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Effects of high-heeled footwear on static and dynamic pelvis position and lumbar lordosis in experienced younger and middle-aged women

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ABSTRACT

There is still conflicting evidence about the effect of high-heeled footwear on posture, especially if methodological confounders are taken into account. The purpose of this study was to investigate the effect of high-heeled footwear on lumbopelvic parameters in experienced younger and middle-aged women while standing and walking. Thirty-seven experienced younger (n = 19:18–25 years) and middle-aged (n = 18:26–56 years) women were included in this randomized crossover study. Using a non-invasive back shape reconstruction device (rasterstereography), static (pelvic tilt and lumbar lordosis angle) and dynamic (pelvic rotation, median lumbar lordosis angle and range of motion) parameters representing pelvis position and lumbar curvature were measured. In order to analyse standing and walking on a treadmill (0.83 m/s), the effects of high-heels (7–11 cm) were compared to standard control shoes. There were no effects on the lumbar lordosis angle or range of motion under static or dynamic conditions ($p > 0.05$, $d \leq 0.06$). But there was a small effect for a reduced pelvic tilt ($p = 0.003$, $d = 0.24$) and a moderate effect for an increased transversal pelvic rotation ($p = 0.001$, $d = 0.63$) due to high heel shoed standing or walking, respectively. There were no significant age-group or interaction effects ($p > 0.05$).

Altered pelvic parameters may be interpreted as compensatory adaptations to high-heeled footwear rather than lumbar lordosis adaptations in experienced wearers. The impact of these findings on back complaints should be revisited carefully, because muscular overuse as well as postural load relieving may contribute to chronic consequences. Further research is necessary to examine clinically relevant outcomes corresponding to postural alterations.

1. Introduction

While commonly used in the female population, high-heeled footwear affects posture and gait and is generally thought to be associated with back complains [1]. High-heeled footwear has been shown to have various effects on foot pathologies like hallux valgus and musculoskeletal pain [2]. It seems obvious that there are alterations in alignment and motion patterns in the foot-ankle complex. Additionally, other authors have discussed various other 'chain reaction' kinematic effects superior to the ankle [3]. A popular hypothesized compensating strategy, and probably the one most frequently investigated, is that of increased lumbar lordosis [1].

There have been conflicting findings and scientific perspectives on the lumbar lordosis and it was shown that the effects of high-heeled footwear are dependent on the habituation to this footwear and the age of the participants [4–12]. Cowley et al. [13] concluded in their review that increased lumbar lordosis angles were found predominantly in inexperienced users.

Furthermore, there have been different methodological confounders leading to difficulties in comparing the published results. While some authors investigate static outcome parameters [3–7,9,11,12], some report dynamic outcomes [6,12,14,15]. In addition, the assessment tools differ between studies using low-dose whole body x-ray [3,5], inclinometers for indirect back surface reconstruction [11], lateral photogrammetry [7] or electromyography [15]. While radiographic assessments have the advantage of direct measurement of the spinal bones it has its disadvantages and ethical limitations due to the ionizing radiation [16]. The rasterstereographic assessment provides a safe and valid alternative that has been used for example in pregnancy [17] and in scoliosis progress-monitoring investigations [18]. Additionally, rasterstereography offers the opportunity for a dynamic spine shape assessment during gait [19,20].

Due to the persistent research gap concerning assessment tools, age and habituation, the aim of this study was to investigate the effects of high-heeled footwear by means of video rasterstereography on static and dynamic pelvis position and lumbar lordosis parameters in young

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and middle-aged females experienced in wearing high-heeled shoes. Despite conflicting evidence, we hypothesized high-heel associated increased lumbar lordosis angles accompanied by corresponding pelvis position adaptations compared to a standard shoe condition.

2. Methods

2.1. Study design

The present investigation had a randomized crossover design. After a preliminary familiarization, the participants went through three repeated measures: a baseline test followed by two measurements in a randomized order (control: standard shoe condition; experimental: high-heeled shoe condition). The baseline and the control condition were the same, and were performed twice to determine the repeatability. All measures were separated by ten minutes for shoe habituation (standing, walking, and sitting).

2.2. Subjects

Thirty-seven healthy women aged 18–56 years (age 27.7 ± 8.7 years, height 1.66 ± 0.06 m, weight 58.8 ± 7.8 kg, Body Mass Index 21.2 ± 2.3 kg/m^2 ranging from 16.5 to 27.4 kg/m^2) were recruited from advertising in local newspapers. For analysis purposes, the sample was subdivided into a younger (≤25 y, n = 19) and a middle-aged (> 25 y, n = 18) group. Participants were informed about the study, the test protocol and the non-invasive character of the data assessment. The study was approved by the local ethics committee (ID: 662016) and participants gave informed consent prior to participation. The study was conducted and data were managed according to the Declaration of Helsinki in its current version.

Participants had to be used to high-heel shod walking for a minimum of three years with an average use of at least two hours per week (inclusion criteria). The presence of low back pain or any back pain history for the last two years served as exclusion criteria due to possible interfering effects on spine shape parameters [21].

High-heel exposure time was ranging between 2 and 50 h per week (13.9 ± 14.8) for a lifetime period ranging from 3 to 25 years (9.9 ± 5.5), and back pain was less than very weak (0.1 ± 0.3 pts.) in terms of a Borg pain scale [22] (Table 1).

2.3. Shoe conditions

To avoid interfering learning or disturbance effects, all participants used their own shoes. The footwear consisted of a pair of sport shoes with flat foam soles and a pair of high-heeled shoes with a recommended heel height between seven and eleven centimetres [4–6,9,10,12,15]. The average heel height was 8.7 ± 1.4 cm.

2.4. Instruments

2.4.1. Rasterstereography

Spine shape was analysed by video rasterstereography (Formetric®-System, Diers, Schlangenbad, Germany), a non-radiating device for an indirect and high resolution (10 pts./cm^2) back shape reconstruction (absolute error 0.2–0.5 mm) [23]. Specific back surface landmarks – like the vertebra prominens, the superior part of the rima ani representing the sacrum point, and the right and left lumbar dimple representing the positions of the posterior superior iliac spine – were recognized automatically to build up a Cartesian coordinate system. This coordinate system served as a body fixed calibration reference frame for a three-dimensional surface reconstruction. The distance between every point on the back surface and the optical system is calculated using triangulations (skin, projection lines, and camera). Based on every single point on the surface and its neighbour points video rasterstereography is able to provide a 3D frontal plane picture with convex, concave, or saddle-shaped areas. Thus, spinal bones beneath the skin surface can be detected. In combination with biomechanical modelling the geometry of vertebral bodies and pelvis bones can be calculated (position and direction). Consecutively, the shape of the vertebral column can be animated with its frontal, sagittal and transversal plane characteristics [23].

For static spine shape assessment, pictures were taken over a time period of 5 s (sample rate 10 frames/s) with an averaging procedure to eliminate postural sway effects. Pelvic tilt (PT°) and lumbar lordosis angle (LA°) served as highly reliable outcome variables (ICC > 0.95, SEM < 1°) in the sagittal plane [24]. For a better understanding of geometry, corresponding anatomical landmarks and subsequently derived spine shape parameters are illustrated (Fig. 1).

A conventional treadmill (Type Omega 2, Horizon Fitness, Lahntal, Germany) with a rope belt height of 15 cm was used in combination with the Formetric®-System in order to assess spinal curvature while walking. According to experiences from a pilot study, walking speed was set at 0.83 m/s with no inclination.

Spine shape was recorded for 5 s – representing approximately 5 double gait cycles – with a five-fold higher sample rate (50 frames/s) during treadmill walking. Dynamic outcomes reflected the sagittal plane lumbar angle range of motion covering all (left and right) double gait cycles (LA_ROM°). Based on this range of motion, the median lordosis angle (MLA°) was calculated representing the central tendency of all 250 sampled lordosis angle values during the observed gait cycles. Additionally, the range of pelvic rotation was examined describing motions in the transversal plane (P_ROT°). Reliability (ICC) for the dynamic variables was calculated from baseline and standard shoe condition measurements.

2.5. Statistical methods

Data were described as mean and standard deviation (SD). Normal distribution was verified (Kolmogorov-Smirnov-test). A Student's t-test was used to verify differences in demographic data between age-groups (Table 1). To analyse systematic effects, a two-way ANOVA with repeated measures (shoe conditions) and a between group effect (women's age) was conducted followed by a post-hoc procedure for the factor shoe conditions (Bonferroni-Test: BASE – CON – HEEL). In case of a significant Mauchly-test, the Greenhouse-Geisser corrected significance level was chosen. Significance was accepted for $p \le 0.05$. Additionally, Cohen's d was calculated for the difference between the

Table 1
Sample characteristics (mean ± SD) for younger (18–25 years: ≤25 n = 19) and middle-aged (26–56 years: > 25 n = 18) women with mean differences and significance level (Student's t-test), and for the total sample (n = 37) with minimum and maximum (range) values.

	age (y)		height (m)		weight (kg)		BMI (kg/m^2)		CR10 (points)		heels (cm)		experience (y)		use/week (h)	
younger	21.7	(2.6)	1.67	(0.06)	58.1	(7.7)	20.9	(2.0)	0.1	(0.3)	8.6	(1.4)	6.6	(2.9)	5.7	(3.2)
middle-aged	34.1	(8.3)	1.66	(0.07)	59.6	(8.1)	21.6	(2.5)	0.1	(0.3)	8.8	(1.4)	13.5	(5.3)	22.5	(17.4)
mean diff. (p-value)	12.4	(< 0.001)	0.01	(0.766)	1.5	(0.566)	0.7	(0.327)	0.0	(0.622)	0.2	(0.668)	6.9	(< 0.001)	16.8	(0.001)
Total	27.7	(8.7)	1.66	(0.06)	58.8	(7.8)	21.2	(2.3)	0.1	(0.3)	8.7	(1.4)	9.9	(5.5)	13.9	(14.8)
range	(18–56)		(1.54–1.78)		(45–80)		(16.5–27.4)		(0–1)		(7–11)		(3–25)		(2–50)	

BMI: Body Mass Index; CR10: category (C) pain scale with ratio (R) properties (Borg, 1990).