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).
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 Hrostobagyi 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 in elderly subjects. Browning and Kram studied plantar flexion torque during walking at different velocities and found that the peak 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.
ACKNOWLEDGEMENTS

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

REFERENCES

1) Hislop HJ, Montgomery J: Daniels and Worthingham’s manual muscle testing. Techniques and manual examination, 8th ed. St. Louis: Saunders Elsevier, 2007, pp 198–204.
2) Jan MH, Chai HM, Lin YF, et al.: Effects of age and sex on the results of an ankle plantar-flexor manual muscle test. Phys Ther, 2005, 85: 1078–1084. [Medline]
3) Kasahara S, Ebata J, Takahashi M: Analysis of the repeated one-leg heel-rise test of ankle plantar flexors in manual muscle testing. J Phys Ther Sci, 2007, 19: 251–256. [CrossRef] [Medline]
4) Maurer C, Finley A, Martel J, et al.: Ankle plantarflexor strength and endurance in 7–9 year old children as measured by the standing single leg heel-rise test. Phys Occup Ther Pediatr, 2007, 27: 37–54. [Medline]
5) Schmid S, Hilfiker R, Radlinger L: Reliability and validity of trunk accelerometry-derived performance measurements in a standardized heel-rise test in elderly subjects. J Rehabil Res Dev, 2011, 48: 1137–1144. [Medline] [CrossRef]
6) Segura-Ortí E, Martínez-Olmos FJ: Test-retest reliability and minimal detectable change scores for seated-to-stand-to-seated, 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]
7) Yocum A, McCoy SW, Bjornson KF, et al.: Reliability and validity of the standing heel-rise test. Phys Occup Ther Pediatr, 2010, 30: 190–204. [Medline] [CrossRef]
8) Houck JR, Neville C, Tome J, et al.: Foot kinematics during a bilateral heel rise test in participants with stage II posterior tibial tendon dysfunction. J Orthop Sports Phys Ther, 2009, 39: 293–303. [CrossRef] [Medline]
9) Flanagan SP, Song JE, Wang MY, et al.: Biomechanics of the heel-rise exercise. J Aging Phys Act, 2005, 13: 160–171. [Medline]
10) Ishikawa M, Komiyama P, Grey MJ, et al.: Muscle-tendon interaction and elastic energy usage in human walking. J Appl Physiol, 1985, 99: 603–608. [Medline] [CrossRef]
11) Azizuki KH, Gartman EJ, Nisonson B, et al.: The relative stress on the Achilles tendon during ambulation in an ankle immobiliser: implications for rehabilitation after Achilles tendon repair. Br J Sports Med, 2001, 35: 329–333, discussion 333–334. [Medline] [CrossRef]
12) Perotto A, Delagi WF: Anatomic guide for the electromyographer. The Limbs, 2nd ed. Springfield: Charles C Thomas Publisher, 1980.
13) Browning RC, Kram R: Effects of obesity on the biomechanics of walking at different speeds. Med Sci Sports Exerc, 2007, 39: 1632–1641. [Medline] [CrossRef]
14) Hansen AH, Childress DS, Miff SC, et al.: The human ankle during walking: implications for design of biomimetic ankle prostheses. J Biomech, 2004, 37: 1456–1474. [Medline] [CrossRef]
15) DeVita P, Hortobagyi T: Age causes a redistribution of joint torques and powers during gait. J Appl Physiol, 2000, 88: 1804–1811. [Medline]
16) Mueller MJ, Minor SD, Schaaf JA, et al.: Relationship of plantar-flexor peak torque and dorsiflexion range of motion to kinetic variables during walking. Phys Ther, 1995, 75: 684–693. [Medline]
17) Suzuki T, Bean JF, Fielding RA: Muscle power of the ankle flexors predicts functional performance in community-dwelling older women. J Am Geriatr Soc, 2001, 49: 1161–1167. [Medline] [CrossRef]
18) Chen WM, Park J, Park SB, et al.: Role of gastrocnemius-soleus muscle in forefoot force transmission at heel rise—a 3D finite element analysis. J Biomech, 2012, 45: 1783–1789. [Medline] [CrossRef]