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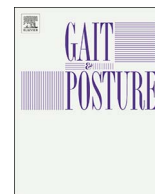
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Short communication

High-heeled walking decreases lumbar lordosis



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ABSTRACT

An estimated 78% of women regularly walk in high heels. However, up to 58% complain about low back pain, which is commonly thought to be caused by increased lumbar lordosis. However, the extent to which a subject's posture is modified by high-heeled shoes during dynamic activities remains unknown. Therefore, we sought to evaluate whether low- or high-heeled shoes influence the kinematics of the pelvis and the spine during walking. Twenty-three inexperienced women, and seventeen women experienced in wearing high-heeled shoes, all aged 20–55 years, were measured barefoot and while wearing low- (4 cm) and high-heeled (10 cm) shoes during gait at a self-selected speed. A 22-camera motion capture system was used to assess the gait patterns for each condition.

No significant inter-experience-group kinematic differences were found. In contrast to the results of some studies, our results show that the heels' height does indeed influence the motion of the pelvis and the spine during walking, whereby low-heeled shoes influenced the subjects' trunk kinematics during gait less than high-heeled shoes compared to barefooted walking. However, inexperienced high-heel wearers showed less thoracic curvature angle while wearing high-heels than while wearing low-heels. Importantly, both groups exhibited significantly lower maximum and minimal lumbar and thoracic curvature angles when wearing high-heeled shoes compared to the barefoot condition. As a result, it seems that low back pain might be associated with other factors induced by high-heels.

1. Introduction

Up to 37% of American women [1] and 78% of British women wear high heels on a daily basis [2,3]. However, the negative side effects of wearing high heels include an increased risk of falling [4,5]; increased risk of foot, tibia, and fibula fracture [6]; increased peak loads on the patellofemoral joint and thus a greater chance of patellofemoral pain [7]; and changes in the distribution of foot pressure [8]. Some 58% of high-heel shoe wearers complain of low back pain (LBP) and 55% feel inconvenienced by heel heights between 6 and 9 cm [9], which might result from increased lumbar lordosis [10,11]. However, contrary to this understanding, Russell et al. [12] reported that high-heeled shoes do not affect lumbar lordosis in a static standing posture. Despite these results, the influence of heel heights on lumbar lordosis and thoracic kyphosis remains controversially discussed [13,14], especially during gait [15]. The goal of this study was to investigate the influence of high-heeled shoes, as well as the role of experienced versus inexperienced wearers, on the kinematics of the pelvis and spine while walking in

shoes with different heel heights.

2. Methods

Inclusion criteria to participate in this study were: female, aged 20–55 years, body mass index 19–24 kg/m², and shoe size 37–40 (EU). A power analysis (*t*-test, $\alpha = 0.05$, $\beta = 0.1$), of the parameter minimal thorax curvature angle based on a test measurement revealed a minimum subject number of 17 with a power level of 0.907. Subjects were excluded if they had undergone an operation on the ankle, knee, hip, or spine prior to this study. The experienced group ($n = 17$; age 32 ± 8 years; mass 59.5 ± 4.8 kg; height 168.5 ± 6.7 cm) must have worn shoes with narrow heels and more than 4 cm in height for at least 12 h per week for at least one year; while the inexperienced group ($n = 23$; age 25 ± 4 years; mass 60 ± 6 kg; height 167.6 ± 5.5 cm) wore such shoes for a maximum of twice a month for ≤ 2 h. All participants provided informed written consent.

The study was approved by the ethics committee of the ETH Zurich

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2.1. Data collection

All participants wore standardized shoes with stiletto heels (1 cm² floor contact area) with a 4 cm (low-heel) or 10 cm heel (high-heel). After collection of their anthropometric data, one motion capture expert attached a previously validated [16,17] marker set, consisting of 77 skin markers [18], including 55 markers on the legs, pelvis, shoulders, and arms, as well as 22 on the back.

All subjects performed initial basic motion tasks to determine the joint centres [18]. Subsequently, they were measured while walking barefoot (BF), as well as in low- and high-heels at a self-selected speed and in a randomized order. As the immediate influence was studied, the subjects had no specific time to familiarize. A minimum of five valid trials, including at least one double-step, was recorded for each condition. A three-dimensional motion capture system (Vicon, Oxford, UK) with 22 cameras was used to capture the subjects' body movements at a sampling rate of 100 Hz [19].

2.2. Data analysis and outcome measures

Data analysis was performed using Matlab (MathWorks Inc., Natick, MA, USA). The sagittal lumbar (TH11-L5) and thoracic (TH3-TH11) minimal and maximal curvatures angles were calculated as the segmental angle of a circle fitted to the corresponding spinal markers [18]. The position and orientation of the proximal and distal segments were also determined relative to the reference segments, and compared to the standing trial using a least-squares fit of the corresponding marker point clouds [19,20]. The relative proximal-to-distal rotations and ranges of motion (ROMs) were based on right-handed orthogonal coordinate systems [21] for the pelvis, lower-back, mid-back, and upper-back segments.

2.3. Statistics

All statistical analyses were performed using SPSS 23 (SPSS Inc., Chicago, IL, USA). A linear mixed model with the shoe and wearer experience as fixed effects, and the subjects as a random effect was used after performing normal distribution tests (Kolmogorov–Smirnov and Shapiro–Wilk). The significance level was set at $p < 0.05$ and adjusted for multiple comparisons using Bonferroni procedure.

3. Results

No significant inter-group differences in any kinematic parameter were detected. The Bonferroni corrected significance level was $p = 0.001$.

3.1. Inexperienced wearers

The minimum and maximum lumbar curvature angles and the minimal thoracic curvature angle decreased significantly from BF to low-heels to high-heels condition (Table 1). A significant decrease in maximum thoracic curvature angle was observed between the BF to high-, and low- to high-heeled condition. A significant increase (approx. 20%) in max. frontal plane movement for BF and low-heels towards high-heels was observed for the pelvis. In the frontal plane, the ROM between lower-back and mid-back increased significantly with heel-height. In the sagittal plane, significant increases in the ROM from BF to high- and low- to high-heels were observed for all segments.

3.2. Experienced wearers

The maximum and minimum lumbar and thoracic curvatures angles all decreased significantly from BF to low-heels to high-heels (Table 2)

Table 1
Results for inexperienced group.

| Inexperienced Footwear Parameters | Barefoot Mean SD | Low heel Mean SD | High heel Mean SD |
|---|---------------------|-----------------------------|--------------------------|
| Max. lumbar curvature [°] | 55.2 ± 17.0 | 54.4 ± 15.0 ^{B,10} | 51.4 ± 16.7 ^B |
| Min. lumbar curvature [°] | 36.9 ± 17.3 | 36.6 ± 16.3 ^{B,10} | 33.8 ± 16.8 ^B |
| Max. thoracic curvature [°] | 36.7 ± 6.8 | 35.8 ± 6.7 ¹⁰ | 34.5 ± 7.7 ^B |
| Min. thoracic curvature [°] | 33.0 ± 6.7 | 31.9 ± 6.6 ^{B,10} | 30.3 ± 7.7 ^B |
| ROM frontal plane pelvis [°] | 13.5 ± 3.5 | 12.9 ± 4.2 ¹⁰ | 16.0 ± 5.1 ^B |
| ROM frontal plane pelvis to lower-back [°] | 3.4 ± 1.0 | 3.5 ± 1.1 ¹⁰ | 3.4 ± 0.9 |
| ROM frontal plane lower back to mid-back [°] | 7.4 ± 1.6 | 8.4 ± 1.9 ^{B,10} | 9.4 ± 2.4 ^B |
| ROM sagittal plane pelvis [°] | 3.7 ± 1.1 | 3.9 ± 1.1 ¹⁰ | 4.5 ± 1.3 ^B |
| ROM sagittal plane pelvis to lower-back [°] | 3.7 ± 1.4 | 3.9 ± 1.2 ^{B,10} | 4.4 ± 1.4 ^B |
| ROM sagittal plane lower-back to mid-back [°] | 13.6 ± 3.4 | 13.4 ± 3.3 ¹⁰ | 14.8 ± 4.2 ^B |
| ROM sagittal plane mid-back to upper-back [°] | 4.5 ± 1.5 | 4.5 ± 1.7 ¹⁰ | 5.6 ± 2.3 ^B |
| ROM transverse plane pelvis [°] | 8.5 ± 1.5 | 8.8 ± 2.1 ¹⁰ | 9.3 ± 2.8 ^B |
| ROM transverse plane pelvis to lower-back [°] | 3.6 ± 1.3 | 3.7 ± 1.3 ¹⁰ | 4.1 ± 1.6 ^B |

^B $p < 0.001$ significant difference to barefoot.

¹⁰ $p < 0.001$ significant difference to high heel 10 cm.

Table 2
Results for experienced group.

| Experienced Footwear Parameters | Barefoot Mean SD | Low heel Mean SD | High heel Mean SD |
|---|---------------------|-----------------------------|--------------------------|
| Max. lumbar curvature [°] | 59.5 ± 21.6 | 58.0 ± 21.6 ^{B,10} | 55.9 ± 22.1 ^B |
| Min. lumbar curvature [°] | 44.0 ± 23.7 | 42.2 ± 23.1 ^{B,10} | 39.6 ± 22.7 ^B |
| Max. thoracic curvature [°] | 37.8 ± 8.9 | 37.7 ± 9.0 ^{B,10} | 36.3 ± 9.1 ^B |
| Min. thoracic curvature [°] | 33.7 ± 9.5 | 33.8 ± 9.6 ¹⁰ | 32.3 ± 9.7 ^B |
| ROM frontal plane pelvis [°] | 15.4 ± 6.0 | 15.2 ± 5.4 ¹⁰ | 16.7 ± 5.7 ^B |
| ROM frontal plane pelvis to lower-back [°] | 3.1 ± 1.0 | 3.4 ± 1.1 ^{B,10} | 3.6 ± 1.1 ^B |
| ROM frontal plane lower-back to mid-back [°] | 8.2 ± 1.8 | 9.9 ± 1.9 ^{B,10} | 11.0 ± 2.3 ^B |
| ROM sagittal plane pelvis [°] | 3.9 ± 1.2 | 4.1 ± 1.3 ¹⁰ | 4.7 ± 1.6 ^B |
| ROM sagittal plane pelvis to lower-back [°] | 3.4 ± 0.9 | 3.8 ± 1.0 ^{B,10} | 4.5 ± 1.2 ^B |
| ROM sagittal plane lower-back to mid-back [°] | 15.8 ± 4.8 | 15.5 ± 4.7 ¹⁰ | 17.0 ± 4.7 ^B |
| ROM sagittal plane mid-back to upper-back [°] | 5.2 ± 2.5 | 5.1 ± 2.1 ¹⁰ | 5.5 ± 2.1 ^B |
| ROM transverse plane pelvis [°] | 8.7 ± 2.1 | 9.3 ± 2.6 ^{B,10} | 10.1 ± 3.1 ^B |
| ROM transverse plane pelvis to lower-back [°] | 3.6 ± 0.9 | 3.8 ± 0.8 ^{B,10} | 4.1 ± 0.9 ^B |

^B $p < 0.001$ significant difference to barefoot.

¹⁰ $p < 0.001$ significant difference to high heel 10 cm.

except that there was no difference in the minimal thoracic curvature angle between BF and low-heels. In the frontal plane, despite no differences in pelvis ROM from BF to low heels, significant increases in ROM from BF to low-heels to high-heels were observed between all segments. In the sagittal plane, the ROM of all segments increased between the BF and low-heel compared to the high-heel condition. A significant difference of approximately 24% was observed between pelvis and lower-back for BF to high-heels and 16% low- to high-heels.

4. Discussion

This study aimed to compare the effects of different heel heights on spinal and pelvic motions in experienced and inexperienced high-heel shoe-wearers during walking. There were no differences between the

experienced and the inexperienced group. This is in agreement to the findings of Hapsari and Xiong [10,22,23] that experienced wearers do not show significantly better overall performance on standing balance and functional mobility than inexperienced controls. Our data reports already differed in the curvature angle and the pelvic motion between the barefoot and low-heeled conditions in both the experienced and inexperienced groups. This is the first time that a detailed dynamic 3-D analysis of pelvis and trunk kinematics has been performed on different heel-heights and provides improved knowledge of the role of shoe types on the dynamics of spinal curvature angle.

Although our results show some small differences between BF and low-heels in pelvic motion and curvature angles with 4 cm shoes, we can support the current opinion in the literature that low-heeled shoes of up to 4 cm–7 cm can be worn while maintaining comfort, balance and mobility, as well as maintaining a low risk of injury [10,22,23]. The role of muscle activation for kinematic stabilization of the joint segments as well as the adaptation time to the shoes was not investigated in this study, but could be a crucial factor in the observed kinematic differences, and indeed in possible relationships between high-heel usage and LBP. Further research is therefore required to clearly determine the point at which heel height becomes biomechanically disadvantageous.

This study adds new evidence to the controversial discussion regarding spinal motion [13,14] in finding that, while high-heeled shoes influence the motion of the pelvis and spine while walking, they do not result in increased lumbar curvature. Our results demonstrate that during gait, inexperienced high-heel wearers in fact exhibited a significant decrease of the minimum and maximum lumbar curvature angles and the minimal thoracic curvature angle from BF to low-heels to high-heels condition and in maximum thoracic curvature angle was observed between the BF to high-, and low- to high-heeled condition. For the experienced wearers, the maximum and minimum lumbar and thoracic curvatures angles all decreased significantly from BF to low-heels to high-heels (Table 2) except that there was no difference in the minimal thoracic curvature angle between BF and low-heels. In no case was an increase in any lumbar or thoracic curvature angle observed with increasing heel-height.

In summary, spinal lordosis and kyphosis *decreased* with increasing heel height. There was no difference between the level of experience for spinal and pelvic motion. As a result, it seems that LBP might be associated with other factors induced by high-heels.

Conflict of interest statement

There were no conflicts of interest in this study.

Acknowledgment

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the

online version, at <http://dx.doi.org/10.1016/j.gaitpost.2017.03.035>.

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