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Age-related changes in posture response under a continuous and unexpected perturbation

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ABSTRACT

Aging is a critical factor to influence the functional performance during daily life. Without an appropriate posture control response when experiencing an unexpected external perturbation, fall may occur. A novel six-degree-of freedom platform with motion control protocol was designed to provide a real-life simulation of unexpected disturbance in order to discriminate the age-related changes of the balance control and the recovery ability. Twenty older adults and 20 healthy young adults participated in the study. The subjects stood barefoot on the novel movable platform, data of the center of mass (COM) excursion, joint rotation angle and electromyography (EMG) were recorded and compared. The results showed that the older adults had similar patterns of joint movement and COM excursion as the young adults during the balance reactive-recovery. However, larger proximal joint rotation in elderly group induced larger COM sway envelop and therefore loss of the compensatory strategy of posture recovery. The old adults also presented a lower muscle power. In order to keep an adequate joint stability preventing from falling, the EMG activity was increased, but the asymmetric pattern might be the key reason of unstable postural response. This novel design of moveable platform and test protocol comprised the computerized dynamic posturography (CDP) demonstrate its value to assess the possible sensory, motor, and central adaptive impairments to balance control and could be the training tool for posture inability person.

1. Introduction

Maintaining a stable upright posture and balance either in static or dynamic requires an accurate organization of control nerve processing, sensory system, and motor coordination. The degeneration of central nerve system due to aging dulls the sensorimotor biofeedback which results in poor motor coordination and increases the risk of fall for the elderly (King and Tinetti, 1995; Rogers et al., 2003), particularly when experiencing a unexpected external disturbance (Gabell et al., 1985; Pavol et al., 2002; Maki and McIlroy, 2003). The mechanism of sensorimotor biofeedback must quickly respond to prevent the body from falling by initiating the joint rotation and muscle synergies. Ankle joint movement and its associate muscles are first activated to keep body balance, followed by activation of the knee and hip when the perturbation is getting larger (Horlings et al., 2009). With the age, the degeneration of sensorimotor feedback and muscle strength results in the inability of posture control, delayed response and lower power of corresponding muscles which increases the risk of fall for the elderly (Allum et al., 2002; Mansfield and Maki, 2009).

In order to differentiate among the many defects and impairments which may affect the posture control and balance ability, the CDP with moving platforms and assessment protocols have been developed since Nashner et al. (1982). For the motor coordination assessment, the moveable platform can be perturbed either in anteroposterior translation or mediolateral translation (Horak and Nashner, 1986; Hughes et al., 1995; McIlroy and Maki, 1996; Brauer et al., 2002; Pavol et al., 2002; Mansfield and Maki, 2009; Wright and Laing, 2011) or sinusoidal tilting in pitch or roll rotation (Carpenter et al., 1999; Allum et al., 2002; Commissaris et al., 2002; Bakker et al., 2006; Horlings et al., 2009; Maeda et al., 2011). The CDP moving platform is not only applied for posture control assessment but also uses for the rehabilitation intervention for the subject with vestibular or neuropathy disorder (Nardone et al., 2010).

While the specific research objective of previous studies varied, the designs of platform movement were about the same with one degree of freedom moved at a time. It is hard to detect or to diagnose the risk of falling with a simple translation perturbation.

The aims of this study were: (1) to develop a real-life perturbation mentioned above by integrating and modifying the previous

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related disturbance designs; (2) to investigate the age-related changes in joint coordination and muscle activation during the balance recovery and its implication for fall prevention.

2. Methods

2.1. Participants

Twenty healthy young females (age: 23 ± 2 years; height: 1.62 ± 0.06 m; weight: 52.30 ± 4.42 kg) and 20 healthy elderly females (age: 66 ± 1 years; height: 1.54 ± 0.06 m; weight: 57.43 ± 8.20 kg) volunteered in this study. All subjects were right foot dominant (determined by ball kick test (Hoffman et al., 1998)) and without neurologic, musculoskeletal or other deficits which might influence the balance performance. Each subject gave written informed consent in accordance

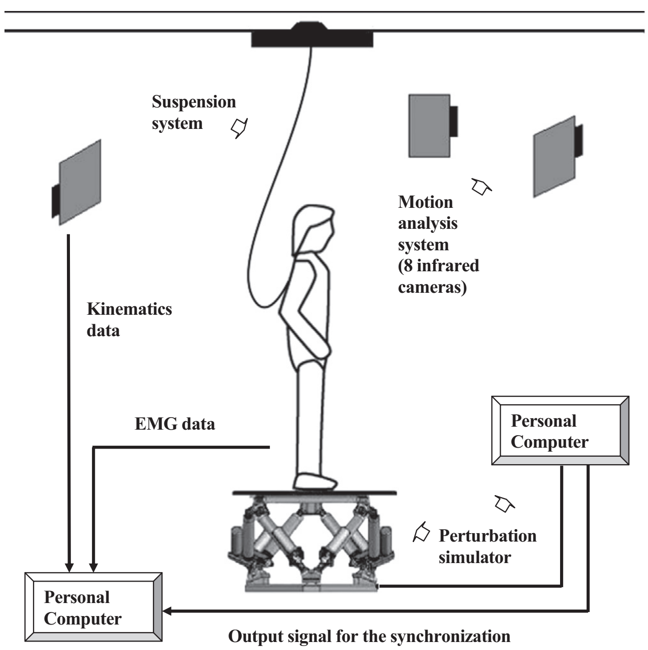

Fig. 1. Experimental setup for perturbation test.

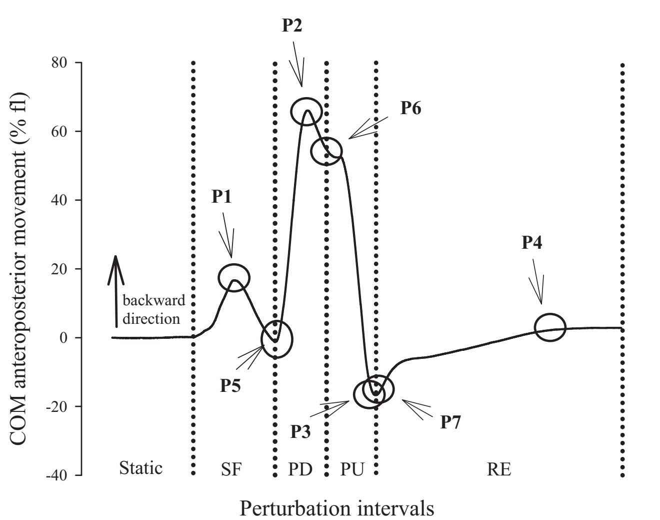

Fig. 2. Average profiles of normalized COM anteroposterior movement in young group. Seven distinctive points (thick solid circles) were selected according to kinematic and interval events during COM anteroposterior movement. SF, slip forward; PD, pitch downward; PU, pitch upward; RE, re-stabilization; fl, foot length; P1, peak point in SF interval; P2, peak point in PD interval; P3, peak point in PU interval; P4, recovery point during RE interval; P5, terminal point of SF interval; P6, terminal point of PD interval; P7, terminal point of PU interval.

with the institutional ethical review board by the Shin Kong Wu Ho-Su Memorial Hospital.

2.2. Perturbation simulator

The main hardware component of the perturbation simulator was a Stewart platform (dimension: 60 × 60 cm; DOF Technology, Inc., Taiwan; Fig. 1). The simulator was constructed with a moveable top steel platform, a fixed base steel platform and six ball screw rods actuated by electro-mechanical servos in six degrees of freedom (Stewart, 1965). The motion of the platform was programmed to provide an unexpected and continuous perturbation consisting of four sequential intervals: (1) SF interval: slip forward from zero to 109.22 ± 1.94 mm (CV, coefficient of variation = 1.7%) in 1000 ms; (2) PD interval: pitch downward from zero to 9.93 ± 0.12° (CV = 1.2%) together with slip forward from 109.22 ± 1.94 to 137.76 ± 1.84 mm (CV = 1.3%), total 633.33 ms; (3) PU interval: pitch upward from the end position of PD interval to zero degree together with slip backward from 137.76 ± 1.84 to 110.72 ± 1.87 mm (CV = 1.7%), total 637.5 ms; (4) RE interval: re-stabilization from the perturbation with no movement for 3000 ms (Beckly et al., 1991; Hughes et al., 1995; Commissaris et al., 2002; Mansfield et al., 2007; Tokuno et al., 2010; Maeda et al., 2011; Wright and Laing, 2011).

2.3. Experimental protocol

Before the perturbation trial, each subject was required to complete a muscle strength measurement and a maximal manual muscle testing (MMT) by the same examiner. Verbal encouragement and practice were given for both tests. Bilateral isokinetic knee flexion and extension from 0° (full extension) to 110° at a velocity of 60°/s and 15° of ankle plantar flexion to 45° of ankle dorsi flexion at a velocity of 30°/s were assessed using the Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Inc., USA) to collect muscle strength data including peak torque to

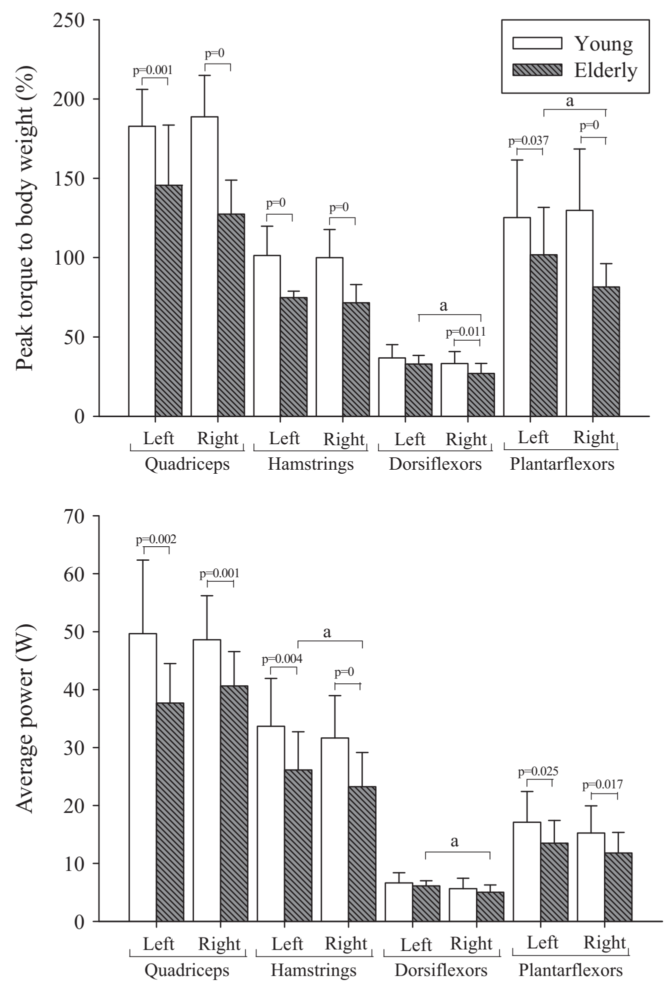

Fig. 3. Average group differences in bilateral (a) muscle peak torque to body weight and (b) average power between young and elderly groups. Values are presented as mean ± standard deviation. [a]Significant difference compared to corresponding contralateral extremity within group ($p < 0.05$).