

## Research on the Influence of High Heels on Gait and Lower Limb Biomechanical Characteristics of Young Women (Postprint)

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### Abstract

**Objective:** To investigate the effects of different heel heights on the gait and lower limb biomechanical characteristics of young women.

**Methods:** Thirty young women aged 18-25 years were selected as subjects. Using equipment such as the Vicon Nexus 3D motion analysis system and the Novel Pedar-X plantar pressure testing system, gait spatio-temporal parameters and lower limb biomechanical parameters (joint angles, range of motion, peak pressure, and peak stress, etc.) were accurately collected while subjects wore flat shoes (heel height  $\leq 1$  cm) and high heels of different heights (5, 7, and 9 cm). The differential changes in the acquired data were compared.

**Results:** Regarding gait parameters, as heel height increased, walking speed, cadence, and stride length significantly decreased ( $P < 0.05$ ). The proportion of the swing phase decreased from  $41.22\% \pm 3.14\%$  to  $31.67\% \pm 2.11\%$ , while the proportions of the single/double support phases increased to  $68.16\% \pm 3.32\%$  and  $33.16\% \pm 4.12\%$ , respectively ( $P < 0.01$ ). The range of motion of the ankle, knee, and hip joints showed a downward trend as heel height increased ( $P < 0.01$ ); furthermore, the ankle joint remained in continuous dorsiflexion during the stance phase, the knee joint exhibited mild flexion in the mid-stance and enhanced extension in the terminal stance, and the decrease in hip joint angle reflected intensified anterior pelvic tilt. The peak pressure and impulse proportion in the forefoot area (M1-M3) significantly increased ( $P < 0.05$ ), the peak stress in the heel area significantly decreased ( $P < 0.05$ ), and the stress in the midfoot area (M4) remained the lowest throughout.

**Conclusion:** High heels lead to gait stability compensation, deviation of joint mechanical axes, and concentrated loading in the forefoot area by inducing a forward shift of the center of gravity, restricted joint mobility, and restructuring of plantar loads. It is recommended that daily heel height be controlled below

5 cm and that long-term continuous wear be avoided to reduce the risk of lower limb injury.

## Full Text

### Preamble

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Study on the Influence of High-Heeled Shoes on Gait and Lower Limb Biomechanical Characteristics of Young Women

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**Abstract: Objective** To investigate the effects of different heel heights on the gait and lower limb biomechanical characteristics of young women. **Methods** A total of 30 young women aged 18 to 25 were selected as subjects. Utilizing the Vicon Nexus 3D motion analysis system and the Novel Pedar-X plantar pressure testing system, the study collected gait spatio-temporal parameters and lower limb biomechanical parameters (including joint angles, range of motion, peak pressure, and peak tension) while subjects wore flat shoes (heel height  $\leq 1$  cm) and high heels of varying heights (5, 7, and 9 cm). **Results** Regarding gait parameters, as heel height increased, walking speed, cadence, and step length significantly decreased ( $P < 0.05$ ). The proportion of the swing phase decreased from  $41.22\% \pm 3.14\%$  to  $31.67\% \pm 2.11\%$ , while the proportions of the single and double support phases increased to  $68.16\% \pm 3.32\%$  and  $33.16\% \pm 4.12\%$ , respectively ( $P < 0.01$ ). The range of motion of the ankle, knee, and hip joints showed a downward trend as heel height increased ( $P < 0.01$ ). During the stance phase, the ankle joint remained in continuous dorsiflexion, the knee joint exhibited slight flexion in the mid-stance and increased extension in the terminal stance, and the decrease in hip joint angle reflected an intensification of anterior pelvic tilt. The peak pressure and impulse proportion in the forefoot area (M1-M3) increased significantly ( $P < 0.05$ ), while the peak pressure in the heel area decreased significantly ( $P < 0.05$ ). **Conclusion** High-heeled shoes lead to compensatory gait stability, shifts in the mechanical axes of joints, and concentrated loading on the forefoot by inducing a forward shift in the center of gravity and restricting joint mobility. It is recommended that daily heel height be kept below 5 cm to reduce the risk of lower limb injury.

**Keywords:** High heels; Walking process; Gait; Biomechanics; Lower limb joints

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## 1 Introduction

High-heeled shoes (HHS) are widely favored by women for their aesthetic appeal, yet prolonged wear significantly alters natural biomechanics. Previous research

has demonstrated that wearing high heels shifts the body's center of gravity forward, forcing the musculoskeletal system to adapt to an unnatural posture [?]. This adaptation manifests as changes in gait parameters, including reduced stride length and altered joint loading patterns [?].

The biomechanical consequences extend throughout the kinetic chain to the knees, hips, and lumbar spine. Chronic use has been linked to clinical conditions such as hallux valgus and an increased risk of knee osteoarthritis [?]. Despite extensive literature, the specific compensatory mechanisms under different heel height conditions remain a subject of active investigation. This study utilizes advanced motion capture and force plates to quantify these changes and evaluate potential long-term health implications for young women.

## 2 Materials and Methods

### 2.1 Participants

A total of 30 healthy young women (age:  $23.38 \pm 2.03$  years; height:  $164.12 \pm 2.52$  cm; weight:  $54.81 \pm 7.16$  kg) were recruited. Inclusion criteria required a frequency of wearing high heels at least three times per week for no less than two hours per instance, and no history of lower limb injuries or neurological disorders within the past six months.

### 2.2 Experimental Design

Participants walked at a self-selected speed under four conditions: flat shoes ( $\leq 1$  cm) and high heels of 5 cm, 7 cm, and 9 cm. To ensure consistency, standardized shoes of the same brand and style were used. The 5, 7, and 9 cm heels were cylindrical with a diameter of 2 cm to minimize interference from heel shape variations.

### 2.3 Data Acquisition

Kinematic data were captured using a Vicon Nexus system (UK) with eight infrared cameras at 200 Hz. Eighteen reflective markers were placed on anatomical landmarks (e.g., anterior superior iliac spine, greater trochanter, malleoli). Plantar pressure was recorded using the Novel Pedar-X in-shoe system (Germany) at 100 Hz, utilizing sensor insoles with 99 piezoresistive sensors.

[FIGURE:1] [FIGURE:2] [FIGURE:3]

### 2.4 Data Processing

The plantar surface was divided into six regions: medial heel (MH), lateral heel (LH), midfoot (MF), and metatarsals M1, M2, and M3. Statistical analysis was performed using SPSS 26.0. Repeated measures ANOVA and Bonferroni post-hoc tests were used to compare differences across heel heights, with significance set at  $P < 0.05$ .

## 3 Results

### 3.1 Gait Spatiotemporal Parameters

As heel height increased, walking speed, step length, and stride length significantly decreased ( $P < 0.05$ ). For example, walking speed dropped from  $1.67 \pm 0.11$  m/s in flat shoes to  $1.28 \pm 0.05$  m/s in 9 cm heels.

### 3.2 Gait Phase Proportions

The proportion of the swing phase decreased significantly as heel height increased ( $P < 0.01$ ), while the double support phase increased from  $22.15\% \pm 1.86\%$  to  $33.16\% \pm 4.12\%$ . This suggests a conservative gait strategy to maintain stability.

### 3.3 Joint Kinematics

During the stance phase, the ankle joint remained in a state of increased dorsiflexion compared to flat shoes ( $P < 0.01$ ). The knee joint showed slight flexion at initial contact ( $Q_1$ ) and increased extension at toe-off ( $Q_4$ ). The hip joint angle decreased, reflecting intensified anterior pelvic tilt.

### 3.4 Range of Motion (ROM)

The ROM for the ankle, knee, and hip joints in the sagittal plane decreased significantly as heel height increased ( $P < 0.05$ ). Ankle ROM decreased from  $42.33^\circ \pm 6.75^\circ$  to  $34.12^\circ \pm 6.38^\circ$  in 9 cm heels.

### 3.5 Plantar Pressure and Impulse

Peak pressure in the forefoot (M1-M3) increased significantly with heel height ( $P < 0.01$ ). In the M1 region, pressure rose from  $313.78 \pm 118.65$  kPa to  $511.75 \pm 118.06$  kPa. Conversely, heel pressure (HM/HL) decreased as the load shifted forward. The impulse proportion in the forefoot (MQ1) rose from 71.66% to 88.04%.

## 4 Discussion

The reduction in walking speed and step length is a compensatory response to the forward shift in the center of gravity. By shortening the swing phase and extending the double support phase, the body attempts to enhance stability on a narrowed base of support [?]. However, this increases the mechanical load on the supporting limb.

The restriction in ankle ROM forces the knee and hip to adopt compensatory angles. The continuous dorsiflexion of the ankle and slight flexion of the knee during the stance phase serve to lower the center of mass but increase compressive loading on the tibial plateau and patellofemoral joint [?].

Figure 4

Figure 1: Figure 4

Figure 5

Figure 2: Figure 5

The shift in plantar pressure to the forefoot is the most critical kinetic change. High localized pressure in the M1 and M2 regions is a primary factor in the development of metatarsalgia and hallux valgus. The “U-shaped” pressure trend in the lateral forefoot (M3) suggests that while moderate heels (5 cm) may temporarily redistribute some load, heights exceeding 7 cm lead to systemic mechanical failure of the foot’s natural shock-absorption mechanisms.

## 5 Conclusion

High-heeled shoes significantly alter gait stability and lower limb kinematics. The forward shift in the center of mass and restricted joint mobility lead to concentrated loading on the forefoot and compensatory adjustments in the knee and hip. It is recommended that daily heel height be kept below 5 cm to mitigate the risk of chronic musculoskeletal injuries. For heights above 7 cm, users should perform regular Achilles tendon and calf muscle stretching to counteract the effects of prolonged joint misalignment.

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## Figures

*Source: ChinaXiv – Machine translation. Verify with original.*