Original article

Impact of heel position on leg muscles during walking

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Abstract

During gait phases, the point of initial contact (IC) between the foot and the floor is positioned outward with respect to the load line. Since typical heeled shoes are designed with the heel in the middle, the foot and the heel positions differ in the point of contact. This suggests that, during walking with heeled shoes, a load that promotes fatigue might be applied to the leg muscles. The present study therefore aimed to investigate the optimal heel position during walking using an electromyograph. Using an electromyograph to set nine conditions for heel position, muscle activity of the leg muscles (the lateral head of the gastrocnemius, the tibialis anterior, and the peroneus longus) was measured. A significant difference was observed between shoes in which the heel position was in the middle and shoes in which it was on the outside, but no significant difference was observed with different heel positions in the anteroposterior direction. The amount of muscle activity of the leg muscles was demonstrated to be reduced by shifting the heel position outward.

Introduction

Reports of research on heeled shoes include studies investigating the pattern of activity of the leg muscles when heels are worn [1,2], how plantar pressure is affected by the height of the heel [3], and how gait is affected by the shape of the heel [4], but there has been no research on heel position. Shoes have six original roles, which are “protecting the foot”, “wearing”, “comfort”, “functionality”, “fit”, and “fashion”, but general shoe manufacturers have tended to emphasize “fashion” in their designs. Heeled shoes have therefore been designed with the heel position in the middle because this is esthetically pleasing and reduces production costs. However, an anatomical feature of the lower leg is that the gravitational line passes through the center of the tibia, moves outward at the location of the ankle joint, and passes through the center of the calcaneus [5], which means that designing the heel to be at the middle causes the load line and the heel position to differ, and the point of contact between the foot and the floor is located outward with respect to the load line at the initial contact (IC) in gait phases [6]. As a result, gait when heeled shoes are worn is very unstable, and this may increase the burden on the leg muscles and promote a feeling of fatigue. The present study therefore aimed to better understand how the leg muscles are affected during walking by moving the heel position in the anteroposterior direction

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and the mediolateral direction, and use the amount of muscle activity to identify the heel positions that affect the body less.

Material and methods

(1) Subjects

The subjects were 34 healthy women (mean age 23.5 ± 3.0 years) with no abnormalities of the foot with a calcaneal valgus angle within 5°.

(2) Footwear conditions

To minimize the impact of poor fit, footwear in the form of sandals was prepared, with Velcro (Kuraray Fastening Co., Ltd., Osaka, Japan) attached to the heel girth/ball girth/MP portion (Figure 1). The shape of the heel lift was a circle, 10 mm in diameter (Figure 2), and the footwear had a heel height of 30 mm.

(3) Heel position conditions

With the point of intersection between the center line (the line connecting the second toe and the heel center) and a line at 16% of the foot length serving as a reference position for the heel, a total of nine conditions was created, with three stages (0, + 5, + 10 mm) to the rear (A-P direction) from the reference position and three stages (0, + 5, + 10 mm) to the outside (M-L direction) (Figure 3). When conditions were changed, the same examiner had the subjects put on the footwear.

(4) Selection of heel lift

The heel lift has a structure in which plastic covers an iron core, to prevent accidents with the heel lift breaking. Even those with the smallest heel have a diameter of 10 mm, and this has become the standard; therefore, a minimum diameter of 10 mm was used in this experiment.

(5) Selection of heel height

A heel height greater than 30 mm results in a Windlass action whereby the arch of the foot is lifted, and this dynamic has widely-varying individual differences, so a heel height of 30 mm, at which the Windlass action does not take place, was used in order to eliminate these individual differences.

Figure 1. Footwear used in the experiment

Figure 2. Heel lift

(6) Electromyograph (EMG)

In each heel position condition, an electromyograph (EMG; by Kissei Comtec Co., Ltd., Nagano, Japan) was used to measure the activity of the leg muscles (the lateral head of the gastrocnemius, the tibialis anterior, and the peroneus longus). Measurements were taken on a treadmill, with a measurement time of 30 s and a walking speed of 3.0 m/s (Figure 4). In addition, the amount of muscle activity during use with each shoe condition was normalized by being divided by the amount of muscle activity in barefoot walking, expressed in units of the percent reference voluntary contraction (%RVC).

(7) Selection of measured muscles

The tibialis anterior and the peroneus longus were selected because it was thought that the pronator and supinator of the ankle joint would be affected by shifting the heel position in the M-L direction, and the tibialis anterior and the gastrocnemius were selected because it was thought that the plantar flexor and dorsiflexor of the ankle joint would be affected in the A-P direction.

(8) Statistical analysis

Two-way analysis of variance (ANOVA) was used to compare the A-P direction groups and the M-L direction groups. The Bonferroni method for multiple comparisons (Wilcoxon *t*-test with Bonferroni correction) was used to compare conditions. The statistical software used the SPSS (Amos)18.0^{MT}.

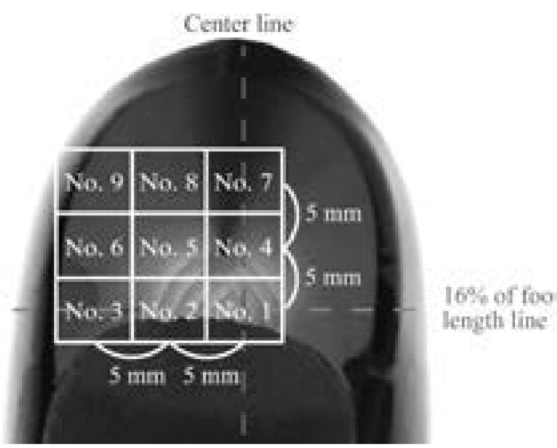

Figure 3. Heel conditions

Results

(1) Two-way ANOVA

Comparing between groups for the A-P direction and the M-L direction, significant differences were found only in the M-L direction (tibialis anterior and peroneus longus, $p < 0.01$; lateral head of the gastrocnemius, $p < 0.05$) for the three muscles of the lateral head of the gastrocnemius, the tibialis anterior, and the peroneus longus (Table 1).

(2) Multiple comparison test (Bonferroni method)

Because the results of the two-way ANOVA showed a significant difference only in the M-L direction, group divisions were made so that group I was conditions 1, 2, 3 for 0 mm in the A-P direction, group II was conditions 4, 5, 6 for 5 mm in the A-P direction, and group III was


Figure 4. Experimental set-up

Table 1. ANOVA results for effects of heel position on three leg muscles in the M-L direction group and the A-P direction group

	M-L direction	A-P direction
FL	**	n.s
GC	*	n.s
TA	**	n.s

** : p < 0.01
* : p < 0.05

conditions 7, 8, and 9 for 10 mm in the A-P direction (Figure 3). Results from the multiple comparison test showed a tendency for significant differences to be observed between 0 and 5 mm and 0 and 10 mm for all three muscles (the lateral head of the gastrocnemius, the tibialis anterior, and the peroneus longus) (Figure 5, Figure 6, Figure 7). There was also a tendency for the amount of muscle activity to be reduced by shifting the heel position outward. In a comparison of 5 and 10 mm, no significant difference was observed in any group other than group III for the lateral head of the gastrocnemius, and the increase or decrease in the amount of muscle activity was not significant between the two conditions.

Discussion

On two-way ANOVA, significant differences were noted only in the M-L direction for all three muscles. The tibialis anterior is a muscle that controls the pronation that occurs in the subtalar joint by centrifugally contracting in the loading response (LR) from IC, where muscle activity ends with the end of movement in pronation [6]. The peroneus longus is a muscle that slows down supination of the subtalar joint from mid-stance (MSt) and smoothly returns to a neutral position on terminal stance (TSt). The lateral head of the gastrocnemius is a muscle that continues contraction from MSt to TSt and aids supination of the subtalar joint and internal rotation of the femur [7]. Therefore, the amount of muscle activity is believed to change depending on the intensity of the moment in the varus-valgus direction that occurs in the ankle joint from IC to TSt in all three muscles, and shifting the heel position in the M-L direction was anticipated to

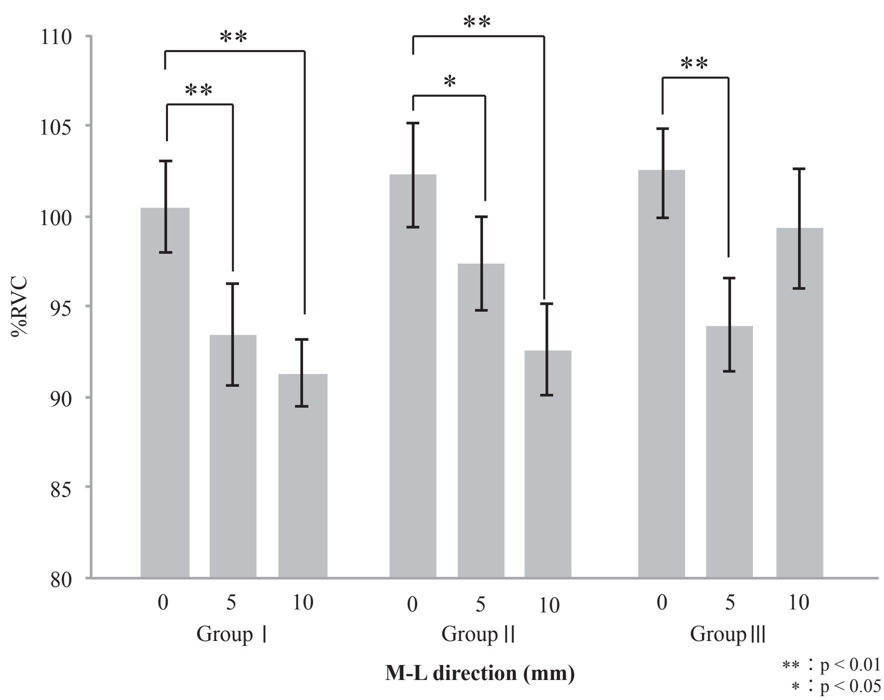

Figure 5. Comparisons of fibularis longus muscle activity for each footwear condition Group I, conditions at 0 mm in the A-P direction; Group II, conditions at 5 mm in the A-P direction; Group III, conditions at 10 mm in the A-P direction; %RVC, reference voluntary contraction

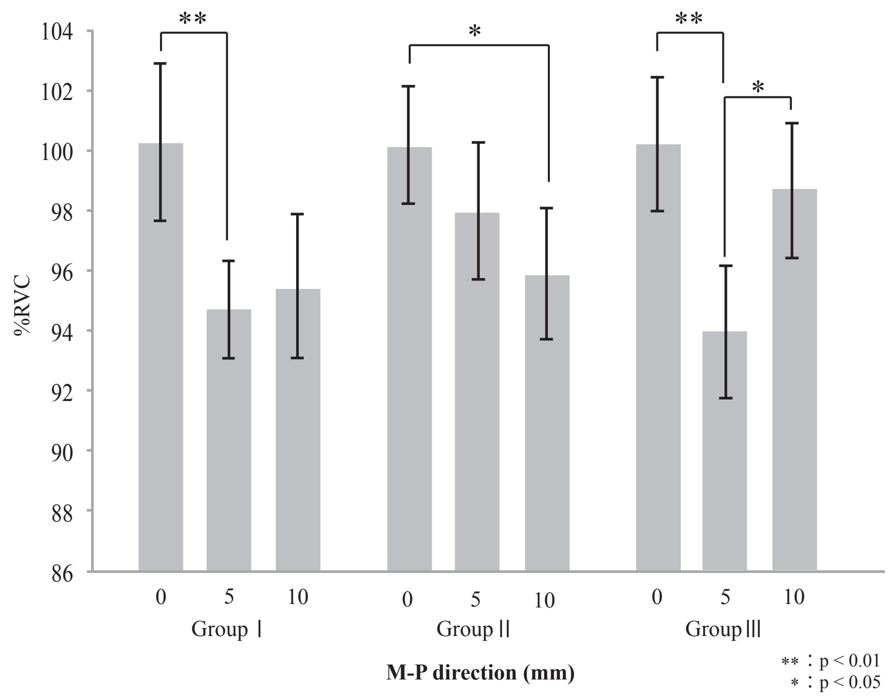

Figure 6. Comparisons of the lateral head of gastrocnemius muscle activity for each footwear condition

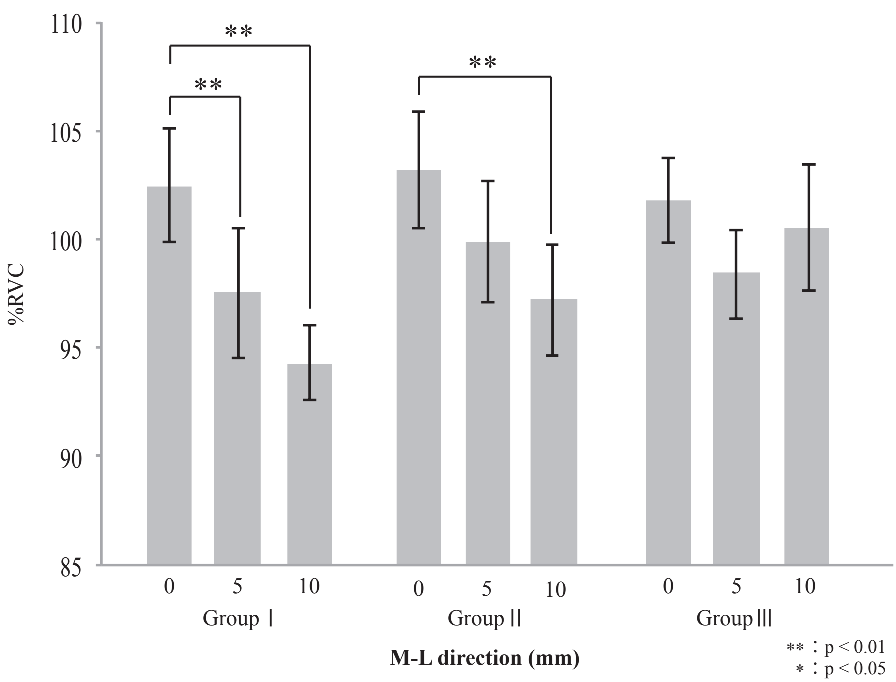

Figure 7. Comparisons of the tibialis anterior muscle activity for each footwear condition

be a factor that increased or decreased the varus-valgus moment of the ankle joint during the time from IC to TSt, which is why a significant difference was observed only in the M-L direction (Figure 8).

In the multiple comparison test, there was a tendency for the amount of muscle activity to be significantly reduced at 5 mm or 10 mm with respect to 0 mm in the M-L direction for all three muscles. At IC, the point of contact between the foot and the floor is positioned outward with respect to the load line [6], and the COP trajectory on IC moves slightly outward and goes in the direction of the hallux ball from MSt onward [8], so COP is outside the foot from IC to MSt in the gait phases. It is thought that shifting the heel in the M-L direction reduces deviation in the position of the COP for the heel and plantar surface on the frontal plane and reduces the moment that occurs in the calcaneus, thereby reducing the amount of muscle activity for all three muscles.

The reason why no significant difference was observed between 5 mm and 10 mm is believed to be because of the individual differences in gait and the different amounts of outward displacement of the COP. There is a need for future research with higher heels, because of the strong desire for shoes with heels greater than 30 mm in the design of footwear for women.

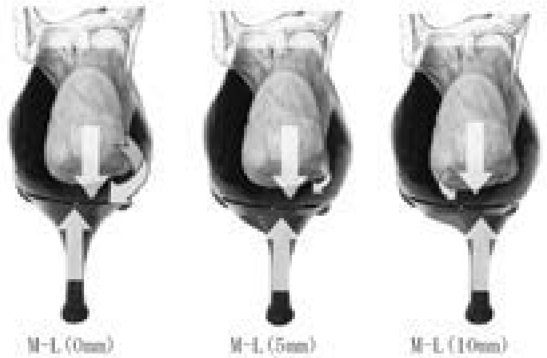

Figure 8. Moment occurring in the calcaneus by heel position

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