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Original Article

Peroneus longus muscle exhibits pre-programmed anticipatory activity before unilateral abduction of the lower limb while standing: a pilot study

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Abstract. [Purpose] This study aimed to develop a method for assessing anticipatory postural adjustments associated with voluntary movements in individuals with functional ankle instability. We examined whether the peroneus longus muscle exhibits anticipatory activation before unilateral abduction of the lower limb in individuals without disability. [Participants and Methods] Twelve healthy young adults participated in this study. Participants maintained a standing posture with 95 ± 2.5% of their weight on the left side and with the thenar of their right foot in contact with a small wooden board fixed to a force platform. Thereafter, they abducted their right lower limb by approximately 35° at maximum speed; during this time, electromyographic activities of the focal and postural muscles were recorded. [Results] The peroneus longus, external oblique, and erector spinae muscles on the left side of the body were activated before the right gluteus medius muscle, which is a focal muscle of abduction of the right lower limb. The activation timing of the left peroneus longus was the fastest among these postural muscles. [Conclusion] These findings suggest that the peroneus longus muscle plays an important role in anticipatory postural adjustments associated with unilateral abduction of the lower limb and that an ankle strategy is adopted in anticipatory postural adjustments during this task.

Key words: Anticipatory postural adjustments, Peroneus longus muscle, Electromyography

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INTRODUCTION

Functional ankle instability (FAI), defined as a tendency of the ankle to give way during normal activity[1)], has been reported to be the most common and serious residual disability following ankle sprains[2)]. Impaired postural control, a factor that contributes to the development of FAI[3)], has been demonstrated in individuals with FAI in previous studies that have examined their static balance control (e.g., maintenance of the single limb stance[4, 5)]) or compensatory postural adjustments (CPAs) to external postural perturbations such as support surface translation[6)].

Along with static balance control and CPAs, the ability to compensate postural disturbance associated with voluntary movements of the limbs and trunk is also required to adequately perform various movements while standing[7)]. For example,

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when individuals without disability move an arm while standing, the postural muscles of the lower limbs and trunk that control the standing posture are activated in advance of the focal muscles that move the arm rapidly[8]. This preceding activation of the postural muscles is believed to be adjusted by a preprogram selected in advance to moderate the effects of the forthcoming disturbance in the posture and equilibrium caused by voluntary movement[9, 10]. Many previous studies have demonstrated that this type of postural control, known as anticipatory postural adjustments (APAs), is impaired in individuals with musculoskeletal disorders, such as low back pain[11]. However, limited information is available regarding APAs in individuals with FAI.

Caulfield et al.[12] reported that individuals with FAI exhibit reduced activation of the peroneus longus muscle immediately before ground contact during jump landing, suggesting that changes in the central motor programming are likely to be important in the development of FAI[13]. This finding raises the possibility that APAs associated with voluntary movement, which is believed to be controlled by centrally preprogramed motor commands[9, 10], may also be impaired in individuals with FAI. Since previous studies on static balance control and CPAs have reported a predominance of hip strategy over ankle strategy in individuals with FAI[4–6], we assumed that individuals with FAI may exhibit deficits in the anticipatory activation of the peroneal muscles during voluntary movement while standing.

In order to test this hypothesis, voluntary movement tasks wherein preceding activation of the peroneal muscles is observed should be used. However, to our knowledge, no previous studies have reported such tasks. One possible task is the unilateral abduction of the lower limb, which requires changes in the standing posture from the double to the single limb stance and thus requires control of the inclination of the body in the frontal plane. It has been reported that postural muscles are activated in a distal-to-proximal sequence before voluntary lateral lift of a lower limb[14]. However, the activities of peroneal muscles have not been recorded in this previous study. Since the peroneal muscles reportedly contribute to lateral ankle stability during movements[15], the peroneus longus muscle may therefore be activated in advance of the focal muscles for adequate performance of unilateral abduction of the lower limb.

In this study, in order to develop a method for assessing the APAs in individuals with FAI, we first examined whether the peroneus longus muscle exhibits anticipatory activation before unilateral abduction of the right lower limb in individuals without disability. We presumed that, in addition to hip and trunk muscles, preceding activation in the left peroneus longus muscle was observed during unilateral abduction of the right lower limb.

PARTICIPANTS AND METHODS

Twelve healthy young adults (6 females and 6 males) aged 20–33 years, participated in this study. Their mean age, height, and weight were 21.7 years (standard deviation [SD]=3.6), 166.4 cm (SD=9.1), and 56.0 kg (SD=8.1), respectively. No participant had any history of neurological or orthopedic impairment. Following an explanation of the experimental protocols, all the participants provided written informed consent in accordance with the Declaration of Helsinki. This study was approved by the Ethics Committee of the Toyohashi SOZO University (approval number: H2009003).

All the measurements were performed with participants standing barefoot on 2 separate force platforms (G-6100, Anima, Tokyo, Japan) (Fig. 1). The force platforms were used to measure the vertical ground reaction forces on each foot and the positions of the center of pressure in the mediolateral and anteroposterior directions under both feet (CoPx and CoPy, respectively).

Electromyograms (EMGs) were recorded during abduction of the right lower limb using bipolar surface electrodes placed over the following muscles: right gluteus medius (rtGM) muscle as a focal muscle of abduction of the right lower limb, and left peroneus longus (ltPL), left tibialis anterior (ltTA), left medial head of gastrocnemius (ltGCM), left rectus femoris (ltRF), left vastus lateralis (ltVL), left biceps femoris (ltBF), left gluteus medius (ltGM), left tensor fasciae latae (ltTFL), left adductor longus (ltAL), left and right rectus abdominis (ltRA and rtRA), left and right erector spinae (ltES and rtES), and left and right external oblique (ltEO and rtEO) muscles as postural muscles. Electrodes were placed on the midportion of the muscle belly. The electrodes were aligned along the long axis of the muscle with an inter-electrode distance of approximately 2 cm. Electrode input impedance was <5 kΩ. The EMG signals from the electrodes were amplified (×2,000) and band-pass filtered (10–1,000 Hz) using an EMG amplifier (MEG-6116, Nihon Kohden, Tokyo, Japan). The EMG signals were recorded using a computer (FMV-C310, Fujitsu, Kanagawa, Japan) via an A/D converter (ADA16-32/2(CB)F, Contec, Osaka, Japan) with a sampling frequency of 2 kHz and 16-bit resolution using BIMUTAS®II-R software (Kissei Comtec, Japan).

The motion of the lower limbs and trunk in the frontal plane during abduction of the right lower limb was recorded using an 8-camera motion analysis system (VICON Motion System, Oxford, UK) with a sampling frequency of 120 Hz. The standard Plug-in-Gait marker protocol (35 reflective markers) was used. The Plug-in-Gait model processing was applied to reprocess all the kinematic data using Vicon Nexus 1.3 software (VICON Motion System, UK). A trigger signal was also recorded to synchronize the motion data with CoP and EMG signals.

In a preliminary experiment, the following problems were identified. First, in the case of abduction of the right lower limb from the double limb stance, the participants initially shifted their weight toward the left lower limb and then abducted their right lower limb. Therefore, we could not distinguish the activation of the postural muscles before abduction between the anticipatory activations and activations for the weight shift. Second, in the case of abduction of the right lower limb from the single limb stance, large background activities of the postural muscles, including ltPL, were observed to maintain the single limb stance. Correct identification of the burst onset of the postural muscles associated with abduction of the right lower limb was difficult owing to the presence of large background activities.

It has been reported that light fingertip contact with the surrounding objects remarkably reduces postural sway while standing[16]. We applied this finding to the current experiment. On the right side of the force platforms, a small wooden board (30 mm ×30 mm × 24 mm) was fixed, while another board (400 mm × 230 mm × 24 mm), with the same height as that on the right side, was fixed on the left side (Fig. 1). Distance between the medial borders of the 2 wooden boards was set at 10 cm. The participants maintained the standing posture with 95 ± 2.5% of their weight on the left side and with the thenar of their right foot in contact with the small wooden board (initial posture). In the case of abduction of the right lower limb from this initial posture, no apparent weight shift or large background activities of the postural muscles before abduction were observed. This procedure was selected for the current study.

Initially, CoPx and CoPy positions were measured for 10 s, while the participants maintained the initial posture on the force platforms with their hands placed in front of their navel. Five measurements were taken, with an intermittent 30-s period of seated rest. The average of the 5 measurements was used to indicate the participant's representative CoPx and CoPy positions during the initial posture.

Then, trials of unilateral abduction of the right lower limb were performed. The abduction angle of the right lower limb was approximately 35° with respect to the vertical line. After 15 practice trials, abduction was repeated 15 times. The activation timing of the postural muscles, with respect to the focal muscles, is reportedly influenced by the CoP position just before the voluntary movement[17, 18]. Therefore, in each trial, the participants maintained the CoPx and CoPy positions within a range of ± 1.5 cm of the initial posture positions, with 95 ± 2.5% of their weight on the left side, while hearing a buzzing sound generated by a computer (PP21L, Dell, Round Rock, TX, USA) connected to the force platforms. The participants started to abduct their right lower limb at their own timing within 3 s after the cessation of the buzzing sound. Participants abducted the limb at maximum speed and maintained the 35° abducted position of the limb for approximately 3 s before returning to the starting position. In previous studies examining APAs, voluntary movements were initiated at participant's own timing and/or in response to a response stimulus. It has been reported that preceding activation of postural muscles (i.e., APAs) is clearer in the own timing task than in the response task[17]. Since the aim of this study was to develop a voluntary movement task in which preceding activation of postural muscles, including PL, is observed, the own timing task was used in this study.

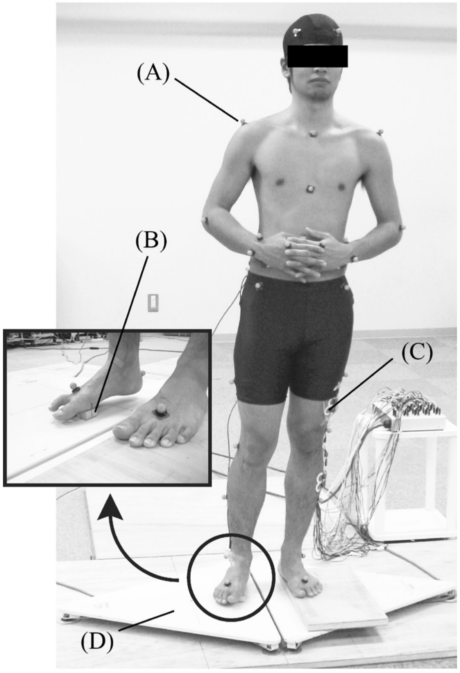

Fig. 1. Experimental setup and initial standing posture before unilateral abduction of the right lower limb.

(A) Reflective marker. (B) Small wooden board. (C) Surface electrode. (D) Force platform. Before abduction of the right lower limb, participants maintained the standing posture with 95 ± 2.5% of their weight on the left side and with the thenar of their right foot in contact with a small wooden board fixed to a force platform.

All the data were analyzed offline using Matlab software version R2011a (MathWorks, Natick, MA, USA). In order to exclude electrocardiogram and movement artifacts, the EMGs were high-pass filtered (20 Hz) using the third-order zero-phase Butterworth method and were full-wave rectified thereafter. None of the participants showed obvious preceding activation, with respect to rtGM, in ltTA, ltGCM, ltRF, ltVL, ltBF, ltAL, ltRA, rtRA, rtES, or rtEO. Those muscles were excluded from the analyses. The time course of the EMG burst of focal (rtGM) and postural muscles (ltPL, ltTFL, ltGM, ltES, and ltEO) in each trial was analyzed as follows. Burst onset of rtGM (T_0) was identified via visual inspection. For the postural muscles, the mean EMG amplitude over the period from −500 ms to −250 ms, with respect to T_0, was defined as the background activity. The EMG burst of the postural muscles that continued for at least 50 ms was determined within the period from −250 ms to +50 ms, with respect to T_0. The period was selected based on previous findings that suggested that the quickest monosynaptic reflexes could be observed after a perturbation in the time interval that is usually longer than +50 ms[9, 19]. The burst onset of the postural muscles was defined as the time at which the rectified EMG deviated more than mean +2SDs of the background activity. The time difference between the burst onset of the postural muscles and T_0 was calculated as the start time of the postural muscles and presented as a negative value when the burst onset was earlier in the postural muscles than in rtGM.

It has been suggested that postural equilibrium in the frontal plane is controlled by postural movements of the lower limbs and trunk[20]. Therefore, the positional data of the left hip joint and the vertebra prominens (C7) was used to assess postural movements of the left lower limb and trunk during abduction of the right lower limb. In order to examine the anticipatory changes in the postural movements, the positional data of the left hip joint and C7 in the frontal plane from −500 ms to +2,000 ms, with respect to T_0 was averaged separately for all trials. The baseline of the averaged positional data was defined as the mean position in the period from −500 ms to −250 ms (initial position) with respect to T_0. When the position moved toward the side opposite to lower limb abduction, the positional change was considered negative.

The mean value of the start times for all trials was calculated separately for each postural muscle and was used to the representative values for each participant. A single-group t-test was used to assess whether the start time of the postural muscles significantly preceded T_0. A single-group t-test was also used to assess whether the position of the C7 and left hip joint at T_0 differed significantly from the initial position. One-way repeated-measures analysis of variance (one-way ANOVA) was used to assess the effect of muscle (ltPL, ltTFL, ltGM, ltES, or ltEO) on the start time. A post-hoc multiple-comparison analysis was performed using Tukey's test to further examine the differences suggested by one-way ANOVA. Alpha level was set at $p<0.05$. All the statistical analyses were performed using PASW Statistics 18 software (SPSS, Chicago, IL, USA).

RESULTS

The percentage of trials wherein the EMG burst was observed in the range from −250 ms to +50 ms, with respect to T_0, was 96.9% (SD=6.0) in ltPL, 99.4% (SD=2.0) in ltTFL, 100% in ltGM, 99.4% (SD=2.0) in ltES, and 97.3% (SD=5.3) in ltEO.

Figure 2 shows representative EMG data. Preceding activations of ltPL, ltTFL, ltES, and ltEO, with respect to T_0, were observed in this trial. Figure 3 shows the start times of the postural muscles in reference to T_0. The start times of ltPL, ltES, and ltEO significantly preceded T_0 ($t_{11}>2.36$, $p<0.05$). A significant effect of muscle was observed for the start time ($F_{4,44}=17.0$, $p<0.001$). The start time of ltPL was significantly earlier than that of ltTFL, ltGM, ltES, and ltEO (ltPL vs. ltTFL, ltGM, and ltES, $p<0.001$; ltPL vs. ltEO, $p<0.01$). The start time of ltEO was significantly earlier than that of ltTFL and ltGM (ltEO vs. ltTFL, $p<0.01$; ltEO vs. ltGM, $p<0.05$).

Figure 4 shows group-averaged data of the abduction angle of the right lower limb (a), the position of the C7 (b), and the position of the left hip joint (c) in the frontal plane. The positions of C7 and left hip joint exhibited anticipatory changes toward the side opposite to lower limb abduction. The positions of the C7 and left hip joint at T_0 differed significantly from 0 (i.e., initial position) (C7: −5.4 mm ± 2.8 mm, $t_{11}=6.54$, $p<0.001$; left hip joint: −2.8 ± 2.7 mm, $t_{11}=3.40$, $p<0.01$).

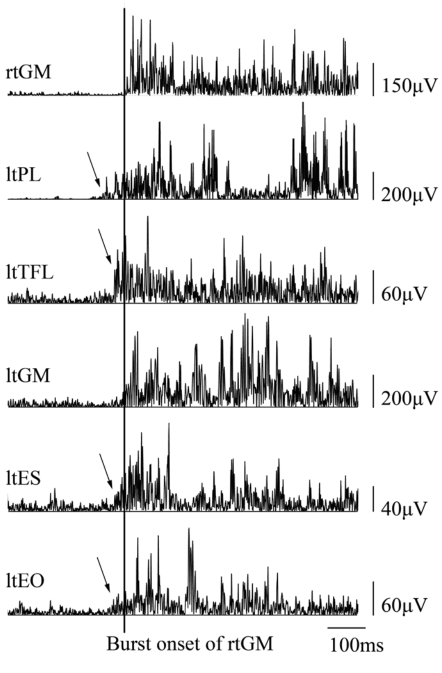

Fig. 2. Representative electromyographic data for the activity in a focal muscle (right gluteus medius [rtGM]) and postural muscles (left peroneus longus [ltPL], left tensor fasciae latae [ltTFL], left gluteus medius [ltGM], left erector spinae [ltES], and left external oblique [ltEO]) in a participant.

In this trial, ltPL, ltTFL, ltES, and ltEO were activated in advance of rtGM (black arrows). Burst onset of rtGM is indicated as a solid line.

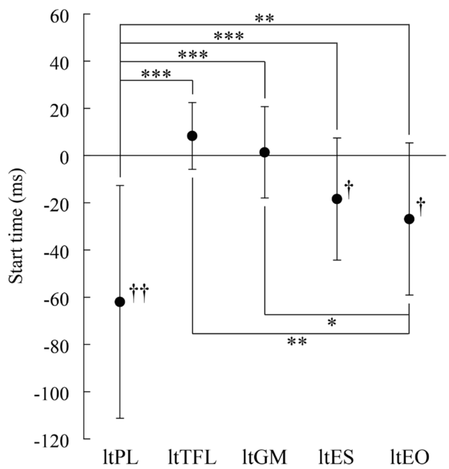

Fig. 3. Mean and standard deviations of the start times of the postural muscles (ltPL, ltTFL, ltGM, ltES, and ltEO) with respect to a focal muscle (rtGM).

A negative value means that the burst onset was earlier in the postural muscles than in rtGM. Values with a significant difference from zero (i.e., burst onset of rtGM) are indicated with daggers (†p<0.05, ††p<0.01). Significant differences in the start times of postural muscles are indicated with asterisks **p<0.01, ***p<0.001).

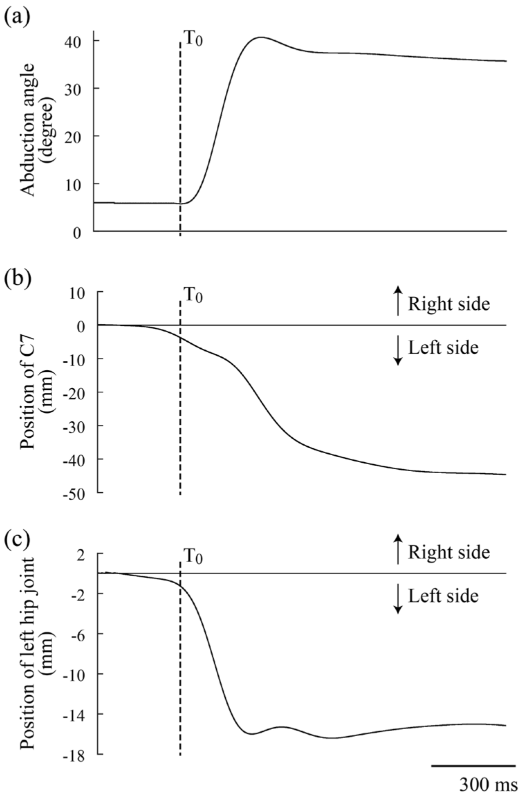

Fig. 4. Group-averaged data of the abduction angle of the right lower limb (a), the position of the C7 (b), and the position of left hip joint (c) in the frontal plane. Onset of abduction of the right lower limb (T_0) is indicated using dashed lines. When the positions of the C7 and left hip joint moved toward the side opposite to the unilateral abduction of the right lower limb, the positional change was considered negative. The positions of C7 and left hip joint exhibited anticipatory changes toward the side opposite to lower limb abduction.

DISCUSSION

No previous studies have reported voluntary movement tasks wherein the anticipatory activation of the peroneal muscles is observed with respect to focal muscles. For example, in unilateral arm abduction while standing at various stance widths, preceding activation, with respect to focal muscles of the arm abduction, is observed in ES, GM, and TFL on the side opposite to arm abduction, but not in PL and GCM[20]. Unlike the sagittal plane, the structural unit comprising the left and right lower limbs and the pelvis functions as a structural foundation for balance in the frontal plane[20]. This results in higher stability in the lower limbs in the frontal plane than in the sagittal plane. Previous studies on static balance control and CPAs in the frontal plane have also suggested that postural equilibrium in the mediolateral direction is primarily controlled by postural movements of the hip and trunk[21–24]. These findings suggest that, in the case of the human bipedal stance, postural equilibrium in the frontal plane is primarily controlled by the hip and trunk muscles.

In this study, we used unilateral abduction of the lower limb as a voluntary movement task, while participants maintained an initial standing posture with most of their weight on the supporting leg and with the thenar of the moving leg in contact with a small wooden board. Consequently, in addition to ltES and ltEO, ltPL exhibited anticipatory activation before abduction of the right lower limb. Since unilateral abduction of the right lower limb disturbs the equilibrium toward the right side of the body, it is likely that the activities of the postural muscles in the lower leg and trunk on the left side of the body are needed to maintain postural equilibrium. Since contraction of the peroneus longs muscle during standing (i.e., closed kinetic chain) inclines the body toward the lateral direction, the peroneus longs muscle in the supporting leg probably plays an important role in counteracting inclination of the body toward the side of the moving leg during unilateral abduction of the lower limb. In addition, based on the analyses of positional data of the left hip joint and C7, the lower limb and trunk moved toward the left side before abduction of the right lower limb. To compensate the effects of disturbance of posture and equilibrium caused by unilateral abduction of the lower limb, it appears that the postural muscles in the lower leg and trunk on the side opposite to abduction are activated in advance of the focal muscles and that postural movements of the lower limb and trunk occur toward the side opposite to abduction.

Previous studies on CPAs have demonstrated that ankle and hip strategies are used to maintain postural equilibrium without stepping in response to external perturbation[25]. The ankle strategy uses distal-to-proximal muscle activation, while the hip strategy uses early proximal hip and trunk muscle activation[26]. In the present study, the start times of the postural muscles with respect to rtGM were earlier in ltPL than in the hip and trunk muscles (i.e., ltTFL, ltGM, ltES, and ltEO). This indicates that the distal-to-proximal muscle activation pattern was used. Therefore, the ankle strategy may have been adopted in the APAs during abduction of the right lower limb.

The present findings suggest that the peroneus longus muscle plays an important role in the APAs associated with unilateral abduction of the lower limb while participants maintained the initial standing posture with most of their weight on the supporting leg. As mentioned in the Introduction section, previous studies on static balance control and CPAs have reported a predominance of hip strategy over ankle strategy in individuals with FAI[4–6]. Therefore, individuals with FAI may also show a predominance of hip strategy in APAs associated with voluntary movements and thus exhibit a reduction in the anticipatory activation of ankle muscles (e.g., the peroneal muscles) in advance of focal muscles. The method used in this study will be useful to test this hypothesis.

Funding and Conflict of interest

None.

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