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Why Does Only Contact the Half Area of the High Heel during Ascending Stairs?

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Abstract

Purpose : Wearing high-heeled shoes leads to foot and ankle instability, which requires leg muscles to remain in constant contraction. In order to adapt to the instability of the feet and ankles caused by wearing high heels, the muscles of the legs continuously repeat contraction and relaxation. Previous studies of the impact of stair climbing in high-heeled shoes have involved placing the entire stepping area of the shoe on the stair. However, high-heeled shoe wearers sometimes unconsciously contact the stair using only half of the stepping area. Therefore, the objective of this study was to examine differences in leg and ankle muscle activation according to stepping area during stair climbing in high-heeled shoes.

Methods : Twenty young women in their early 20s voluntarily agreed to participate in this study. We used surface electromyography to measure gastrocnemius and tibialis anterior activation in the right leg during stair climbing under three conditions: barefoot, using half of high-heeled shoe stepping area, and using the total of high-heeled shoe stepping area. Barefoot, half of high heeled shoe, and total of high-heeled shoe were used to evaluate the effects of different areas of the foot or high heels touching the stairs.

Results : Both muscles showed significant activity differences among the three stair climbing conditions. Gastrocnemius activity was significantly different between the high-heeled shoe conditions (p= .032), and tibialis anterior activity was significantly different between barefoot stair climbing and climbing with half of the high-heeled shoe stepping area (p= .021).

Conclusion : The stepping area increased as heel size increased, thus increasing excessive gastrocnemius and tibialis anterior activity to control excessive ankle joint movement. We infer that using half of the high-heeled shoe stepping area prevents muscle fatigue by reducing excessive leg and ankle muscle activation.

Key Words : ascending stairs, barefoot, high heel, stepping area, stepping stairs

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Ⅰ. Introduction

Because young women in generally wish to appear tall, many show a great deal of interest in high-heeled shoes and wear them for long periods during their everyday life (Lewis et al., 2017). However, high heels lead to displacement of the center of gravity and a reduction of the supporting surface of the feet, thereby increasing the activity of leg muscles and causing various musculoskeletal disorders such as arthritis (Mika et al., 2016). In addition, the curvature of the lumbar vertebrae becomes more severe, the center of gravity in the upper body moves forward, and the center of gravity in the lower body moves backward, leading to negative effects on the movement of the ankle joints (Cronin, 2014). Walking in high heels causes the reaction force given from the ground to increase. This leads to increases loads to ankle joint, which in turn causes weakness of the ankle and the calf muscles, resulting in ankle and body instability (Simonsen et al., 2012).

Thus far, a diverse range of studies related to shoes has been conducted. In research on the effects of different types of shoes, plantar pressure was shown to be greater in the case of high-heeled shoes compared to sneakers because high heels caused the weight to shift forward during walking (Lee et al., 2006). In an evaluation of plantar pressure and subjective discomfort from high heels and sneakers, it was found that the subjects felt more discomfort when they were wearing high heels because intense pressure was imposed on the front part of the feet (Song et al., 2009). In studies on the heel height of high heels, the higher the heels were, the more the center of pressure and ground reaction force changed (Gefen et al., 2002; Hong et al., 2005), and such changes would cause lordosis, pelvic tilt, and muscle fatigue (Weitkunat et al., 2016). In a study conducted by Gerber et al. (2012) that compared women wearing high- and low-heeled shoes, it was found in the case of those wearing high-heeled shoes that the vibration of the center of pressure increased regardless of visual restriction, static balance was negatively affected, muscle fatigue occurred easily due to the state of excessive plantar flexion, ankle instability, and the incidence of ankle trauma was high (Valentini et al., 2009). Also, female college students were often found to experienced fatigue all over their body, and the higher the heel of the shoes they wore, the quicker they were fatigued their feet deformed (Cheong & Hyeon, 2013).

In order to adapt to the instability of the feet and ankles caused by wearing high heels, the muscles of the legs continuously repeat contraction and relaxation. Therefore, wearing high heels increases the fatigue of the muscles around the feet and ankle joints while the person performs tasks (Oh et al., 2010). In addition, muscle fatigue is known to negatively affect the ability to control and maintain posture and balance by reducing the efficiency of neuromuscular control mechanisms (Mello et al., 2007). Most of previous studies on high heels conducted tasks related to walking. However, since stair climbing is often performed in daily life, it is also necessary to examine changes in muscle activation that occur when climbing stairs in high heels. In addition, all the experiments in studies on high-heel stair walking have been conducted with the subjects climbing stairs with the whole high-heeled shoes placed on each step. However, in actual stair walking, the person will often step on stairs with only the front part of the high-heeled shoe and not the heel. Therefore, it is necessary to examine whether there are differences in the activity of the leg muscles between stepping on stairs with only the front part of a high-heeled shoe and doing so with the entire shoes. The purpose of this study is to examine the effect of the area of high heels used to step on the stairs on the activity of the ankle muscles during stair climbing.

Ⅱ. Methods

1. Participants

The subjects of this study were 20 young women in their early 20s who voluntarily agreed to participate in this program. Those who had worn high heels for at least 4 hours in a day at least once a week for at least one year were included in the study (Malick et al., 2020). Subjects who had any orthopedic problem of the ankle or knee, had any injury of the ankle or knee, complained of discomfort and pain throughout their body, or had a leg length difference of 30 ㎜ or more were excluded from the study (Brady et al., 2003). The age of the study subjects was 21.30±1.70 years, their height was 159.80±8.20 ㎝, and their weight was 52.70±12.30 ㎏. The study was approved by Silla University Institutional Review Board (approval number; 1041449-202110-HR-002).

2. EMG recording and data processing

The activity of the gastrocnemius (G) and tibialis anterior (TA) muscles of the right leg was measured using surface electromyography (EMG; 4D-SES, RELIVE, Korea) during stair climbing in both bare feet and high heels. After hair removal and ethyl alcohol disinfection of the electrode attachment site were carried out, surface electrodes (Ag/AgCl) were attached. The diameter of the surface electrodes was 10 ㎜ and the distance between the two electrodes was 20 ㎜. The electrodes for the G were attached below the knee at a horizontal distance of 2 ㎝ from the midline behind the calf, and the electrodes for the TA were attached to a point at a horizontal distance of 2 ㎝ lateral to the medial shaft of the tibia (Criswell, 2010). In order to remove artificial noises caused by the movement of the wires, the wires and electrodes were fixed using tapes and elastic bands. The sampling rate of the EMG signals was 2,000 ㎐, a 60 ㎐ notch filter was used to remove noises caused by the electrical signals, and a 25~450 ㎐ band-pass filter was used. The measured data were processed into root mean square (RMS) values and then standardized into percentages of the RMS values of maximal voluntary isometric contraction (MVIC). MVIC was measured in the manual strength test posture of the plantar flexor and dorsi flexor of the ankle recommended by Kendall et al. (2005). The subjects were asked to contract the muscles 5 times for 7 sec, and the data for the 5 sec in the middle, excluding the first 1 sec and the last 1 sec, were averaged and used.

Barefoot (BF), half high heels (HH), and total high heels (TH) were used to evaluate the effects of different areas of the foot or high heels touching the stairs. When HH were in contact the stairs, the area of surface contact was about 26 ㎠, and when TH touched the stairs, the area of surface contact was about 27 ㎠. All high heels were 7 ㎝ in height, and their sizes were applied to fit the subjects' feet (224.80±7.60 ㎜). The stairs used were 15 ㎝ high, 30 ㎝ deep, and 75 ㎝ wide, and there were no bannisters on either side (Fig 1).

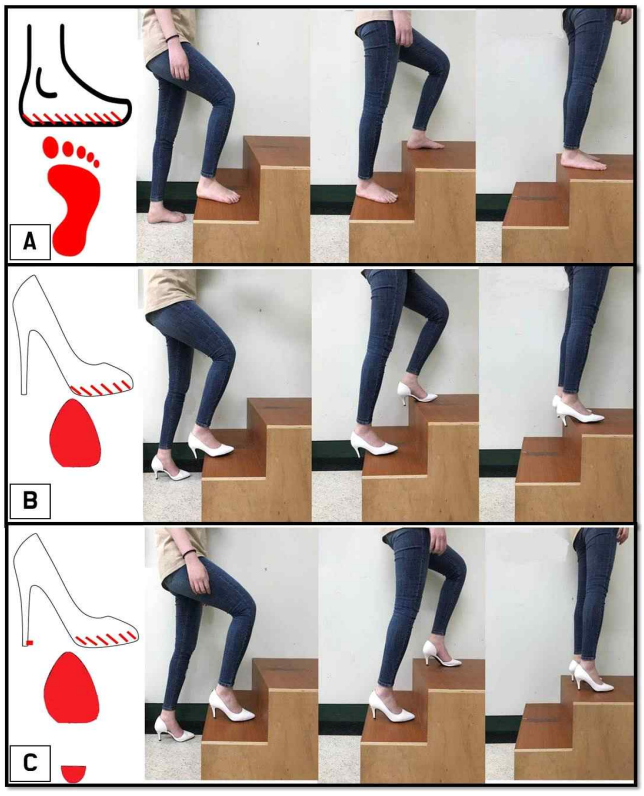

Fig 1. Different areas of foot or high heel touching the stairs
A. Barefoot (BF), B. Half of high heels (HH), C. Total of high heel (TH)

3. **Procedure**

The stair climbing began with the subjects looking straight ahead, placing their arms comfortably, and positioning their legs a pelvis-width apart in a standing posture in front of the stairs. The subjects did not hold an assistive tool at the sides of the stairs while they climbed them. Movement speed was controlled using a metronome so that the subjects would climb one step each second. The subjects were asked to use their right foot to go up to the first step, their left foot to go up to the second step, and finally their right foot to step onto the second step. As for the duration of measurement, the muscle activity of the right leg was measured from the time point when the right foot touched the first step until the time point when the left foot touched the second step. Sufficient practice was conducted so that the subjects could become accustomed to the movement, and assistants were always standing by on both sides of the stairs to prevent the risk of falling. The stair climbing was carried out under three conditions (BF, HH, TH) according to the areas touched by the foot or high-heeled shoes, five times per condition, and a break of 5 minutes was given after each condition.

4. **Statistical analysis**

The data were statistically processed using the SPSS version 24.0 for Windows. Out of the data from the stair climbing carried out by the subjects five times per condition, the smallest and largest values were excluded, and the remaining data were averaged and used as statistical data. The independent variables were BF, HH, and TH, and the dependent variables were the activity of the G and TA. All data were tested for normality by the Shapiro-Wilk test and analyzed through one-way ANOVAs. The Bonferroni method was used post hoc to find differences between the two conditions. To verify statistical significance, the significance level was set to $\alpha = .05$.

Ⅲ. Results

The activity levels of the G and TA under three conditions, BF, HH, and TH, were compared. According to the results, significant differences between the three conditions appeared in both muscles. In the post-hoc tests, there was a significant difference both between the HH and TH conditions in the case of the G ($p = .032$) and the BF and HH conditions in the case of the TA ($p = .021$) (Table 1).

Table 1. Muscle activation during ascending stairs under three conditions

Variables	BF	HH	TH	f	*p*
Gastrocnemius (%MVIC)	46.67±8.92	55.99±11.42	66.65±8.69*	18.595	.001
Tibialis anterior (%MVIC)	25.49±6.00	32.95±8.74**	39.99±8.40	14.571	.001

BF; barefoot, HH; half of high heel, TH; total of high heel, *significant difference between HH and TH, **significant difference between BF and HH

Ⅳ. Discussion

This study investigated differences in muscle activity between the tibialis anterior (TA) and the gastrocnemius (G) during stair climbing under the conditions of barefoot (BF), half of high heel (HH), and total of high heel (TH) among women in their early 20s who were used to wearing high-heeled shoes. Significant differences in muscle activity

of both muscles appeared in all three conditions, and the higher the heel height, the greater the muscle activity. In addition, a significant difference appeared both between the HH and TH conditions in the case of the G and the BF and HH conditions in the case of the TA.

When walking in high-heeled shoes, the body's center of gravity is moved to the front of the foot, causing pain in the back of the body such as the rear of the waist, the thigh, and the calf (Hsue & Su, 2009) and increasing the plantar flexion of the ankle joint leading to changes in the relative position of the bones in the joint and the attachment site of the muscles to the body (Sussman & D'Amico, 1984). In addition, Son et al. (2007) reported that the higher the heels, the greater the activity of the G muscles because the ankle joint is plantar flexed further. In addition, a study examining the muscle activity of G and hamstring muscles when wearing high-heeled or low-heeled shoes confirmed the high activity of these muscles when most subjects wore high-heeled shoes (Lee et al., 1990). With regard to the increase in muscle activity when high-heeled shoes are worn, Simonsen et al. (2012) stated that since the center of gravity of the human body is placed at the front of the sole of the foot, the posture becomes unstable and the tension of the G muscles increases to compensate for the foregoing. Jeong (2004) showed a correlation between high-heeled shoes and the activity of the leg muscles, with the latter increasing during walking to maintain stability. Therefore, as shown in the results of this study, the muscle activity increased more under the condition of HH than under BF and increased under the condition of TH than under HH. Given the foregoing, the reason why the activity of the G under the condition of HH was shown to be lower than that under TH was considered to be the fact that heel height can be reduced under the condition of HH so that the movement of the body's center of gravity to the front can be controlled and fatigue of the G can be reduced.

Lee et al. (2006) found that during stair climbing, the degree of muscle use was higher in the G and lumbar muscles, except for the muscles around the thighs, and the activity of the G muscles was particularly high when backless shoes were worn compared to when regular shoes were worn. In addition, since the center of gravity of the human body moves to the front of the ankle joint, repeated eccentric and concentric activation of the plantar flexor muscles is controlled when a static posture is maintained without body agitation Schmidt et al. (2018) the activity of the plantar flexor increases to maintain posture, and the activity of the dorsiflexor decreases on the contrary (Son et al., 2007). In the results of this study, HH caused the activity of the G muscles to increase compared to BF, but contrary to the previous study, the higher the heels of the high-heeled shoes, the higher the activity of the TA compared to BF. Given these results, it is considered that the efferent activity of the TA increased during the transition to the foot flat after heel strike because more dorsiflexion was required during heel strike than BF to place the entire high-heeled shoe on the stairs. The efferent activity of TA after heel strike plays an important role in limiting sudden plantar flexion of the ankle joint to absorb the ground reaction force caused by body weight (Neumann, 2016). However, given that the higher the high heels, the greater the activity of the TA, and using TH would be expected to cause much fatigue during stair climbing. Therefore, stair climbing with HH would be expected to reduce TA fatigue by reducing dorsiflexion of the ankle joint.

In all previous studies on leg muscle activity during stair climbing in high heels, TH were used when stair climbing was performed (Ghaderi et al., 2021; Kim & Song, 2011; Oh & Kim, 2009). However, since there are many cases whereby those who actually walk in high heels step on stairs with only the front part of their high heels rather than the whole of the shoe, the stair climbing in the previous studies is different from that in real life. According to the results of this study, stair climbing with HH can reduce the activity of the G and TA compared to stair climbing with TH, indicating that it is more comfortable in daily life.

Therefore, future studies should examine the differences in muscle activity during stair climbing with HH when comparing diverse shoe conditions.

This study has several limitations. First, since the study subjects were healthy women in their 20s, the findings cannot be safely generalized to people with lesions or all age groups. Second, since this experiment was carried out with stair climbing while stepping on one step with one foot, studies on various cases such as stepping on one step with two feet or going up two steps at a time with one foot could not be conducted. In addition, since this study did not have different shoe conditions, it would be necessary to compare muscle activity for sneakers or shoes mainly used in daily life. Third, the angle of the ankle joint during the stair climbing according to the three shoe conditions could not be measured. In a future study, the results of this study will be supported by adding changes in muscle activity according to changes in ankle angles.

Ⅴ. Conclusion

This study compared muscle activity levels in the G and the TA when climbing stairs using BF, HH, and TH. According to the results of the study, there were significant differences in the activity of G and TA in all three conditions, and muscle activity increased under the condition of HH more than under BF and increased under the condition of TH more than under HH. Therefore, it seems that since the height of the heels should increase when the area of high heeled shoes that touches the step increases during stair climbing, the excessive activity of the G and the TA increases in order to control excessive ankle joint movements. Therefore, climbing stairs using HH in daily life will help reduce muscle fatigue by reducing excessive activity of the muscles around the ankles more than climbing stairs using TH.

References

Brady RJ, Dean JB, Skinner TM, et al(2003). Limb length inequality: clinical implications for assessment and intervention. J Orthop Sports Phys Ther, 33(5), 221-234. DOI: 10.2519/jospt.2003.33.5.221

Criswell E(2010). Cram's introduction to surface electromyography. 2nd ed, St. Louis, Jones & Bartlett Publishers, pp.196-197.

Cronin NJ(2014). The effects of high heeled shoes on female gait: a review. J Electromyogr Kinesiol, 24(2), 258-263. DOI: 10.1016/j.jelekin.2014.01.004

Gefen A, Megido-Ravid M, Itzchak Y, et al(2002). Analysis of muscular fatigue and foot stability during high-heeled gait. Gait Posture, 15(1), 56-63. DOI: 10.1016/s0966-6362(01)00180-1

Gerber SB, Costa RV, Grecco LAC, et al(2012). Interference of high-heeled shoes in static balance among young women. Hum Mov Sci, 31(5), 1247-1252. DOI: 10.1016/j.humov.2012.02.005

Ghaderi F, Shahmoradi E, Moghadam Salimi M, et al(2021). The effect of heel height of shoe on ankle muscle activation pattern in women with functional ankle instability during stair descending. Muscles Ligaments Tendons J, 11(4), 666-672. DOI: 10.32098/mltj.04.2021.08

Hong WH, Lee YH, Chen HC, et al(2005). Influence of heel height and shoe insert on comfort perception and biomechanical performance of young female adults during walking. Foot Ankle Int, 26(12), 1042-1048. DOI: 10.1177/107110070502601208

Hsue BJ, Su FC(2009). Kinematics and kinetics of the lower extremities of young and elder women during stairs ascent while wearing low and high-heeled shoes. J Electromyogr Kinesiol, 19(6), 1071-1078. DOI: 10.1016/j.jelekin.2008.09.005

Jeong EH(2004). The study on the biomechanical effects of the heel types (height and area) of heel shoes. Graduate

school of Dongeui University, Republic of Korea, Doctoral dissertation.

Kendall FP, McCreary EK, Provance PG, et al(2005). Muscles: testing and function with posture and pain. 3rd ed, Baltimore, Lippincott Williams & Wilkins, pp.312-313.

Kim HH, Song CH(2011). Effects of shoe heel height on the onset of VMO relative to VL and VMO/VL EMG ratio during stair ascent in women without knee pathology. J Korean Soc Phys Med, 6(2), 135-143.

Lee CM, Oh YJ, Lee KD, et al(2006). The study on effect of the muscle activities for dietshoes (backless). Korean Journal of Applied Biomechanics, 16(3), 117-124. DOI: 10.5103/KJSB.2006.16.3.117

Lee KH, Shieh JC, Matteliano A, et al(1990). Electromyographic changes of leg muscles with heel lifts in women: therapeutic implications. Arch Phys Med Rehabil, 71(1), 31-33.

Lewis DMG, Russell EM, Al-Shawaf L, et al(2017). Why women wear high heels: evolution, lumbar curvature, and attractiveness. Front psychol, 13(1), Printed Online. DOI: 10.3389/fpsyg.2017.01875

Malick WH, Khalid H, Mehmood Z, et al(2020). Association of musculoskeletal discomfort with the use of high heeled shoes in females. J Pak Med Assoc, 70(12), 2199-2204. DOI: 10.47391/JPMA.536

Mello RGT, Oliveira LF, Nadal J(2007). Anticipation mechanism in body sway control and effect of muscle fatigue. J Electromyogr Kinesiol, 17(6), 739-746. DOI: 10.1016/j.jelekin.2006.08.011

Mika A, Oleksy Ł, Kielnar R, et al(2016). The influence of high-and low-heeled shoes on balance in young women. Acta Bioeng Biomech, 18(3), 97-103.

Neumann DA(2016). Kinesiology of the musculoskeletal system. 3rd ed, Mosby, Elsevier, pp.658-660.

Oh DW, Chon SC, Shim JH(2010). Effect of shoe heel height on standing balance and muscle activation of ankle joint. Journal of the Ergonomics Society of Korea, 29(5), 789-795. DOI: 10.5143/JESK.2010.29.5.789

Oh DW, Kim SY(2009). Effect of shoe heel height on vastus medialis and vastus lateralis electromyographic activity during stair ascending and descending. Phys Ther Korea, 16(3), 24-31.

Ryew CC, Hyun HS(2013). Kinetic comparison of the gait pattern by body weights and shoe's heel heights in the 20's age women. Journal of Sport and Leisure Studies, 51(2), 563-575. DOI: 10.51979/KSSLS.2013.02.51.563

Schmidt RA, Lee TD, Winstein C, et al(2018). Motor control and learning: a behavioral emphasis. 6rd ed, Winstein, Human Kinetics, pp.229-231.

Simonsen EB, Svendsen MB, Nørreslet A, et al(2012). Walking on high heels changes muscle activity and the dynamics of human walking significantly. J Appl Biomech, 28(1), 20-28. DOI: 10.1123/jab.28.1.20

Son JS, Choi HS, Hwang SJ, et al(2007). Changes of muscle length and roll-over characteristics during high-heel walking. Journal of the Korean Society for Precision Engineering, 24(12), 29-35.

Song JW, Kim SJ, Lee GH, et al(2009). Evaluation of foot pressures and subjective discomfort ratings associated with sneakers, high heels, and kill heels. Journal of the Ergonomics Society of Korea, 28(3), 95-102. DOI: 10.5143/JESK.2009.28.3.095

Sussman RE, D'Amico JC(1984). The influence of the height of the heel on the first metatarsophalangeal joint. J Am Podiatry Assoc, 74(10), 504-508. DOI: 10.7547/87507315-74-10-504

Valentini R, Martinelli B, Mezzarobba S, et al(2009). Optokinetic analysis of gait cycle during walking with 1 cm-and 2 cm-high heel lifts. Foot, 19(1), 44-49. DOI: 10.1016/j.foot.2008.09.002

Weitkunat T, Buck FM, Jentzsch T, et al(2016). Influence of high-heeled shoes on the sagittal balance of the spine and the whole body. Eur Spine J, 25(11), 3658-3665. DOI: 10.1007/s00586-016-4621-2