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Effect of the muscle coactivation during quiet standing on dynamic postural control in older adults

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ABSTRACT

Recently, several studies have reported that muscle coactivation during static postural control increases with aging. Although greater muscle coactivation during quiet standing enhances joint stability, it may reduce dynamic postural control. The purpose of this study was to investigate the effect of muscle coactivation during quiet standing on dynamic postural control. Seventy older adults (81.1 ± 7.2 years) participated in this study. Static postural control was evaluated by postural sway during quiet standing, whereas dynamic postural control was evaluated by the functional reach and functional stability boundary tests. Electromyography of the soleus (SOL) and tibialis anterior (TA) was recorded during quiet standing, then coactivation was evaluated using the co-contraction index (CI). We used multiple regression analysis to identify the effect of muscle coactivation during standing on each dynamic postural control variable using age, body mass index (BMI), gender, timed up and go (TUG) tests, postural sway area and CI during quiet standing as independent variables. TUG tests were added to the model to evaluate the effect of functional mobility on dynamic postural control with a fixed base. The multiple regression analysis revealed that CI during standing was significantly related to all of the dynamic postural control tasks. The functional reach distance was significantly associated with CI during standing, age and TUG ($p < 0.05$). The functional stability boundary for forward and backward were associated only with CI during standing ($p < 0.05$). This study revealed that muscle coactivation during quiet standing is independently associated with dynamic postural control abilities.

1. Introduction

Both static and dynamic postural controls are fundamental components of human activity. Aging has been associated with deterioration in postural control, manifesting itself by an increase in postural sway as static postural control (Era & Heikkinen, 1985; Shumway-Cook, Baldwin, Polissar, & Gruber, 1997) or a decrease in the voluntary movement capacity of the body's center of gravity (COG) as dynamic postural control (Duncan, Studenski, Chandler, & Prescott, 1992; Slobounov, Moss, Slobounova, & Newell, 1998). Deterioration in these functions leads to a higher risk of falling, which in turn may increase the number of bedridden persons (Duncan et al., 1992; Lord, Clark, & Webster, 1991).

Several studies have reported age-associated increases in muscle coactivation during dynamic movements (*i.e.* walking and stair climbing) (Hortobagyi et al., 2009; Schmitz, Silder, Heiderscheit, Mahoney, & Thelen, 2008) and postural control (Allum, Carpenter, Honegger, Adkin, & Bloem, 2002; Ge, 1998; Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989; Melzer, Benjuya, & Kaplanski, 2001; Nagai, Yamada, Uemura, Yamada, et al., 2011; Tang & Woollacott, 1998; Tucker, Kavanagh, Barrett, & Morrison, 2008). Increased muscle coactivation in older adults is often described as a compensatory mechanism to increase joint stiffness that thereby enhances joint and postural stability (Manchester et al., 1989; Melzer et al., 2001; Tucker et al., 2008). On the other hand, some researchers have pointed out negative effects of coactivation on postural control and movement, observing that excessive muscle coactivation increases postural rigidity and might restrict dynamic postural control. A rigid posture induced by strong muscle coactivation reduces flexibility (Ge, 1998; Tucker et al., 2008) and may compromise the ability to adjust to unexpected perturbations (Allum et al., 2002). This could increase the risk of falling (Hortobagyi et al., 2009).

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Previously, we demonstrated that muscle coactivation at the ankle joint during quiet standing and dynamic postural control in older adults is greater than those of young adults. Additionally, the decline of dynamic postural control ability has been correlated with increased muscle coactivation during task performance (Nagai, Yamada, Uemura, Yamada, et al., 2011; Nagai et al., 2012). Hsiao-Wecksler et al. (2003) have reported that sway of the center of pressure (COP) during quiet standing relates to dynamic postural control ability. In upright postural control, active COP movement during dynamic postural control starts generally from quiet standing. Hence, muscle coactivation during quiet standing can also influence dynamic postural control similarly to, but not identically with, muscle coactivation during dynamic postural control tasks. However, little has been reported on the effect of muscle coactivation during quiet standing on dynamic postural control. Clarification of this relationship would be helpful to developing optimal rehabilitation strategies that improve dynamic postural control ability in older adults. The purpose of this study was to investigate the effect of muscle coactivation during quiet standing on dynamic postural control.

2. Materials and methods

2.1. Participants

Resident and community dwelling older adults were recruited using advertising literature and oral announcements by research staff and staff members in nursing homes. Seventy older adults (56 residents, 14 community dwellers; 11 males, 59 females; mean age = 81.1 ± 7.2 years) participated in this study (Table 1). Because of gender proportion in the nursing home residents, the number of male participants was relatively small. Subjects were excluded if they had neurological impairment (stroke, Parkinson's disease, paresis of the lower limbs), severe cardiovascular disease, severe cognitive impairment (Rapid Dementia Screening Test score of four points or less (Kalbe, Calabrese, Schwalen, & Kessler, 2003)), persistent joint pain, or musculoskeletal impairment. Each subject gave informed consent indicating their agreement with the study protocol. This research was approved by the Ethical Review Board of Kyoto University Graduate School of Medicine, Kyoto, Japan.

2.2. Testing procedures and protocol

To measure static postural control ability, which reflects movement of the COG in a quiet situation (Era & Heikkinen, 1985), we performed tests for postural sway during quiet standing. To measure dynamic postural control ability involving active COG movement capacity in the base of support (Slobounov et al., 1998), we carried out functional reach and functional stability boundary tasks.

Table 1
Characteristics of subjects (mean ± SD).

Characteristic	n = 70
Physical characteristics	
Age, mean ± SD (range)	81.1 ± 7.2
Female (%)	84.3
Height (cm)	151.4 ± 6.4
Weight (kg)	52.2 ± 7.0
BMI	22.9 ± 3.5
Physical performance	
Postural sway area (cm^2)	1.7 ± 1.03
Functional reach (cm)	20.9 ± 7.9
Functional stability boundary (forward) (%)	25.5 ± 9.7
Functional stability boundary (backward) (%)	18.4 ± 4.6
Walking speed (m/s)	0.9 ± 0.3
TUG test (s)	9.7 ± 5.2

2.2.1. Postural sway

Postural sway during quiet standing was measured with a force plate (Kistler 9286 force platform, Kistler Instruments Inc., Amherst, NY). Signals were sampled at 20 Hz and processed by a low pass filter (6 Hz cut off frequency). Subjects were instructed to stand with their feet together as symmetrically as possible. Quiet standing balance was registered for a period of 10 s, from which the root mean square (RMS) area of the COP was calculated. The intraclass correlation coefficient ($ICC_{1.1}$), calculated from two immediately repeated tests, for the RMS area was 0.72. Electromyographic (EMG) measurements of the SOL and TA were collected for three seconds, starting just after the standing posture stabilized. The EMG data recording period of three seconds is widely used for tasks with isometric muscle contraction. The testing reliability was confirmed previously (Nagai, Yamada, Uemura, Yamada, et al., 2011).

2.2.2. Functional reach

The functional reach test (Duncan, Weiner, Chandler, & Studenski, 1990; Duncan et al., 1992) measures the distance that subjects are able to reach forward while maintaining a fixed base. The position of the fingertip is determined with the shoulder of the subject flexed at 90° along a wall. The subjects then were instructed to reach as far forward as possible without moving their feet, thus moving the COG forward over a fixed base, and keep their position for 3 s. Functional reach was defined as the difference between arm's length and maximal forward reach. After a trial, the test was performed once.

2.2.3. Functional stability boundary

Functional stability boundary tasks were performed on the force plate (Slobounov et al., 1998). The subjects were instructed to stand with their heels positioned on a line 10 cm anterior to the posterior edge of the plate. The subjects were instructed to stand still for 5 s and then to shift their body weight first toward their toes and then toward their heels over the largest possible amplitude. They were further instructed to maintain full contact between their feet and the plate (avoiding toes off or heels off). For each direction (forward and backward), the subject maintained his/her posture for 3 s, from which the averaged COP displacement from the initial position was calculated. The COP displacement for each subject was normalized individually to the length of that subject's foot. After a trial, the test was performed once. The $ICC_{1.1}$ for the functional stability boundary tests were 0.95 for forward and 0.94 for backward in this study.

2.2.4. Additional physical performance test

The 10 m walking test and TUG test (Shumway-Cook, Brauer, & Woollacott, 2000) were performed without EMG monitoring. Subjects were asked to perform walking trials at their preferred speed. The walking speed (m/s) was calculated from the 10 m walking time.

2.3. EMG recording

EMG data were collected by sampling at 1500 Hz using the Telemyo 2400 (Noraxon USA Inc., Scottsdale, AZ). The skin of the dominant leg was shaved over the fibular head, TA, and SOL (Melzer et al., 2001) and then washed with alcohol. Bipolar surface electrodes (Ambu, Blue sensor M, Denmark) with a 2.0 cm inter-electrode distance were placed on the skin around the probable motor point of the muscles (Hermens). The ground electrode was affixed to the skin over the fibular head of the dominant leg.

EMG activity was recorded from the SOL and TA while the subjects were performing maximal voluntary contractions (MVCs). The MVC of the SOL was obtained during maximal isometric