual target stimulus was a sphere (10 cm in diameter, textured to resemble a green tennis ball) traveling at a constant velocity from the center of the visual field towards the participant's head (Fig. 1a). Participants were instructed to avoid collision with the sphere by displacing their trunk and head together as a unit along the Medio–Lateral (ML) axis, without moving the feet. Head-centered collision AV movements (increased head movements while displaying minimal trunk displacement) were discouraged as this could compromise postural stability. Particularly, moving the head