Effects of shoe type on lower extremity muscle activity during treadmill walking

Mi-Kyoung Kim, PT1, Young-Hwan Kim, PhD2, Kyung-Tae Yoo, PT, PhD1)*

1) Department of Physical Therapy, Namseoul University: 21 Maeju-ri, Sungwan-eup, Seobuk-Gu, Cheonan-Si 331-707, Republic of Korea
2) Graduate School Physical Education, Kyung Hee University, Republic of Korea

Abstract. [Purpose] The purpose of this study was to analyze the effects of different shoe types on lower extremity muscle activity in healthy young women by using electromyography. [Subjects and Methods] Fifteen healthy young women in their 20s were included in this single-group repeated measures study. The subjects were divided into three groups: Converse sneakers, rain boots, and combat boots. The subjects walked on a treadmill at 4 km/h for 30 min, during which six muscles were examined using electromyography: the rectus femoris, vastus medialis, semimembranosus, tibialis anterior, peroneus longus, and medial head of the gastrocnemius. Between switching shoe types, a 24-h rest period was instated to prevent the fatigue effect from treadmill walking. [Results] One-way analysis of variance used to compare electromyography results among the three groups showed that the main effect of group differed significantly for the vastus medialis. Vastus medialis activity was higher in the rain boots group than the Converse sneakers group, and it was higher in the combat boots group than rain boots group. [Conclusion] Shoe type affects lower extremity muscle activity. Our findings may help individuals choose the ideal shoes for daily walking.

Key words: Electromyography, Lower extremity, Shoe type

INTRODUCTION

Shoes provide protection from the environment and functional assistance, are fashionable, and enable adjustments for deformed feet and treatment for musculoskeletal injuries. Although the origin of shoe wearing by humans is not known, they have been worn for the convenience of walking and protection of the feet for long1). The material and shape of shoes have evolved in modern times to suit the purpose of wearing shoes, but the main purpose of wearing shoes in the past was for protection3). Shoes can be easily changed to alter the load of the human body, since the material, shape, and heel height affect mobility and stability5).

Body movements, such as walking, are facilitated by the movement of the skeleton through muscle contraction, and the muscle activity can be analyzed using electromyography (EMG), which is a method of obtaining muscle information.

It is essential to functionally analyze EMG data during various activities to understand the effects of changes to muscle length5). EMG examines biological electric activity around muscle contractions and muscle control actions. Functional analysis of EMG data demonstrates the relationships between movements and time about movement of the body, EMG and power production, and EMG and muscle fatigue5).

A previous study analyzed static balance and muscle activity of the lower extremities in young adults depending on the period of high-heeled shoe wearing and reported that the rectus femoris (RF) and tibia anterior (TA) muscles did not appear to show significant differences6). Another study related to kinetic differences between normal running shoes and spring-loaded running shoes reported that the RF activity on EMG was higher with the latter shoes7). The effect of unstable sandals on instability during gait in healthy adults has been previously examined, and unstable shoes showed significant differences in the ankle joint and increased peroneal activity during pre-swing, while stable shoes increased medial gastrocnemius (GM) and decreased TA activities during mid-stance. The stable shoes changed gait and muscle activity related to braking and progression and a softer and less stable forefoot increased evertor action during toe-off in the frontal plane. These results indicated that the specific designs of shoes could affect stability8).

Although the use of and aesthetic interest in the shoes of young women have increased in modern society, previous studies demonstrated that EMG activity and muscle fatigue are related to high-heeled shoes and functional running shoes. Thus, the purpose of this study was to analyze the effects of muscle activity on walking according to various shoes frequently worn by young women.
SUBJECTS AND METHODS

The 15 participants were students in their 20s at N University, Cheonan-si, Republic of Korea. They had not had any musculoskeletal or neurological injuries, an athletic career, or strengthen training experience in the last 6 months. They were provided detailed information on this study and voluntarily provided written informed consent before the experiment. This study was approved by the Institutional Review Board of Namseoul University.

A body composition analyzer (InBody720; Biospace O. Ltd., Seoul, Republic of Korea) was used to determine the general characteristics of the subjects. A treadmill (SNS care m-400m; SNS Care Co., Ltd., Goyang, Republic of Korea) was used for walking, and a Free EMG system (Free EMG; BTS Inc., Milan, Italy) was used to measure the muscle activity of the lower extremities while the subjects wore different types of shoes and walked on the treadmill.

The experimental design of this study is a repeated measures experiment. The participants were divided into three groups according to the types of shoes they wore: a Converse sneakers group, a rain boots group, and a combat boots group. Surface electrodes (3 M Red Dot 2570; 3 M Center, St. Paul Minnesota, USA) were cleaned using alcohol-soaked cotton to minimize errors due to skin impedance and used to measure EMG activity. They were attached to the muscles at maximal static contraction to avoid errors that could affect the results. Six muscles, namely, the RF, vastus medialis (VM), semimembranosus (SM), TA, peroneus longus (PL), and GM, were examined. The RF is halfway between the patella and iliac spine on the front of the femur. The VM is 50 degrees on the femoral longitudinal axis and 5 cm above the superomedial patella. The SM is 3 cm from the lateral border of the thigh and halfway along the distance from the gluteal fold to behind the knee. The TA is 33% between the tip of the fibula and medial malleolus. The PL is 25% between the fibula head and lateral malleolus. Finally, the GM is 35% medially from the distal median line of the knee joint and 2 cm above this joint. In all cases, the surface electrodes were 2 cm from the muscles. All electrodes were attached by the same researchers. The root mean square of EMG data was determined during walking, and the maximal voluntary muscle contraction was used to eliminate data errors due to personal characteristics. The EMG signal was normalized, the sampling rate was 1,000 Hz, and the band-pass filter was 20–500 Hz. Muscle activity was measured during treadmill walking. The participants walked at a speed of 4 km/h for 30 min and rested 24 h between wearing each shoe to avoid fatigue effects.

Statistical analysis was performed using SPSS version 18.0 for Windows (SPSS, Inc., Chicago, IL, USA). The general characteristics of the participants are given as mean and standard deviation. The Kolmogorov–Smirnov test was used to demonstrate normal distribution. The Levene F-test was used to verify homogeneity. One-way analysis of variance (ANOVA) was used to compare differences in muscle activity among shoe groups. If significant differences were found, the Scheffe test was used for post-hoc analysis. Statistical significance was set at α = 0.05.

RESULTS

The study participants were healthy women in their early 20s (Table 1) and wore three types of shoes during the test: converse sneakers, rain boots, and combat boots (Table 2). Differences in the interaction effect of group and time were not noted in the one-way ANOVA used to compare muscle activity among the three groups. The main effect of time did not differ significantly. However, the main effect of group showed significant differences for the VM (Table 3). Further, in the results of multiple comparisons of VM, the rain boots group showed significantly higher VM activity than the Converse sneakers group, and the combat boots group showed significantly higher VM activity than the rain boots group.

DISCUSSION

Shoes that do not fit the feet change the foot bones and hamper gait posture, in addition to causing various adverse conditions, including calluses,corns, neuroma, hallux valgus, toe deformities, ankle sprains, Achilles tendinitis, and knee and back pain. In modern society, women tend to disregard their own physical characteristics while choosing shoes.

The present study was conducted to analyze the muscle activity of the lower extremities depending on shoe type during walking among individuals in their 20s. The results showed significant differences in the interaction effects of group and time or the main effect of time. However, the main effect of group differed significantly for VM activity. VM activity differed significantly among the three groups: the activity in the rain boots group was significantly higher than that in the Converse sneakers group, and that in the combat boots group was significantly higher than the activity in the rain boots group.

A previous study found that the impulsive force increased rapidly at heel-strike, because it made an angle like an edge, and the knee joint was unable to extend adequately at heel-strike. Another study that analyzed the effect of shoe sole form on knee and ankle joint muscle activity reported that VM activity was higher with high-heeled shoes and house shoes than with shoes that had a curved outsole. Further, because high-heeled shoes elevate the anterior foot, the

Table 1. General characteristics of the participants

| Subjects | Age (years) | Height (cm) | Weight (kg) |
|----------|-------------|-------------|-------------|
| M ± SD   | 20.5 ± 0.5  | 159.0 ± 4.9 | 51.4 ± 7.2 |
| M ± SD; means ± standard deviation |

Table 2. General characteristics of the shoes

| Shoes         | Weight (kg) | Shaft height (cm) |
|---------------|-------------|-------------------|
| Converse sneakers | 0.71        | 17                |
| Rain boots    | 0.80        | 17                |
| Combat boots  | 1.00        | 17                |
TA activity increased, GM activity decreased and led to increased knee extension at heel-strike, and VM activity increased\textsuperscript{10}. A previous study analyzed the effects of the form of the outsole on lower leg EMG signals during gait. When shoes with a curved outsole were used, the ankle joint showed increased dorsiflexion during heel-strike and the dorsiflexion state was maintained in the stance phase, while joint motion was decreased in the sagittal plane. The curved outsole reduced the load on the joint, as dorsiflexion agonist activity increased and dorsiflexion antagonist activity decreased. In addition, as ankle push-off and push-off movement were delayed, unnecessary movement was avoided and the center of gravity was maintained during gait. For these reasons, the VM activity was increased when shoes with a curved outsole were used as compared to other shoes, since muscle activity was balanced on a supporting base. Similar effects were noted with shoes that had an insole of the elevator shoe type\textsuperscript{18}. The VM activity emphasized the function of contracture related to the stability of the medial knee joint at the end of extension\textsuperscript{19}; when foot orthotic quadriceps and gluteus medius EMG signals were tested during a selected exercise, the VM activity was found to be higher in the three-orthotic condition (7° medial rearfoot post, 4° lateral rearfoot post, and neutral rearfoot post) than the no-orthotic condition. This was because excessive lateral tracking was prevented. Another study reported that the VM activity induced mechanical changes in the patellofemoral joint to facilitate the VM activity during an orthotic intervention\textsuperscript{20}. Further, the angle of the last rotation of tibialis anterior reportedly increases VM activity\textsuperscript{21}.

The results of the present study showed significant differences in VM activity depending on the shoe type: the rain boots group had significantly higher VM activity than the Converse sneakers group, and the combat boots group had significantly higher activity than the rain boots group. In the groups of increasing VM activity, knee extension increased because of gait to leaning the anterior part; further, the angle of tibial rotation and mechanics of the patellofemoral joint changed to prevent lateral tracking and improve medial stability with the increase in knee extension. VM activity was considered to increase for efficient walking, as this reduced the load on the joint, prevented unnecessary movements, and balanced the center of gravity and support base.

**Table 3.** Comparison of pre- and post-test muscle electromyography signals according to the groups (mV)

| Variable | Group           | Pre-test      | Post-test     |
|----------|-----------------|---------------|---------------|
|          |                 | M ± SD        | M ± SD        |
| RF       | Converse sneakers | 14.5 ± 9.7    | 14.4 ± 7.9    |
|          | rain boots      | 11.2 ± 4.1    | 16.9 ± 10.7   |
|          | combat boots    | 12.1 ± 4.5    | 14.2 ± 13.1   |
| VM\*     | Converse sneakers\textsuperscript{b} | 28.9 ± 12.3   | 32.4 ± 15.3   |
|          | rain boots      | 42.3 ± 18.0   | 42.5 ± 21.5   |
|          | combat boots    | 50.2 ± 32.0   | 52.0 ± 24.0   |
|          | Converse sneakers | 213.8 ± 125.8 | 220.7 ± 116.8 |
| SM       | rain boots      | 169.0 ± 70.4  | 224.4 ± 134.8 |
|          | combat boots    | 197.7 ± 112.1 | 215.4 ± 89.7  |
| TA       | Converse sneakers | 38.4 ± 18.9   | 33.9 ± 11.2   |
|          | rain boots      | 32.6 ± 16.3   | 31.8 ± 14.0   |
|          | Converse sneakers | 37.2 ± 12.4   | 32.1 ± 14.3   |
| PL       | rain boots      | 36.2 ± 18.3   | 38.4 ± 17.7   |
|          | combat boots    | 36.1 ± 15.2   | 36.5 ± 17.6   |
| GM       | rain boots      | 52.7 ± 26.8   | 49.8 ± 14.8   |
|          | combat boots    | 52.4 ± 29.3   | 48.8 ± 22.7   |

\*p < 0.05; \textsuperscript{abc}: significant differences between groups; \textsuperscript{a}: Converse sneakers; \textsuperscript{b}: rain boots; \textsuperscript{c}: combat boots; RF: rectus femoris, VM: vastus medialis; SM: semimembranosus; TA: tibialis anterior; PL: peroneus longus; GM: medial head of the gastrocnemius; M ± SD: mean ± standard deviation
rotation depending on knee joint movement. Our findings may promote further investigation of various shoe types.

ACKNOWLEDGEMENT

Funding for this research was provided by Namseoul University.

REFERENCES

1) Barton CJ, Bonanno D, Menz HB: Development and evaluation of a tool for the assessment of footwear characteristics. J Foot Ankle Res, 2009, 2: 10. [Medline] [CrossRef]

2) Kim YW: Effects of the gait types on shoes with curved out-sole and bare-foot. Korean J Exerc Rehabil, 2011, 7: 145–153.

3) Song CH, Lee JD, Kwon YJ, et al.: The study of footwear preferences and the wearing conditions in the older women. J Korean Soc Phys Med, 2009, 4: 63–71.

4) Mohamed O, Perry J, Hislop H: Relationship between wire EMG activity, muscle length, and torque of the hamstrings. Clin Biomech (Bristol, Avon), 2002, 17: 569–579. [Medline] [CrossRef]

5) Park IB, Kim JT: The effects of elastic resistance and pilates exercise on EMG in baseball pitcher. Korean J Sport Biomech, 2007, 17: 127–139. [CrossRef]

6) Lee MH, Chang JS, Lee SY, et al.: The effects of high-heeled shoes on static balance and EMG activity of lower extremity muscles for young women. J Korean Soc Phys Med, 2009, 4: 43–48.

7) Lee CH: Kinetic differences between normal-design running shoes and spring-loaded running shoes. Korean Journal of Sport Biomech, 2009, 19: 581–592. [CrossRef]

8) Price C, Smith L, Graham-Smith P, et al.: The effect of unstable sandals on instability in gait in healthy female subjects. Gait Posture, 2013, 38: 410–415. [Medline] [CrossRef]

9) Kim MK, Yoo KT: Effect of isotonic and isokinetic exercise on muscle activity and balance of the ankle joint. J Phys Ther Sci, 2015, 27: 415–420. [Medline] [CrossRef]

10) Yoon SW, Lee JW, Choi MS: Effect of shoes sole form on knee and ankle muscle activity. J Korean Soc Phys Med, 2014, 9: 347–354. [CrossRef]

11) Lee A, Park J, Lee S: Gait analysis of elderly women after total knee arthroplasty. J Phys Ther Sci, 2015, 27: 591–595. [Medline] [CrossRef]

12) Park S, Kang YS, Ko YM, et al.: Differences in onset timing between the vastus medialis and lateralis during concentric knee contraction in individuals with genu varum or valgum. J Phys Ther Sci, 2015, 27: 1207–1210. [Medline] [CrossRef]

13) Kim SH, Kwon OY, Park KN, et al.: Comparison of erector spinae and hamstring muscle activities and lumbar motion during standing knee flexion in subjects with and without lumbar extension rotation syndrome. J Electromyogr Kinesiol, 2013, 23: 1311–1316. [Medline] [CrossRef]

14) Kavanagh JJ, Bisset LM, Tsao H: Deficits in reaction time due to increased motor time of peroneus longus in people with chronic ankle instability. J Biomech, 2012, 45: 605–608. [Medline] [CrossRef]

15) Roerdink M, Coolen BH, Clairbois BH, et al.: Online gait event detection using a large force platform embedded in a treadmill. J Biomech, 2008, 41: 2628–2632. [Medline] [CrossRef]

16) Smith BS, Burton B, Johnson D, et al.: Effects of wearing athletic shoes, five-toed shoes, and standing barefoot on balance performance in young adults. Int J Sports Phys Ther, 2015, 10: 69–74. [Medline]

17) Hur YG: The effects of calf cramp muscle shortening followed by shoe heel height on fatigue. Korean Acad Phys Ther Sci, 2013, 20: 17–25.

18) Kim JS, Choi HH: The effect of form of outsole on lower leg electromyography during gait. Journal of the Korea Academia-Industrial Cooperation Society, 2012, 13: 227–235. [CrossRef]

19) Powers CM: Patellar kinematics, part I: the influence of vastus muscle activity in subjects with and without patellofemoral pain. Phys Ther, 2000, 80: 956–964. [Medline]

20) Hertel J, Sloss BR, Earl JE: Effect of foot orthotics on quadriceps and gluteus medius electromyographic activity during selected exercises. Arch Phys Med Rehabil, 2005, 86: 26–30. [Medline] [CrossRef]

21) O’Sullivan SP, Popelka CA: Activation of vastus medialis obliquus among individuals with patellofemoral pain syndrome. J Strength Cond Res, 2005, 19: 302–304. [Medline]