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Are age-related impairments in change-in-support balance reactions dependent on the method of balance perturbation?

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ABSTRACT

Rapid "change-in-support" (stepping or grasping) balance-recovery reactions play a critical role in preventing falls. Studies investigating age-related impairments in these reactions using differing perturbation methods have shown contradictory results. The discrepancies could be due to the different mechanical and sensory stimuli provided by the different perturbation methods, but could also be due to other confounding factors (e.g. differences in perturbation predictability). This study compared two commonly used perturbation methods: weight-drop cable-pulls (CPs) and motor-driven surface-translations (STs). For each perturbation method, effects of aging on the change-in-support reactions were established by comparing 10 young (22–28 years) and 30 older (64–79 years) adults, using large unpredictable multi-directional perturbations similar to those used in previous studies showing age-related differences. Age-related differences in the pattern and spatio-temporal features of the limb movements were examined for stepping and grasping reactions evoked by antero-posterior perturbation of stance, as well as stepping reactions evoked by lateral perturbations delivered while subjects walked "in-place". Although age-group effects were almost always more pronounced for ST perturbations, the direction of the effect was always the same for both perturbation methods; hence, the perturbation-dependent differences in mechanical and sensory stimuli did not seem to be a critical factor. Perturbation waveform appeared to be a more important factor. For the perturbation methods used here, the ST perturbations were more destabilising than the CP perturbations (leading to a more rapid rise in perturbatory ankle-torque and greater centre-of-mass motion prior to the onset of the postural reaction), and were consequently more effective in revealing age-related deficiencies.

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1. Introduction

The ability to react to sudden perturbations is critical to balance control. Of particular importance in preventing falls are change-in-support reactions, involving rapid stepping and grasping movements (Maki and McIlroy, 2006). These reactions are the only defence against large postural perturbations (Shumway-Cook and Wollacott, 1995), but are frequently recruited following smaller perturbations when subjects are allowed to react naturally (McIlroy and Maki, 1993b; Jensen et al., 2001).

Age-related differences in change-in-support reactions have been studied using cable-pull (CP, e.g. Luchies et al., 1994; Rogers et al., 2001), surface-translation (ST, e.g. McIlroy and Maki, 1996; Brauer et al., 2002), and release-from-lean (RFL) perturbations (e.g. Thelen et al., 1997; Hsiao-Wecksler and Robinovitch, 2007). Contradictory age-related effects have emerged from these studies. For example, some studies showed that foot-off times were slower in older adults (OA), some showed that young adults (YA) were slower, and some showed no age-related difference (Table 1).

The cause of the contradictory findings is unclear. One possibility pertains to differences in perturbation method, which result in differing mechanical and sensory stimuli. For example, CPs apply pressure at the pelvis whereas STs induce shear forces at the foot–sole; therefore, there are differences in cutaneous stimuli. Furthermore, differences in the point-of-application of perturbatory force could affect induced patterns of motion as well as associated proprioceptive, visual and vestibular stimuli (Liu et al., 2003). Differing mechanical and sensory stimuli, and age-related differences in the ability to respond to specific types

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Table 1
Examples of previous perturbation studies showing contradictory age-related differences in characteristics of stepping reactions.

Study	Unpredictability			Instruction	AP-step measures			ML-step measures	
	Onset timing	Magnitude	Direction[a]		Foot-off time	Swing duration	Step length	Cross-over steps	Foot collisions
Cable-pull (CP) perturbations:									
Luchies et al. (1994)	Yes	Yes (10 different pull distances)	No (B only)	Not specified	OA<YA[b]	OA<YA	OA<YA	–	–
Rogers et al. (2001)[c]	Not specified	Yes (five different magnitudes)	No (F only)	React naturally	OA<YA	OA<YA	–	–	–
Rogers et al. (2003)[c]	Not specified	No	No (F only)	React naturally	OA = YA	–	–	–	–
Schulz et al. (2005)	Not specified	Yes (five different magnitudes)	Yes (F, B)	React naturally	OA = YA	OA = YA	OA<YA (B only)	–	–
Mille et al. (2005)[c]	Not specified	No	Yes (L, R)	React naturally	–	–	–	OA>YA	OA>YA
Present findings	**Yes**	**Yes (STs included)[d]**	**Yes (L, R, F, B)**	**React naturally but minimise number of steps**	OA<**YA**	**OA = YA**	**OA<YA**	**OA = YA[e]**	**OA = YA[e]**
Surface-translation (ST) perturbations:									
McIlroy and Maki (1996)	Yes	No	Yes (F, B)	Try not to fall	OA = YA	OA = YA	OA = YA	–	–
Maki et al. (2000)	Yes	Yes ('low' and 'high' magnitude)[d]	Yes (L, R, F, B)	React naturally	–	–	–	OA = YA[e]	OA>YA[e]
Present findings	**Yes**	**Yes (CPs included)[d]**	**Yes (L, R, F, B)**	**React naturally but minimise number of steps**	OA<**YA**	**OA = YA**	**OA = YA**	**OA = YA[e]**	**OA>YA[e]**
Release-from-lean (RFL) perturbations:									
Thelen et al. (1997)	Yes	No	No (F only)	Take a single step forward with right foot	OA>YA	–	–	–	–
Wojcik et al. (1999)	Yes	No	No (F only)	Take a single step forward with right foot	OA>YA	–	OA>YA	–	–

The findings of the present study are also included (bold characters).
[a] Direction of falling motion induced by perturbation: L = leftward, R = rightward, F = forward, and B = backward.
[b] OA = older adults (⩾65 years), YA = young adults (⩽40 years). "OA<YA" indicates that the OA mean was significantly smaller than the YA mean, etc.
[c] These cable-pull studies used an electromechanical actuator, rather than a weight-drop mechanism.
[d] These studies included ST perturbations that were also unpredictable in terms of their waveform, i.e. the timing of the acceleration and deceleration of the moving surface was not the same for all trials.
[e] These findings pertain to trials in which the perturbation was delivered while subjects walked "in-place" (in all other cases the perturbations were applied during bipedal stance).

of stimuli, may influence characteristics of balance-recovery reactions and the degree to which age-related differences are observed. It is also possible that differences in the time-history and amplitude of the perturbatory force affect the degree to which age-related differences emerge; however, few studies have provided details regarding the perturbation waveform and reported amplitude variables can be difficult to compare (e.g. cable-pull force versus support-surface acceleration).

The contradictory findings could also be due to differences in the predictability of perturbation characteristics, which could affect the ability to adopt predictive control strategies (Horak et al., 1989; Maki and Whitelaw, 1993). During release-from-lean perturbations, perturbation direction and magnitude are entirely predictable. Unpredictable multi-directional CP and ST perturbations are possible (Henry et al., 1998; Luchies et al., 1999; Maki et al., 2000; Mille et al., 2005; Schulz et al., 2005); however, CP and ST studies have varied in the degree of unpredictability used. Additionally, there are often differing instructions given to subjects, which can have a strong influence on certain features of postural reactions (Maki and McIlroy, 1997).

This study aimed to determine if previously reported age-related differences in change-in-support reactions are dependent on perturbation method, under conditions where other confounding factors are controlled. We compared CPs delivered by a weight-drop apparatus and STs delivered by a motor-driven motion-platform, using perturbation parameters (weight-drop magnitude/distance, platform-acceleration profile) similar to previous studies (e.g. Luchies et al., 1994; McIlroy and Maki, 1996). In each case, we gave the same instructions to subjects and varied the perturbation features in an unpredictable manner. We hypothesised that both perturbation methods would reveal the same fundamental age-related deficiencies. However, we also suspected that the two methods would exhibit differences in perturbation waveform that could influence the degree to which these deficiencies are revealed. To explore this possibility, we developed a simple model to compare the time-history of the perturbatory torque and also analysed differences in evoked center-of-mass (COM) motion.

2. Methods

We recruited 10 YA (22–28 years; five men; height 1.63–1.83 m; weight 57–104 kg) and 30 community-dwelling OA with a history of falls or instability (64–79 years; 15 men; height 1.51–1.82 m; weight 52–118 kg). Subjects were right handed with no neuromusculoskeletal conditions adversely affecting daily activities. Ethical approval was obtained from the institutional review board and subjects provided written informed consent. The OA were participants in a balance-training study; the pre-training data presented here are also reported as part of that study (Mansfield et al., 2008).

As detailed previously (Mansfield et al., 2007), subjects either stood or walked in-place on a large (2 × 2 m) multi-axis motion platform that delivered ST perturbations (Fig. 1). Multi-axis CP perturbations were delivered using a weight-drop system connected to a belt (worn at the height of the anterior–superior iliac spines) via

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