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Differences in muscle coactivation during postural control between healthy older and young adults

Koutatsu Nagai [a,*], Minoru Yamada [a], Kazuki Uemura [a], Yosuke Yamada [b], Noriaki Ichihashi [a], Tadao Tsuboyama [a]

[a] Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan
[b] The Fukuoka University Institute for Physical Activity, 1-19-8 Nanakuma, Jyonanku, Fukuoka 814-0180, Japan

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ABSTRACT

The purpose of this study was to clarify the difference in muscle coactivation during postural control between older and young adults and to identify the characteristics of postural control strategies in older adults by investigating the relationship between muscle coactivation and postural control ability. Forty-six healthy older adults (82.0 ± 7.5 years) and 34 healthy young adults (22.1 ± 2.3 years) participated. The postural tasks selected consisted of static standing, functional reach, functional stability boundary and gait. Coactivation of the ankle joint was recorded during each task via electromyography (EMG). The older adults showed significantly higher coactivation than the young adults during the tasks of standing, functional reach, functional stability boundary (forward), and gait ($p < 0.01$). Postural sway area ($\rho = 0.42$, $p < 0.05$) and functional reach distance ($\rho = -0.52$, $p < 0.05$) significantly correlated with coactivation during the corresponding task in older adults, i.e., muscle coactivation was significantly higher in the elderly with low postural control ability than in the elderly with high balance ability. Increased muscle coactivation could be a necessary change to compensate for a deterioration in postural control accompanying healthy aging. Further research is needed to clarify in greater detail positive and negative effects of muscle coactivation on postural control.

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1. Introduction

Appropriate temporal separation between agonist and antagonist activation of muscles has been observed for well-controlled voluntary movements (Fujii et al., 2009). In clinical situations, however, this separation is attenuated, muscle coactivation is increased, and motor control becomes poor (Dierick et al., 2002). Even with normal aging, greater coactivation is induced during single-joint movements (Klein et al., 2001; Macaluso et al., 2002) and gait (Mian et al., 2006; Hortobagyi et al., 2009) in the elderly. Greater muscle coactivation, in turn, increases the metabolic cost of gait (Mian et al., 2006), which can cause fatigue and shorten activity duration.

Although several studies have reported age-associated increases in muscle coactivation during dynamic movements (Schmitz et al., 2008; Hortobagyi et al., 2009), limited information is available regarding muscle coactivation under static postural control (Melzer et al., 2001). Increased muscle coactivation in older subjects is most commonly described as a compensatory mechanism to increase joint stiffness that thereby enhances stability (Baratta et al., 1988; Solomonow et al., 1988; Hortobagyi and DeVita, 2000). Older adults may walk with high muscle coactivation as a balance-maintaining strategy in response to perturbations during dynamic movement (Manchester et al., 1989). If the high muscle coactivation is induced in order to maintain postural balance, this elevation should be observed even in static postural control and should be associated with the level of postural control ability.

Both static and dynamic postural controls are necessary during activities of daily living. Aging has been associated with deterioration in postural control, which manifests itself by an increase in postural sway (Era and Heikkinen, 1985), a decrease in reach distance (Duncan et al., 1992), and a decrease in capacity for locomotion (Oberg et al., 1993). Deterioration in these functions leads to a higher risk of falling, which may increase the number of bedridden persons (Lord et al., 1991; Duncan et al., 1992). However, the relationship between muscle coactivation and balance ability has not been clarified. Clarification of this relationship would be helpful to developing optimal rehabilitation strategies for older people.

The purpose of this study was to clarify the differences in muscle coactivation during postural control between older and

* Corresponding author. Tel.: +81 75 751 3935; fax: +81 75 751 3948.
E-mail address: k.nagai@ky2.ecs.kyoto-u.ac.jp (K. Nagai).

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young adults and to identify the characteristics of postural control strategies in older adults by investigating the relationship between muscle coactivation and postural control ability. We hypothesized that muscle coactivation during postural control in older adults is higher than that in young adults. We also hypothesized that muscle coactivation relates to postural control ability in young and older adults.

2. Subjects and methods

2.1. Participants

Forty-six healthy older adults (10 males, 36 females; age, 82.0 ± 7.5 years) and 34 healthy young adults (14 males, 20 females; age: 22.1 ± 2.3 years) participated in this study (Table 1). Oral and written explanations of the study were offered to participants. Subjects were excluded if they had acute neurological impairment (stroke, Parkinson's disease, paresis of the lower limbs), severe cardiovascular disease, severe cognitive impairment: rapid dementia screening test score is of four points or less (Kalbe et al., 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

The postural tasks selected for testing consisted of static standing, functional reach, functional stability boundary (forward and backward), and gait because similar movements are performed frequently during activities of daily living.

2.2.1. Postural sway

Postural sway during static 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). The participants were required to stand on a force plate with their feet together and then asked to gaze at a mark at eye level. Subjects were instructed to stand still as symmetrically as possible. Static standing balance was registered for a period of 10 s, from which the root mean square (RMS) area was calculated. EMG was measured for 3 s starting at the beginning of static standing.

2.2.2. 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 their posture for 3 s for EMG measurements, from which the averaged peak center of pressure (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.

Table 1
Physical characteristics of the subjects, n, mean ± S.D., or %.

Parameters	Elderly	Young
Number	46	34
Age (years)	82.0 ± 7.5	22.1 ± 2.3
Female (%)	58.8	78.3
Height (cm)	151.3 ± 6.8	164.6 ± 7.9
Weight (kg)	51.9 ± 6.6	56.7 ± 8.0

2.2.3. Functional reach

The functional reach test (Duncan et al., 1990, 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 center of gravity forward over a fixed base. Additionally, the subjects were instructed to keep their position for 3 s for EMG measurements. Functional reach was defined as the difference between arm's length and maximal forward reach.

2.2.4. Gait

Subjects were asked to perform walking trials at their preferred speed over a 12-m walkway. The examiner measured the time and the number of steps for the middle 10-m. A single trial was conducted following instruction. Walking speed (m/s) and step cadence (steps/min) were calculated as variables. EMG was analyzed for three gait cycles as determined from signals from the foot switch sensors (Noraxon USA Inc., Scottsdale, AZ) during the one gait trial.

2.2.5. Additional physical function characteristics

The timed up and go test (TUG) (Shumway-Cook et al., 2000) and the timed one-leg standing test for the dominant leg with eyes open were performed without EMG monitoring. The maximum duration of the one-leg standing test was set at 30 s.

2.3. EMG recording

EMG data were collected with the Telemyo 2400 (Noraxon USA Inc., Scottsdale, AZ). The skin of the dominant leg was shaved over the fibula head, tibialis anterior (TA), and soleus (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, 2011). The ground electrode was affixed to the skin over the fibula head of the dominant leg. The EMG data were sampled at 1500 Hz.

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 plantar flexion, and maximal TA activation was recorded during maximal isometric dorsiflexion of the ankle at 90° (anatomically neutral position). Strong verbal encouragement was given during every contraction to promote maximal effort. The EMG data from the MVCs were used to normalize the EMG amplitude (%MVC) during the postural tasks.

2.4. Muscle coactivation analysis

The original raw EMG signal was band-pass filtered at 20–500 Hz. We computed the root mean-square amplitude of the signal using a 50-ms window. The EMG of each muscle was then expressed as a percentage of the EMG value during the MVC.

To evaluate the relative level of co-contraction of the TA and SOL muscles, the co-contraction index (CI) was calculated using the method of Falconer and Winter (Falconer and Winter, 1985). Specifically, the following equation was used:

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