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Original Article

# The effects of the length of rain boots on balance during treadmill walking

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**Abstract.** [Purpose] Effects of muscle fatigue on lower-extremity balance were evaluated in 12 healthy young women in their 20s while they walked on a treadmill wearing rain boots of different lengths. [Methods] The rain boots were divided into three groups based on the shaft length (Long, Middle, Short). Romberg's test was applied and limits of stability were measured before and after treadmill walking. [Results] Romberg's test showed a significant main effect for time. There were significant differences between the center of gravity area, length, and velocity when the eyes were open and the center of gravity length, velocity, and length/cm$^2$ when the eyes were closed. Changes in the limits of stability also showed a significant main effect of time. There were significant differences in pre-test and post-test values in the left, right, forward, and total directions. [Conclusion] It was found that muscle fatigue in the lower extremities generated by walking in rain boots affected the joints and the adjuster muscles, depending on shaft lengths. Compensation due to visual feedback and the length of the boot shaft affected movement of the distal joints, resulting in a reduced ability to balance.
**Keywords:** Balance, Treadmill walking, Rain boots length

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## INTRODUCTION

An important role of footwear is to prevent injury by decreasing fatigue in the foot and lower extremity while walking[1)]. The characteristics of the footwear material are closely related to muscle and joint movements of the lower extremities[2)], and contact between the body and the supporting surface may potentially influence balance and the risk of falls[3)]. Rain boots made of rubber and waterproof shoes are worn in the rainy spells in the summer as fashion items by younger women. However, due to the hard and flat soles of the footwear, the entire foot is used during walking, which focuses pressure on the heels and reduces surface contact; this may significantly influence impact absorption of the joints in the lower extremities[4)].

The maintenance of balance is a crucial requirement in one's daily living, work, and sports activities[5)]. Balance and postural control are maintained through environmentally-related factors and the dynamic integration of internal and external forces[6)]. This is a specialized, complex process that includes various sensory and motor components and requires accurate afferent and efferent output from the associated joints and muscles[7)]. The maintenance of balance relies on influx from the visual, vestibular, and somatosensory systems[8)], while fatigue of the postural muscles generated during postural maintenance affects the systems responsible for maintaining balance, damaging postural control[7)]. Fatigue refers to the reduction in efficiency and muscle capacity generated by energy, due to exposure to continuous activities[9)]. Neuromuscular fatigue is a specific condition resulting from an inability to maintain a given degree of strength, and fatigue is the basis for some widely known changes, such as reduced capacity during functional activities and sport activities. Moreover, fatigue includes central mechanisms originating proximally from the motor neurons as well as from peripheral mechanisms originating distally from the neuromuscular junction, which includes contractile components within the muscles[10)]. Muscle fatigue is an inevitable phenomenon of the workings of the central nervous system during daily physical activities, as well as the inability to produce expected power according to power output. It has a negative effect on the proprioceptive receptors by reducing the activity of muscular mechanoreceptors or decreasing muscular function[7)].

According to previous studies that analyzed the effects of flat and high-heeled shoes frequently worn by women on the spine and joints, it was found that the maximum pressure on the heels was increased more by flat shoes than by shoes with 3 cm-high and 7 cm-high heels[11)]. Moreover, a study of the dynamic equilibrium according to the shoe characteristics in young adults and the elderly reported that stiff shoes, rubber tread soles, and high heel-collar shoes did not improve stability during walking[3)]. Additionally, according to the results of a pilot study on sensory integration and

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balance training, based on the visual feedback of performed actions with older adult subjects, balance ability with the eyes open improved both the anteroposterior (AP) sway and the mediolateral (ML) sway; however, only ML sway was improved with the eyes closed[12]. The field of vision plays an overriding role before sensory orientation brings the appropriate adjustment of posture[7], and muscle fatigue has been proven to be a major component in the impairment of the proprioceptive senses and postural control[5]. Although there have been numerous research studies regarding the visual information responsible for postural control and muscle fatigue of the lower extremities and relevant research on functional shoes and high heels, research on rain boots worn with regard to the particular characteristics of the material in special circumstances is insufficient. Thus, the purpose of this study was to investigate the effects of muscle fatigue of the lower extremities, generated while walking in rain boots of different shaft lengths, on balance abilities according to visual feedback.

## SUBJECTS AND METHODS

The subjects of this study included twelve healthy female students in their 20s enrolled at a university in Cheonan, Republic of Korea. Those with medical conditions that could affect the study, such as neurological and musculoskeletal conditions (or other medical conditions)[13], pregnancy, knee injuries, and those who had undergone lower extremity surgeries were excluded[9]. Regardless of whether they wore glasses or not, those with normal vision were selected[14]. The subjects comprehended the purpose and content of the experiment before providing voluntary written consent to participate in the research. The physical characteristics of the subjects participating in the study are shown in Table 1. This study was approved by the Namseoul University Research Ethics Committee (NSU-141006-1).

The experimental design of this study was a one-way repeated-measures test, in which one subject performed walking exercises wearing the three types of rain boots (Table 2), and the subjects were divided into Long, Middle, and Short groups according to the length of the rain boot shaft. There were three types of shoe groups and a 24-hour rest period[15]. Before the experiment, Body Composition Analyzers (Inbody 720, Biospace, Seoul, Republic of Korea) were used to identify the physical characteristics of the subjects. In order to determine the ability to balance before fatigue, a professional balance assessment and training platform (BT4, HUR labs Oy, Tampere, Finland) were used, while Romberg's test was applied and the limits of stability were measured. To induce fatigue in the lower extremity muscles, treadmill walking (SNS care m-400m, SNS Care Co., Ltd., Goyang, Republic of Korea) was performed while wearing each pair of rain boots. Then, the ability to balance was measured immediately after the exercise in order to determine the ability to balance after fatigue[16].

Treadmill walking for inducing muscle fatigue was performed for 30 minutes at a constant speed and a normal pace[17]. In this study, treadmill walking was performed at a speed of 4 km/h, a normal pace[18], with a 5-minute rest to avoid the fatigue effects. In order to determine the balance ability of the subjects before and after fatigue, Romberg's test according to visual feedback, with eyes opens (EO) and closed (EC), and limits of stability were measured. In Romberg's test, the subjects were asked to bend one leg along the anterior-posterior axis of the balance platform at a 30° angle, stand on the opposite leg, and maintain as stable a stance as possible[19] for a 60-second. In the limits of stability test, the subjects' feet were aligned along the heel and medial malleolus landmarks printed on the top of the platform. The subjects were then instructed to shift their body weight (using their ankle joints as the primary axis of motion, without changing the feet position) in different directions (one direction at a time) as quickly as possible following the appearance of a target on the monitor. Each direction of the target was randomly selected by the researcher and displayed for 8 seconds only once[20]. The measured directions were left (LT), right (RT), forward (FW), backward (BW), and total directions in this study.

The data for this study were analyzed using the statistical program SPSS version 18.0 for Windows. Levene's F-test was used to verify the homogeneity of the data, and the Kolmogorov-Smirnov test was used to prove the normal distribution. Multivariate analysis of variance (MANOVA) was used to compare the balance of the groups (Long, Middle, Short) according to timing (before and after exercise) in each walking condition. If results of MANOVA indicated significant differences in the groups, Scheffe's test was used as a post hoc analysis. When a significant difference in time was indicated, the dependent t-test was used. Statistical significance was set at $p \leq 0.05\%$.

**Table 1.** Characteristics of the subjects (N = 12)

| Characteristic | M±SD |
|---|---|
| Age (years) | 20.5±0.5 |
| Height (cm) | 159.1±5.0 |
| Weight (kg) | 51.4±7.3 |

M±SD: mean ± standard deviation

**Table 2.** General characteristics of the rain boots

| Boot type | Height (cm) | Weight (kg) |
|---|---|---|
| Long | 40 | 1.6 |
| Middle | 29 | 1.3 |
| Short | 17 | 0.8 |

## RESULTS

As a result of Romberg's test comparison of the ability to balance according to the shaft length of the rain boots, the changes in the balance ability with the eyes open are shown in Table 3, and changes in the balance with the eyes closed are shown in Table 4. There were neither interactions between the groups and time, nor the main effects of the groups, however, in terms of the main effects of the time, there were statistically significant differences between the pre-test and post-test for EO-COG area, -COG length, -COG velocity,

**Table 3.** Romberg's test comparison according to shaft length (eyes open)

| | Boots | Pre-test | Post-test |
|---|---|---|---|
| COG area** (mm$^2$) | Long | 18.92±13.79 | 59.33±85.21$^+$ |
| | Middle | 18.92±13.79 | 70.92±69.29$^+$ |
| | Short | 18.92±13.79 | 101.75±128.55$^+$ |
| COG length** (mm) | Long | 5.42±0.99 | 8.39±4.03 |
| | Middle | 5.42±0.99 | 8.28±5.29 |
| | Short | 5.42±0.99 | 7.83±3.57$^+$ |
| COG velocity** (mm/s) | Long | 0.26±0.49 | 0.35±0.13$^+$ |
| | Middle | 0.26±0.49 | 0.33±0.14 |
| | Short | 0.26±0.49 | 0.32±0.15$^+$ |
| COG length/cm$^2$ (mm/cm$^2$) | Long | 50.33±45.68 | 33.23±25.00 |
| | Middle | 50.33±45.68 | 46.30±63.89 |
| | Short | 50.33±45.68 | 19.92±22.93 |

Values are mean ± SD; COG: center of gravity; * $p < 0.05$; **$p < 0.01$; $^+p < 0.05$: compared with post-test

**Table 4.** Romberg's test comparison according to shaft length (eyes closed)

| | Boots | Pre-test | Post-test |
|---|---|---|---|
| COG area (mm$^2$) | Long | 21.66±30.55 | 29.24±34.63 |
| | Middle | 21.66±30.55 | 53.00±120.45 |
| | Short | 21.66±30.55 | 59.33±82.30 |
| COG length* (mm) | Long | 5.25±1.24 | 6.84±4.32 |
| | Middle | 5.25±1.24 | 7.69±6.23 |
| | Short | 5.25±1.24 | 7.34±3.39 |
| COG area velocity* (mm/s) | Long | 0.25±0.67 | 0.32±0.10 |
| | Middle | 0.25±0.67 | 0.32±0.25 |
| | Short | 0.25±0.67 | 0.35±0.16 |
| COG length/cm$^2$* (mm/cm$^2$) | Long | 80.20±73.27 | 52.37±45.35 |
| | Middle | 80.20±73.27 | 45.46±31.81 |
| | Short | 80.20±73.27 | 35.11±35.49$^+$ |

Values are means ± SD; COG: center of gravity; * $p < 0.05$; **$p < 0.01$; $^+p < 0.05$: compared with post-test

**Table 5.** Limits of stability comparison of ability to balance according to rain boot shaft length

| | Boots | Pre-test | Post-test |
|---|---|---|---|
| Left** | Long | 634.0±1,803.9 | 6,990.2±2,161.0 |
| | Middle | 634.0±1,803.9 | 8,368.6±2,209.3$^+$ |
| | Short | 634.0±1,803.9 | 8,465.3±2,209.3$^+$ |
| Right** | Long | 5,760.5±1,689.2 | 6,400.2±2,409.2 |
| | Middle | 5,760.5±1,689.2 | 7,323.9±1,554.5$^+$ |
| | Short | 5,760.5±1,689.2 | 6,990.1±1,332.0 |
| Forward** | Long | 7,853.2±3,008.3 | 9,925.9±3,376.5 |
| | Middle | 7,853.2±3,008.3 | 10,497.8±2,291.5$^+$ |
| | Short | 7,853.2±3,008.3 | 11,141.7±2,292.5$^+$ |
| Back | Long | 3,970.9±1,177.3 | 4,224.8±2,880.8 |
| | Middle | 3,970.9±1,177.3 | 5,077.0±2,113.3 |
| | Short | 3,970.9±1,177.3 | 4,313.8±1,887.9 |
| Total** | Long | 12,102.5±3,384.5 | 13,390.9±4,404.8 |
| | Middle | 12,102.5±3,384.5 | 15,574.9±2,723.6$^+$ |
| | Short | 12,102.5±3,384.5 | 14,807.1±3,512.4$^+$ |

Values are means ± SD; *$p < 0.05$; **$p < 0.01$; $^+p < 0.05$; compared with post-test

and for EC-COG length, -COG velocity, -COG length/cm$^2$. As a result of the dependent t-test, in the Long group, there were statistically significant differences in the EO-COG area and -COG velocity; in the Middle group, there were statistically significant differences in the EO-COG area; and in the Short group, there were statistically significant differences in the EO-COG area, EO-length, and EO-velocity, and the EC-COG length/cm$^2$ also showed a statistically significant difference.

The results of the limits of stability comparison of balance ability according to the shaft length of the rain boots are shown in Table 5. The interaction of the groups and time and the main effects of the groups were not significant. The main effects of time showed statistically significant differences between the pre-test and post-test values in the LT, RT, FW, and total directions. The dependent t-test results of the Long group did not show statistically significant differences between the pre-test and post-test; in the Middle group, there were statistically significant differences in the LT, RT, FW, and total directions between the pre-test and post-test; and in the Short group, there were statistically significant differences in the pre-test and post-test values in the LT, FW, and total directions.

## DISCUSSION

The postural control system is a dynamic feedback control system that incorporates visual, vestibular, and somatosensory information and also integrates the motor system and central nervous system. Muscle fatigue has been identified as a factor having detrimental effects on balance control[21]. The post-fatigue impairment in balance control is often attributed to deficits in neuromuscular control resulting from altered somatosensory inputs[22]; overall muscle fatigue and local muscle fatigue may restrict balance control output[23].

This study sought to determine the effects of lower-extremity muscle fatigue on balance while walking in three types of rain boots with different shaft lengths in healthy young adults. As a result of the comparative analysis of the Romberg's test, there were significant differences for time in EO-COG area, -COG length, -COG velocity and in the EC-COG length, -COG velocity, -COG length/cm$^2$. As a result of the analysis of the changes in each group pre-test and post-test, according to visual input, there were significant differences in the EO-COG area and -COG velocity in the Long group; EO-COG area in the Middle group; and EO-COG area, -COG length, -COG velocity, and EC-COG length/cm$^2$ in the Short group.

In a previous study on young healthy adults, it was reported that as a result of analyzing the effects of visual and proprioceptive sensory information on the muscle activity of the ankle joints in maintaining static balance, the workings of the ankle muscle became diversified through sensory deprivation or changes. This is because visual perception helps to maintain the standing posture and directional orientation the conscious and unconscious correction of posture is made possible through visual input. These results show the importance of visual perception in the mechanism of proprioception in the body by emphasizing its importance in postural control[24]. As a result of analyzing the changes in the angle of the joints and the position of the upper extremities, due to fatigue induced in the ankle joints and the plantar flexors in which the visual information was removed, the participants' upper extremities moved forward while their pelvises moved to the rear, and the flexion in the ankles, knees, and waist increased. This refers to the negative effects of fatigue and compensation for the deficiency of visual information in terms of postural adjustment. This strategy could increase the role of the muscles that are not fatigued and could be utilized to optimize the use of all of the associated joints in a one-leg stance[25]. In another prior study, in which a group wearing unstable footwear was compared to a control group, there were no significant difference in the hip joint, but there were significant differences in the joints of the ankle and knee. Compensation for postural sway was shown to be more in the distal joints than that in the proximal joints; the increased joint excursion of the ankle and knee while wearing the unstable shoes in a standing sway was reported to be a compensatory mechanism in response to the displacement of the center of pressure (COP) and the center of mass (COM)[26].

In this study, using the Romberg's test, it was determined that there were differences in the EO-COG area, length, and velocity and in the EC-COG length, EC-COG velocity, EC-COG length/cm$^2$, due to the effects of fatigue on the muscles of the lower extremity induced by walking in rain boots, leading to the impairment of the ability to balance. Due to muscle fatigue, visual information could not be received and it caused impairment of the balance ability. Because of the impairment of the balance ability, leading to a failure to perform the unconsciousness adjustment of posture necessary for maintaining balance. The results of the changes according to time showed significant differences when subjects performed the treadmill walking wearing the three types of rain boots (Long, Middle, Short) with the eyes open. With the eyes closed, there was a significant difference in the Short group in the COG length/cm$^2$, which may be explained by the fact that the muscle fatigue induced by walking reduced the ability to balance, and the relatively short shaft length of the rain boots increased the movement of the ankle joints. Therefore, the workload of the joints in the lower extremity increased as a compensatory mechanism due to the lack of visual feedback when the visual information was eliminated. As a result of the increased work of the distal joints, the shift in the COP and COM caused the COG to shift in the standing balance, bringing about a significant difference in the EC-COG length/cm$^2$.

In this study of the results of the comparative analyses of the limits of stability according to time, there were significant differences in pre-test and post-test values in the LT, RT, FW, and total directions. However, the results of the analysis regarding the changes in each group before and after testing showed no significant differences in the Long group while there were significant differences in the LT, RT, FW, and total directions in the Middle group and in the LT, FW, and total directions in the Short group. In a study analyzing the effects of plantar flexor fatigue on posture control, it was determined that localized plantar flexor muscle fatigue caused major impairment to sagittal postural control. When compared to the postural coordination without fatigue, plantar flexor fatigue caused a higher than average threshold sway[27]. In previous studies, it was determined that a higher response to ML sway training, with regard to rearward fall, was related to specific fundamental defects in the ML balance. These results are due to the inherent structural mechanisms of the ankle and hip joints. In contrast, a study that reported that the postural sway in healthy individuals was larger in the AP direction compared to that in the ML direction showed that when compared to that in the AP direction, the risk of falling brought about a higher sway threshold in the ML direction[12]. In the unstable shoe group, both the young adult and older adult groups had increased initial response times for joint excursion. Such results have resulted in longer reaction times when unstable shoes are worn in terms of response to the rearward sway, due to the flexing of the ankle joints and the hip joints, in which the COP has been moved forward over the forefoot because of changes in the ankle and hip joints. These differences in increased distal joint excursion and reaction time are responses to the backward sway, such as in a fall, which can result in increased instability[26]. Although physical balance improved when the shaft length of the shoes was increased[3], according to the results of a study on the effects of shoes and shoe soles on the lower extremities and the subjects' discomfort, the shoes and the shoe soles affected discomfort of the lower extremities during a long prolonged stance[28].

Accordingly, as a result of the comparison of the changes in the limits of stability in this study, it was determined that muscle fatigue induced by walking, when compared to that in a non-fatigued state, brought about increases in postural sway, causing an impairment of postural control and reducing the ability to balance, in turn causing significant differences according to time in the LT, RT, FW, and total directions. In terms of time, the results of the analysis of the changes in each group before and after showed that there were no significant differences in the Long group while there were significant differences in the LT, RT, FW, and total directions in the Middle group; and the LT, FW, and total directions in the Short group. In the Long group, the relatively long shaft of the rain boots affected the movement of the joints and did not cause a reduction in the balance ability; thus, there were no significant differences in the limits of stability. There were significant differences in the LT and RT directions in the Middle group and the LT in the Short group due to the reduced ability to balance as a result of muscle fatigue, as well as a basic balance defect in the ML direction due to the risk of a backward fall, causing the ML sway to increase. Moreover, there were significant differences in the forward direction in both the Middle and Short groups due to increased muscle fatigue-induced instability. As a response to the rearward sway, the relatively shorter shaft of the rain boots caused flexion of the ankle and hip joints to increase the shifting of the COP forward. Therefore, it was determined that instability with regard to falling caused fear, bringing about no significant differences in the rear direction of all three groups.

In conclusion, this study sought to determine the effects of muscle fatigue on the lower extremities induced by walking, wearing three types of rain boots with different shaft lengths, on balance. The subjects comprised young and healthy adults in their 20s. (1) The changes in the Romberg's test scores, the interactions of the groups and time, and the main effects of the groups did not appear to be significant. However, the main effects of time showed to be significant in the EO-COG area, EO-COG length, and EO-COG velocity as well as in the EC-COG length/cm$^2$. There were significant differences in the EO-COG area and EO-COG velocity in the Long group; the EO-COG area in the Middle group; and the EO-COG area, EO-COG length, EO-COG velocity and EC-length, EC-velocity, EC-length/cm$^2$ in the short group. (2) The changes in the results of the limits of stability, the interaction of the groups and time, and the main effects of time did not appear to be significant. The main effects of time were not significant in the LT, RT, FW, total directions, and there were no significant differences in the all directions in the Long group. However, there were significant differences in the LT, RT, FW, and total directions in the Middle group and in the LT, FW, and total directions in the Short group. These results showed that muscle fatigue in the lower extremities was induced by walking in rain boots and affected the joints and the postural control muscles. The compensatory mechanism due to the visual feedback and the length of the shoe shaft affected the motion of the distal joints more than it did the proximal joints and caused an impaired ability to balance. Thus, these results, in which muscle fatigue induced by the shoe soles and the shaft length of the shoes affected the ability to balance, are expected to aid in future research with regard to postural control, according to visual feedback and the shoe-related ability to balance.

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