Comparison of ankle plantar flexor activity between double-leg heel raise and walking

HIROYUKI FUJISAWA, PT, PhD1, HIROTO SUZUKI, PT, MS1), TORU NISHIYAMA, PT, PhD1), MAKOTO SUZUKI, PT, PhD1)
1) Department of Rehabilitation, Faculty of Medical Science and Welfare, Tohoku Bunka Gakuen University: 6-45-1 Kunimi, Aoba-ku, Sendai 981-8551 Japan

Abstract. [Purpose] We aimed to evaluate the difference in the muscle activity between the double-leg heel raise (DHR) and treadmill walking. [Subjects] Thirty healthy males aged 21.5 ± 1.6 years (body mass 63.6 ± 9.3 kg, height 171.0 ± 4.5 cm) participated in the study. [Methods] Electromyograms were simultaneously recorded from both heads of the gastrocnemius and the soleus of the right side during the DHR and treadmill walking. The DHR conditions were maximum plantar flexion (MPF), 3/4 MPF, 2/4 MPF, and 1/4 MPF, and the walking speeds were 20, 40, 60, 80, and 100 m/min. [Results] The muscle activity during the DHR and walking significantly increased with increments in the height of the heel raise and walking speed, respectively. Comparison of the muscle activity at MPF with that at each walking speed revealed that the muscle activity in the soleus and gastrocnemius medial head during walking exceeded that during the DHR in less than 3.3% of cases. [Conclusion] The DHR test is useful for evaluating the ankle plantar flexor activity necessary for walking.

Key words: Double-leg heel raise, Walking, Plantar flexor

INTRODUCTION

The heel raise test is often used in a clinical setting to evaluate the function of the calf muscle. Muscle activities are increased during activities such as walking, running, and jumping. The standing heel raise, called the “calf raise”, is a commonly prescribed exercise for improving the strength and power of the ankle plantar flexors. In physical therapy, the strength of the ankle plantar flexors is also measured during one-footed standing1–7). However, the single-leg heel raise can be difficult for patients with ankle disorder and elderly people because of decreased balance function. Therefore, the double-leg heel raise (DHR) is potentially useful for the clinical evaluation of ankle plantar flexors8).

There have been few studies on the maximum plantar flexion (MPF) moment during the DHR. Flanagan9) reported that the MPF moment for older adults was 0.85 ± 0.18 Nm/kg during the DHR and 1.50 ± 0.23 Nm/kg during the single-leg heel raise. The strength of the plantar flexor muscles is particularly important for walking. The activity of the plantar flexor muscles increases during the single stance phase: from the mid-stance to terminal stance phase. Ishikawa10) indicated that tendinous tissues of both the soleus and gastrocnemius muscles slowly stretched during the single support phase and dramatically recoiled during the pre-swing phase, contributing to the storage of elastic energy. Akizuki et al.11) reported that the plantar flexor activity was 30% of the maximum voluntary contraction (MVC) during normal speed walking. However, little attention has been paid to the plantar flexor activity during walking in comparison with that during the calf raise. Therefore, in the present study, we aimed to evaluate the difference in the muscle activity between the DHR and walking.

SUBJECTS AND METHODS

Thirty healthy young males participated in this study (age 21.5 ± 1.6 years, weight 63.6 ± 9.3 kg, height 171.0 ± 4.5 cm). All the subjects provided written informed consent prior to participation, and the Human Subjects Ethics Committee of Tohoku Bunka Gakuen University approved the study.

The passive ROM of plantar flexion at the right ankle joint was measured with subjects in a supine position using a goniometer (TTM-KJ; Sakai Medical Co., Ltd., Tokyo, Japan). The active ROM of plantar flexion was measured in a standing position under weight-bearing conditions.

EMG data were simultaneously acquired from both heads of the gastrocnemius and the soleus muscle of the right leg during the DHR and treadmill walking. After shaving and scrubbing the skin with alcohol, disposable Ag/AgCl surface electrode discs with a diameter of 10 mm (Blue-Sensor N-00-S, Ambu, Copenhagen, Denmark) were attached to the skin at locations recommended by Perotto and Delagi12).
Table 1. Peak muscle activity during the double-leg heel raise (n=30)

<table>
<thead>
<tr>
<th>%MPF</th>
<th>Soleus</th>
<th>Gastrocnemius medial head</th>
<th>Gastrocnemius lateral head</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% MPF</td>
<td>0.233 ±0.101</td>
<td>0.279 ±0.139</td>
<td>0.110 ±0.049</td>
</tr>
<tr>
<td>50% MPF</td>
<td>0.269 ±0.119</td>
<td>0.333 ±0.199</td>
<td>0.141 ±0.053</td>
</tr>
<tr>
<td>75% MPF</td>
<td>0.317 ±0.134</td>
<td>0.372 ±0.211</td>
<td>0.192 ±0.072</td>
</tr>
<tr>
<td>MPF</td>
<td>0.399 ±0.208</td>
<td>0.456 ±0.249</td>
<td>0.304 ±0.128</td>
</tr>
</tbody>
</table>

There were significant differences between all conditions in each muscle (mV).

Table 2. Peak muscle activity during walking (n=30)

<table>
<thead>
<tr>
<th>Walking speed</th>
<th>Soleus</th>
<th>Gastrocnemius medial head</th>
<th>Gastrocnemius lateral head</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 m/min</td>
<td>0.078 ±0.017</td>
<td>0.079 ±0.018</td>
<td>0.054 ±0.009</td>
</tr>
<tr>
<td>40 m/min</td>
<td>0.092 ±0.023</td>
<td>0.103 ±0.027</td>
<td>0.064 ±0.011</td>
</tr>
<tr>
<td>60 m/min</td>
<td>0.104 ±0.026</td>
<td>0.107 ±0.025</td>
<td>0.073 ±0.014</td>
</tr>
<tr>
<td>80 m/min</td>
<td>0.132 ±0.031</td>
<td>0.120 ±0.025</td>
<td>0.098 ±0.018</td>
</tr>
<tr>
<td>100 m/min</td>
<td>0.179 ±0.040</td>
<td>0.146 ±0.028</td>
<td>0.137 ±0.026</td>
</tr>
</tbody>
</table>

Soleus muscle activity: there are the significant differences except for between 20 and 40 m/min and between 40 and 60 m/min. Gastrocnemius medial head muscle: there are the significant difference except for between 40 and 60 m/min and between 60 and 80 m/min. Gastrocnemius lateral head: there are significant differences between all speeds (mV).

For each muscle, two electrodes were placed approximately 20 mm apart, in the direction of the muscle fiber. A reference electrode, shared by the four measurement channels, was placed on the bony part of the malleolus lateralis. EMG was amplified by bipolar leads with an input impedance >10 MΩ and a gain was 80dB (MT-11; GEHC-J, Tokyo, Japan).

The foot-switch sensors (P002; DKH Co., Ltd., Tokyo, Japan) were attached to the planta pedis, at the center of a line between the malleolus lateralis and the malleolus medialis. The pressure data from the foot-switch sensors were amplified (PH-462; DKH Co., Ltd., Tokyo, Japan), and downloaded onto a personal computer through an A/D converter at a sampling frequency of 1 kHz.

After EMG and the foot-switch sensors were set up, each subject performed the DHR on a flat structure consisting of a load cell (SB-200K12; Kyowa, Japan) and hard wooden boards. The right foot was placed on the load cell and loaded as much as the leg on the other side. The subjects received feedback information from the load cell via a digital amplifier and indicator (AD-4532; A&D, Tokyo, Japan), and they controlled the load placed on the right foot so that it was half of body weight.

The heel raise was performed under four conditions: MPF, 3/4 MPF, 2/4 MPF, and 1/4 MPF. MPF was based on the active ROM in a standing position under weight-bearing conditions. The subjects followed a rhythm of 1 Hz produced with an electronic metronome, raising their heels for 1 s and lowering them until they touched the ground in the next second; therefore, the complete movement cycle was over 2 s. For each heel-raise condition, the DHR was performed five times in succession. The height of the heel raise was controlled using the bar of a device that was adjusted to touch the dorsum pedis at the selected heel-raise height.

After the DHR test, the subjects walked on a treadmill (Evolve JP; Jonson Health Tech Japan, Tokyo, Japan). The walking speed was set at 20, 40, 60, 80, or 100 m/min, and the subjects walked for 1 min at each speed. The EMG and foot-switch data were recorded during the last 30 s at each speed.

The analog EMG signals and foot-switch data were passed through a 16-bit A/D board (PowerLab; ADInstruments, Nagoya, Japan), and all signals were sampled at 1 kHz. The foot-switch data were filtered with an 89-ms moving average window. The onset of right heel contact was determined during the DHR and treadmill walking. The EMG data were filtered with a 10-Hz high-pass IIR digital filter and zero-phase filtering. After the signal was full-wave rectified, the moving average was calculated for an 89-ms window. For the EMG data during the DHR, the peak values were detected for each heel-raise movement. We calculated the average of five peak values and adopted it as the indicator of the muscle activity during the DHR. On the other hand, during treadmill walking, EMG data of each gait cycle were converted into 100 data using a spline; the data for each gait cycle was interpolated to 100% of gait cycle at 1% intervals. After calculating the addition average values for all gait cycles, the peak value was determined for each subject. We adopted the peak value as the indicator of the muscle activity during treadmill walking.

A within-subject one-way analysis of variance (ANOVA) was used to analyze differences in the activity of the three muscles. The independent variables were the height of the heel raise and the walking speed, and the dependent variable was muscle activity. Significant individual differences were evaluated using the Scheffe test. Differences were assessed using two-sided tests, and an alpha level of 0.05.

RESULTS

The passive MPF in the supine position was 53 ± 6 degrees, and the active MPF in the standing position was 50 ± 6 degrees. There was no significant difference between the passive MPF and the active MPF. There were significant main effects of both the height of the heel raise (p < 0.001) and walking speed (p < 0.001). The muscle activity during the DHR significantly increased with the increase in the height of the heel raise (Table 1). In addition, there were significant differences in muscle activity between walking speeds for each muscle (p < 0.001). During treadmill walking, muscle activity significantly increased with the increase in the walking speed (Table 2). There were significant differences in the muscle activity of the gastrocnemius lateral head between all walking speeds; however, there were no significant differences in the gastrocnemius medial head activity between 40 and 60 m/min and between 60 and 80 m/min, and there were no significant differences in the soleus activity between 20 and 40 m/min and between 40 and 60 m/min.

In the comparison of the muscle activity at 1/4 MPF with that at each walking speed, the activity of the soleus...
in 26.7% of the subjects at a walking speed of 100 m/min was higher than that during the DHR, while the activity in the gastrocnemius lateral head in 80.0% of the subjects was higher than that during the DHR. However, in the comparison of the muscle activity at MPF with that at a walking speed of 100 m/min, this value decreased to 23.3% for the gastrocnemius lateral head. Furthermore, in the comparison of the muscle activity at MPF with that at each walking speed, the activities of the soleus and gastrocnemius medial head during walking exceeded those during the DHR in only 3.3% of subjects (Table 3).

**DISCUSSION**

The heel-raise test is often used in a clinical setting to evaluate the function of the calf muscles. However, the single-leg heel raise can be difficult for the elderly and other people with decreased balance function. Therefore, we proposed that the DHR test could be a useful alternative to the single-leg heel raise test for the clinical assessment of ankle plantar flexors. The results of this study indicated that the DHR test is useful for evaluation of the ankle plantar flexor activity necessary for walking.

There have been many studies on the plantar flexion torque of the ankle joint during walking; however, the findings have been variable, and many gait characteristics are also dependent on gait velocity. DeVita and Hortobagyi showed that the peak torque of the ankle joint at a comfortable walking velocity of 89 m/min was 136 ± 27 Nm in young subjects and 102 ± 29 Nm at 90 m/min. Flanagan et al. reported that plantar flexion torque was 63.9 ± 4.85 Nm at 30 m/min and 85.8 ± 8.03 Nm at 90 m/min. Flanagan et al. reported that the peak torque was 0.85 Nm/kg during the DHR. Therefore, if the body mass of the subjects ranged from 60 to 80 kg, the peak torque would range from 51 to 68 Nm. In that study, the plantar flexion peak torque for the DHR was lower than that for walking. However, analysis of the muscle activity of the main plantar flexors in the present study provided different results.

The heel-raise test involves eccentric-concentric muscle contraction of the plantar flexors. Eccentric pre-activation renders an increase in performance during the concentric phase, partly through the utilization of the elastic energy stored during the pre-activation phase. Mueller et al. reported that the plantar flexion peak torque, measured using an isokinetic device, accounted for 40% and 53% of the variance in peak ankle moment and power during walking, respectively, and that there was a strong correlation between plantar flexion peak torque and dorsiflexion ROM. The authors explained that an increase in the dorsiflexion ROM allows for an increase in the requirement for the external dorsiflexion moment and necessarily increases the requirement for internal (muscle generated) control of the plantar flexion moment during walking. However, ankle dorsiflexion during the mid-stance phase may be important for other reasons. Ishikawa et al. noted that the tendinous tissues of both the soleus and gastrocnemius muscles were slowly stretched during the single support phase and dramatically recoiled during the pre-swing phase, contributing to the storage elastic energy. In this respect, the DHR is similar to walking. However, during walking, the kinetics change from the closed kinetic chain of the stance phase to the open kinetic chain of the swing phase. On the other hand, there is no change during the DHR. This suggests that humans use muscle activity more efficiently during walking. In the present study, the activities of the soleus and gastrocnemius muscles during walking were less than those of these muscles during MPF.

Suzuki et al. reported that the isometric strength of the plantar flexors was an important independent predictor for habitual gait velocity in community-dwelling older women. The plantar flexor muscles of the ankle joint play an important role in the generation of torque during walking. In addition, low torque of the plantar flexor muscles has been linked to an increased risk of falling in older individuals. Therefore, a simple method for evaluation of plantar flexor function is important for clinical assessment, and the DHR test fulfills this role.

In the present study, measurement of the plantar flexor muscle activity was limited to two muscles. However, the gastrocnemius and soleus muscles can produce a large amount of torque compared with other plantar flexor muscles. Although the maximum force of the triceps surae is 1620 N, the maximum force of the tibialis posterior is only 267 N. If a moment arm is considered, the plantar flexion torque of the tibialis posterior is much smaller than that of the triceps surae. In addition, the double-leg heel raise does not allow us to evaluate the strength of the right and left calf muscle independently. However, the present study, which examined the DHR with half the body weight bearing by each lower extremity, indicates that it may be used as a criterion of muscle weakness if the center of gravity shifts into the left or right.

### Table 3. Percentage of subjects in whom walking generated higher EMG activity than the DHR for each plantar flexion condition at each walking speed (n = 30)

<table>
<thead>
<tr>
<th>Walking Speed</th>
<th>So</th>
<th>Gm</th>
<th>Gl</th>
<th>So</th>
<th>Gm</th>
<th>Gl</th>
<th>So</th>
<th>Gm</th>
<th>Gl</th>
<th>So</th>
<th>Gm</th>
<th>Gl</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 m/min</td>
<td>6.7</td>
<td>0.0</td>
<td>6.7</td>
<td>3.3</td>
<td>3.3</td>
<td>20.0</td>
<td>3.3</td>
<td>6.7</td>
<td>30.0</td>
<td>10.0</td>
<td>3.3</td>
<td>56.7</td>
</tr>
<tr>
<td>40 m/min</td>
<td>0.0</td>
<td>0.0</td>
<td>6.7</td>
<td>0.0</td>
<td>0.0</td>
<td>10.0</td>
<td>3.3</td>
<td>6.7</td>
<td>13.3</td>
<td>6.7</td>
<td>6.7</td>
<td>36.7</td>
</tr>
<tr>
<td>60 m/min</td>
<td>3.3</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>3.3</td>
<td>6.7</td>
<td>0.0</td>
<td>3.3</td>
<td>10.0</td>
<td>0.0</td>
<td>3.3</td>
<td>23.3</td>
</tr>
<tr>
<td>80 m/min</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>3.3</td>
<td>10.0</td>
</tr>
<tr>
<td>100 m/min</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>3.3</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**Note:** MPF: maximum plantar flexion; So: soleus; Gm: medial head of gastrocnemius; Gl: lateral head of gastrocnemius (%)
ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of the following individuals: Junpei Kano, Saki Itagaki, Takeshi Onodera, Kenta Kimura, and Airi Shinatake.

REFERENCES

6) Segura-Ortí E, Martínez-Olmos FJ: Test-retest reliability and minimal detectable change scores for sit-to-stand-to-sit tests, the six-minute walk test, the one-leg heel-rise test, and handgrip strength in people undergoing hemodialysis. Phys Ther, 2011, 91: 1244–1252. [Medline] [CrossRef]