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Ankle muscle coactivation during gait is decreased immediately after anterior weight shift practice in adults after stroke

Ryosuke Kitatani [a,b,*], Koji Ohata [a], Kaoru Sakuma [a,c], Yumi Aga [d], Natsuki Yamakami [e], Yu Hashiguchi [a,b], Shigehito Yamada [a]

[a] Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan
[b] Japan Society for the Promotion of Science, Tokyo, Japan
[c] Department of Rehabilitation Sciences, Kansai University of Welfare Sciences, Osaka, Japan
[d] Aijinkai Rehabilitation Hospital, Osaka, Japan
[e] Fujita Health University Hospital, Aichi, Japan

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ABSTRACT

Increased ankle muscle coactivation during gait has frequently been observed as an adaptation strategy to compensate for postural instability in adults after stroke. However, it remains unclear whether the muscle coactivation pattern increases or decreases after balance training. The aim of this study was to investigate the immediate effects of balance practice on ankle muscle coactivation during gait in adults after stroke. Standing balance practice performed to shift as much weight anteriorly as possible in 24 participants after stroke. The forward movement distance of the center of pressure (COP) during anterior weight shifting, gait speed, and ankle muscle activities during 10-m walking tests were measured immediately before and after balance practice. Forward movement of the COP during anterior weight shifting and gait speed significantly increased after balance practice. On the paretic side, tibialis anterior muscle activity significantly decreased during the single support and second double support phases, and the coactivation index at the ankle joint during the first double support and single support phases significantly decreased after balance practice. However, there were no significant relationships between the changes in gait speed, forward movement of the COP during anterior weight shifting, and ankle muscle coactivation during the stance phase. These results suggested that ankle muscle coactivation on the paretic side during the stance phase was decreased immediately after short-term anterior weight shift practice, which was not associated with improved gait speed or forward movement of the COP during anterior weight shifting in adults after stroke.

1. Introduction

Gait is a fundamental component of activities of daily living, and regaining the ability to walk is a major goal of stroke rehabilitation for adults with hemiplegia [1]. Common characteristics of hemiplegic gait are decreased gait speed [2], asymmetrical gait pattern [2], and increased energetic cost [3]. These gait dysfunctions are mainly caused by impaired function of the paretic lower limb due to muscle weakness [4], sensory dysfunction [4], and disturbed control of lower limb muscle activation [5,6]. One of the well-documented muscle activation patterns during gait after stroke is a coactivation pattern of several lower limb muscles [5,6].

Postural control ability is strongly related to gait speed, and balance training is found to improve postural control ability and gait speed in adults after stroke [7]. It is well documented that improvements in postural control following balance training are accompanied by adaptations within the central nervous system [8]. These adaptations of neuromuscular properties are represented as changes in lower limb muscle activation during postural tasks [8–10]. Balance training has been shown to lead to decreased antagonist muscle coactivation in healthy young adults [9]. In healthy older adults, an enhancement in balance performance was concurrently observed with decreased muscle coactivation after balance training [10]. These previous results suggest that

* Corresponding author at: Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, 53, Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan. Tel.: +81 75 751 3935; fax: +81 75 751 3948.
E-mail address: kitatani.ryosuke.88x@st.kyoto-u.ac.jp (R. Kitatani).

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decreased muscle coactivation is helpful for improving balance performance in healthy subjects.

Increased ankle muscle coactivation on both the paretic and non-paretic sides during gait is frequently observed in adults after stroke [3,11–13], and it has both positive and negative effects on functional performance. Lower limb muscle coactivation is an important postural control mechanism that contributes to enhancement of postural stability during the weight acceptance phase in healthy subjects [14], and difficulty of postural control has been shown to lead to increased ankle muscle coactivation during beam walking in healthy subjects [15]. Therefore, increased ankle muscle coactivation during gait represents an adaptation strategy to compensate for postural instability in adults after stroke [11,13], and it may be possible to improve gait function using this compensation strategy by increasing ankle muscle coactivation after balance training in adults after stroke. However, excessive muscle coactivation induces high joint stiffness, which reduces the degrees of freedom for postural control [16], and induces a high energetic cost during gait in adults after stroke [3]. Therefore, a decrease in ankle muscle coactivation after balance training may indicate efficient improvement in gait speed in adults after stroke. However, no previous studies have investigated the changes in ankle muscle coactivation during gait after balance training in adults after stroke. It is important to investigate whether the muscle coactivation pattern increases or decreases after balance training for clarifying the mechanisms by which balance training may improve gait speed in adults after stroke.

The aim of the present study was to investigate the immediate effects of short-term balance practice on gait speed and ankle muscle coactivation during gait in adults after stroke. We hypothesized that ankle muscle coactivation during gait would decrease, associated with improvements in gait speed after balance practice.

2. Methods

2.1. Subjects

Twenty-four community-dwelling subjects with chronic hemiplegia after stroke (age 57.8 ± 9.9 years, height 164.3 ± 9.5 cm, weight 62.2 ± 9.8 kg, 15 men, time post-stroke 4.7 ± 4.3 years, 14 right side affected) and age- and sex-matched nine healthy control subjects (55.8 ± 3.9 years, 165.0 ± 8.5 cm, 60.4 ± 10.5 kg, 6 men) participated in the present study. Inclusion criteria of the participants after stroke were (1) a single stroke >6 months prior to this study, (2) no history of neurological diseases (e.g., parkinsonism and ataxia) or rheumatic or orthopedic conditions that could interfere with gait, (3) the ability to walk independently without an ankle-foot orthosis for at least 10 m, and (4) no difficulty understanding experimental tasks due to cognitive problems. None of the control subjects had a neurological or orthopedic disorder or apparent gait abnormality. All subjects provided informed consent prior to initiating this study. All procedures were approved by the ethics committee of Kyoto University Graduate School and the Faculty of Medicine, and were consistent with the Declaration of Helsinki.

2.2. Measurement set-up and procedures

Before data measurements, all participants walked on a 10-m walkway several times for a warm-up. After the warm-up session, all participants performed the 10-m walking tests without an ankle-foot orthosis immediately before and after balance practice. All participants were asked to walk on a 10-m walkway, with a 2-m distance for acceleration and deceleration, at a comfortable speed with or without a cane. All healthy controls were asked to walk slowly on the walkway to match the gait speed of participants after familiarization with walking slowly. We calculated the gait speed (m/s) by averaging the outcomes of each of 2 walking tests.

2.3. Balance practice procedure

Balance practice was performed with anterior weight shifting during standing without an ankle-foot orthosis because a forward movement of body weight is a fundamental component of gait [17]. Furthermore, adults after stroke have reported that shifting weight is more challenging in the forward direction than in the lateral direction on the paretic side during standing [18].

To estimate the immediate effects of balance practice on the performance of anterior weight shifting, all participants performed quiet standing for 5 s and anterior weight shifting for 5 s immediately before and after balance practice. During anterior weight shifting, the participants were encouraged to shift as much weight anteriorly as possible and maintain this forced position for 5 s. The center of pressure (COP) position was recorded during quiet standing and anterior weight shifting using a platform (Win-pod; Medicapteurs SA, Toulouse, France) that measured foot pressure at a sampling rate of 20 Hz. Participants stood on the platform with a foot position of 0.17 m between heel centers and an angle of 14 degrees between the long axes of the feet [19]. The distances between the average COP position during quiet standing and during anterior weight shifting in the anterior-posterior direction were calculated before and after balance practice. These distances were expressed as percentages relative to foot length.

Anterior weight shift practice was also performed on a platform. Participants stood quietly on the platform for 5 s and were then encouraged to shift as much weight anteriorly as possible and maintain this forced position for 5 s. They used biofeedback of the COP position to shift as much weight anteriorly and symmetrically as possible (Fig. 1). This protocol was repeated 5 times for each training block. Four blocks of balance practice, for a total of 20 weight shifts, were conducted with 1-min resting periods in a sitting position among each block and supervised by experienced physical therapists. All blocks of balance practice and measurements were conducted for approximately 20–25 min.

2.4. Data recording and analysis during gait

Electromyography (EMG) signals were recorded during the 10-m walking tests using a TeleMyo system (Noraxon USA Inc., Scottsdale, AZ, USA) at a sampling rate of 1500 Hz. Each subject's skin was carefully cleaned with alcohol to reduce impedance, and then bipolar Ag-AgCl surface electrodes (BlueSensor M, Ambu A/S, Ballerup, Denmark) were placed on the skin over the tibialis anterior (TA) and lateral gastrocnemius (LG) muscles on both the paretic and non-paretic sides in participants after stroke and on the right side in healthy controls. Electrode placement was based on SENIAM project recommendations (http://www.seniam.org).

Raw EMG signals were initially band-pass filtered at 10–500 Hz, and then full-wave rectified. EMG signals were time-normalized to 100% of each side's gait cycle. Ten gait cycles were used to determine the EMG parameters for each individual muscle before and after balance practice. EMG amplitudes were normalized by the average amplitude of each muscle over the entire gait cycle before balance practice because this normalization method has been considered feasible and reliable for normalizing EMG data during gait in adults after stroke [20,21]. The magnitude of agonist–antagonist muscle coactivation at the ankle joint (TA–LG coactivation) was quantified with the coactivation index (CoI) using the normalized EMG [12,21]. The CoI was calculated from the area of TA–LG overlap (i.e., the area of lower antagonistic muscle activity) divided by the number of data points (Fig. 2A) [12]. Two triaxial accelerometers (TeleMyo system; Noraxon USA Inc.)