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Effect of arm swing on single-step balance recovery

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ABSTRACT

Balance recovery techniques are useful not only in preventing falls but also in many sports activities. The step strategy plays an important role especially under intense perturbations. However, relatively little is known about the effect of arm swing on stepping balance recovery although considerable arm motions have been observed. The purpose of this study was to examine how the arms influence kinematic and kinetic characteristics in single-step balance recovery. Twelve young male adults were released from three forward-lean angles and asked to regain balance by taking a single step under arm swing (AS) and arm constrained (AC) conditions. It was found that unconstrained arms had initial forward motion and later upward motion causing increased moment of inertia of the body, which decreased falling angular velocity and allowed more time for stepping. The lengthened total balance time included weight transfer and stepping time, although duration increase in the latter was significant only at the largest lean angle. In contrast, step length, step velocity, and vertical ground reaction forces on the stepping foot were unaffected by arm swing. Future studies are required to investigate optimal movement strategies for the arms to coordinate with other body segments in balance recovery and injury reduction.

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1. Introduction

Maintaining balance during standing and walking is critical for healthy daily living. Since the cost of medical treatment after falls is usually expensive, falls prevention rather than injury treatment should be the top priority. More thorough understanding of biomechanical characteristics of balance recovery and more efficient/effective balance movements are certainly necessary.

Applying balance recovery techniques can be observed in many sports including gymnastics, dancing, and martial arts. Excellent balance ability is required in these sports activities to counteract excessive body linear/angular momentum. It can be achieved by muscle activation and joint coordination, and this ability can be improved through training (Misiaszek, 2003). In addition, strategies for standing balance recovery have been identified and classified as: (1) ankle strategy, (2) hip strategy, (3) step strategy, and (4) load–unload strategy (Duncan, Studenski, Chandler, Bloomfeld, & LaPointe, 1990; Winter, 1995). Based on the equations of motion of an inverted pendulum, three mechanisms for standing balance were also revealed: (1) change of the center of pressure (COP) position with respect to ground projection of the center of mass (COM), (2) counter-rotation of body segments about the COM, and (3) use of external forces other than the ground reaction force (Hof, 2007).

Although minor perturbations can usually be recovered by the ankle and hip strategies, the step strategy is often called upon as a natural and preferred reaction especially under violent disruption of balance (Duncan et al., 1990). In the step strategy, the central nervous system sends signals to indicate the need to re-position the base of support by stepping forward, backward or laterally until a new base of support which stabilizes body posture is achieved.

Many experimental paradigms have been utilized to simulate loss of balance in order to investigate stepping or other balance recovery strategies. For instance, these methods include having unexpected obstacles or floor translation during walking (Maki, McIlroy, & Fernie, 2003; Pijnappels, Bobbert, & van Dieën, 2004) or a sudden pushing/pulling force during upright stance (Rogers, Hedman, Johnson, Cain, & Hanke, 2001). For producing repeatable balance perturbations, the tether-release method has often been used (Hsiao-Wecksler, 2008) to investigate parameters such as step time, step lengths, joint torques, and joint angles. Balance ability between different age and/or gender groups was often assessed by simulating forward falls with this method (Thelen, Wojcik, Schultz, Ashton-Miller, & Alexander, 1997; Wojcik, Thelen, Schultz, Ashton-Miller, & Alexander, 1999).

Vigorous arms movements have been observed during balance recovery (Dietz, Fouad, & Bastiaanse, 2001; Marigold, Bethune, & Patla, 2003; Roos, McGuigan, Kerwin, & Trewartha, 2008). Muscle activation latency was found to be around 80 ms for arms, and 35–40 ms for feet. Arm movements have been considered to represent two strategies in balance recovery: the protective and preventive strategies (Roos et al., 2008). Old adults generally apply the protective strategy to grasp something for support and avoid direct impact on the floor. However, young adults are more likely to utilize the preventive strategy, for instance, to shift the body center of mass (COM) opposite to the direction of the fall (Allum, Carpenter, Honegger, Adkin, & Bloem, 2002; Misiaszek, 2003). The arms can also produce joint torque to counteract the angular momentum generated by loss of balance (Pijnappels, Bobbert, & van Dieën, 2005; Roos et al., 2008). Furthermore, in human walking although arm movements are mainly passive, there is an active contribution of muscles rather than purely stretch reflexes (Meyns, Bruijn, & Duysens, 2013). The functional role of arm swing in postponing momentum transfer from the arms to the trunk was identified in tripping movements (Pijnappels, Kingma, Wezenberg, Reurink, & van Dieën, 2010). In addition, although arm swing would have a negative effect on balance at initial perturbation, the recovery actions of the arms still contribute to the overall gait stability (Bruijn, Meijer, Beek, & van Dieën, 2010). However, detailed investigation on how arm movements affect standing balance recovery using the stepping strategy has not been found.

Previous studies on regaining balance have focused on lower body extremities or recovery from small perturbations. Although considerable arm motions have been observed during stepping balance recovery, the effects of arms remain unclear and further investigation is necessary. For example, it is unknown whether movement time, step length, and/or ground reaction forces during balance recovery are affected by the use of arms. Thus, the purpose of this study was to examine how the arms