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Original Research

The influence of foot position on lower leg muscle activity during a heel raise exercise measured with fine-wire and surface EMG

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ABSTRACT

Objective: Exercises for lower leg muscles are important to improve function. To examine the influence of foot position on lower leg muscle activity during heel raises.
Design: Cross-sectional laboratory study.
Setting: Laboratory.
Participants: Fourteen healthy men participated in this study.
Main outcome measures: The muscle activity levels of the tibialis posterior (TP), peroneus longus (PL), flexor digitorum longus (FDL) and medial gastrocnemius (MG) were measured. The heel raises consisted of three foot positions: 1) neutral, 2) 30° abduction, and 3) 30° adduction. The EMG data for five repetitions of each foot position were normalized to maximum voluntary contraction. One-way repeated measure ANOVA was employed for statistical analysis.
Results: The muscle activity level of TP, PL and FDL was significantly different between the three foot positions during the heel raises. TP and FDL showed the highest activity level in 30° foot adduction while PL demonstrated the highest activity level in 30° foot abduction.
Conclusions: Heel raises with 30° foot adduction and abduction positions can change lower leg muscle activity; These findings suggest that altering foot posture during the heel raise exercise may benefit patients with impaired TP, PL or FDL function.

1. Introduction

The mechanism of muscular stabilization plays an important role in controlling foot stability. To absorb the impact force and to transmit the propulsion force, the foot is required to alter its flexibility and rigidity. Muscular control is important in satisfying complex functional demands. Several lower leg muscles contribute to achieving reasonable stability and flexibility of the foot segments during weight bearing activities.

Lower leg muscles, such as tibialis posterior (TP), peroneus longus (PL), flexor digitorum longus (FDL) and gastrocnemius are fundamental and synergistic muscles that aid in controlling foot flexibility and rigidity while these muscles function to produce propulsion force (Kokubo et al., 2012; Murley, Buldt, Trump, & Wickham, 2009; Semple, Murley, Woodburn, & Turner, 2009). The activity pattern of TP shows two peaks when walking, one at the contact phase and one at the propulsion phase (Murley et al., 2009; Semple et al., 2009). These peak activities occur when TP resists excessive pronation and increases stiffness of the foot (Kamiya et al., 2012; Kokubo et al., 2012; Murley et al., 2009). On the other hand, PL tension reduces the stiffness of the foot but increases the energy dissipation rate and absorbs the loading force (Kokubo et al., 2012).

TP and PL have synergic function and control the subtalar joint as a supinator and pronator (Murley et al., 2009). FDL contracts isometrically to maintain the longitudinal arch while conserving the propulsion force during the stance phase of gait (Hofmann, Okita, & Sharkey, 2013). Functioning with these muscles, the gastrocnemius and soleus effectively produces the propulsion force.

Since insufficient activity of these muscles is associated with flat foot deformity, decreased stability of the foot, and an increased risk of injury (Johnson & Christensen, 1999; Kamiya et al., 2012; Neal et al., 2014), a variety of training procedures have been proposed in order to improve the function of the lower leg muscles. Heel raise is a popular exercise improving strength of the ankle plantar flexor

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muscles. Because TP, PL, FDL and the gastrocnemius function as an ankle plantar muscle, heel raise can activate these muscles. Previous studies reported the muscle activity levels of TP and PL during heel raises (Bellew, Frilot, Busch, Lamothe, & Ozane, 2010; Kulig, Burnfield, Requejo, Sperry, & Terk, 2004). However, heel raises were performed only in the neutral position in the horizontal plane in these studies. There is a possibility that foot posture alteration in the horizontal plane can change the muscle activity patterns of the lower leg muscles. There was no study that measured FDL muscle activity while performing heel raises. Thus, no previous studies were identified that compared muscle activity level of the lower leg muscles among several foot positions.

This study aimed to identify the influence of foot position and weight bearing points in the muscle activity level of TP, PL, FDL and the gastrocnemius muscles during heel raises. We hypothesized that heel raises with the foot in an abducted position with weight bearing on the first metatarsal phalangeal joint would further activate PL. Also with the foot in an adducted position with weight bearing on the fifth metatarsal phalangeal joint, TP and FDL will be increased. This is because the function of these muscles are eversion and abduction, and inversion and adduction, respectively.

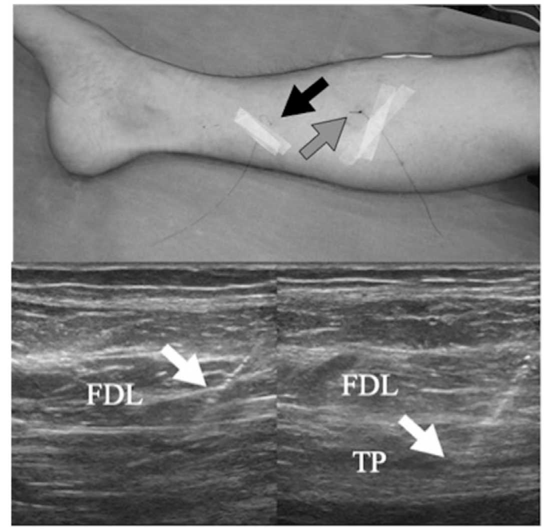

Fig. 1. Fine-wire insertion into the TP and FDL.
Gray arrow: fine-wire insertion into TP, Black arrow: fine-wire insertion into FDL, White arrow: inserted needle.

2. Materials and methods

2.1. Participants

Fourteen healthy men (age: 24 ± 5.1 years, height: 169.2 ± 5.9 cm, and weight: 63.1 ± 9.5 kg) who had no history of right leg injury for 6 months, no recent surgical treatment for the right leg within one year, and no neurological problems participated in this study. All participants were provided with and signed written informed consent forms prior to participation. The Ethical Committee of Waseda University University approved this experiment in accordance with the Helsinki Declaration.

2.2. Instrumentation

Bipolar fine-wire intramuscular electrodes (Unique medical, Japan) were used to measure muscle activity of TP and FDL. A Tefron coating covered the bipolar fine-wired intramuscular electrodes, except for the tips. The electrode wires were placed into 23-gauge sterilized needles, and the 3-mm and 5-mm tips were bent to hook into the muscle. Sterilization was performed in an autoclave prior to insertion. The electrode wires were inserted into the right TP and FDL muscle belly and guided by using an ultrasound system (LOGIQ e, GE, USA) (Fig. 1). To insert the fine-wire electrodes into TP, the posterior approach was employed (Murley et al., 2009; Won, Kim, Yoon, & Kim, 2011). Insertion point into TP is at the proximal one-third of the calf length. In the same way, insertion location to the right FDL was at the half distance between the tibial tubercle and the medial malleolus. To confirm the accurate insertion, the EMG amplitude was checked with active foot pronation, adduction and plantar flexion for TP and toes flexion for FDL. To measure PL and the medial gastrocnemius (MG) muscle activity, the surface electrodes (BlueSensor N-00-S, METS Co., Japan) were attached to the right of PL and medial head of gastrocnemius muscle belly, which were parallel to the muscle fiber, after rubbing the skin with an abrasive and alcohol to reduce skin impedance. Size of the surface electrodes was 8- mm diameter and the electrode distance was 20-mm. Placement of the electrodes followed the recommendation of SENIAM (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). For PL, electrodes were placed at upper one fourth on the line between the head of fibula and the lateral malleolus. For MG, electrodes were placed on the most prominent bulge of the muscle. Electrodes were placed parallel to the muscle fiber of the muscles. Both fine-wire and surface EMG were measured by using a wireless EMG telemeter system (BioLog DL-5000, S&ME Co., Japan). The sampling rate of the EMG data was 1000 Hz.

2.3. Measurement protocol

The heel raises consisted of three foot positions including a neutral position (normal heel raise), 30° of abduction (ABD heel raise), and 30° of adduction (ADD heel raise).

Normal heel raise. In the starting position, the hip, knee, and foot joints were in a neutral position and the toes were pointed forward. Participants were asked to place their weight underneath the first and fifth metatarsal phalangeal joint equally during the heel raises (Fig. 2 (a)).

ABD heel raise. The foot was positioned into 30° abduction. To confirm the angle, an arm of the goniometer was placed parallel to the floor tiles and the other arm was aligned parallel to the medial foot while performing a heel raise. However, the trunk, pelvis, and lower limb were retained in a neutral position as much as possible. The ABD heel raise consisted of placing the weight underneath the first metatarsal phalangeal joint. Participants were instructed to emphasize foot eversion during the heel-raise (Fig. 2(b)).

ADD heel raise. The foot was positioned into 30° adduction; confirmed by using a goniometer the same as ABD heel raise. Participants were asked to place their weight on the fifth metatarsal phalangeal joint and emphasize foot inversion during the heel raise (Fig. 2c).

Participants stood on their right foot during the heel raises. Participants were instructed to raise their heel as high as possible and lower the heel every one second, respectively. Participants performed ten heel raises in each of the three foot positions. An electrometronome was used to monitor the tempo. To help maintain balance, participants were allowed to place their fingertips of their left hand on the backrest of a chair, but leaning on the chair was prohibited. Sufficient practice was allowed for the participants to be familiar with each heel raise task. The order of each foot position was randomized and a one-minute resting period was allowed between each repetition set to minimize the possibility of muscle adaptation or fatigue influencing the measurements. The heel raises were recorded from the sagittal plane by using a high-