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# Biomechanical Aspects of the Spine of Women with High Heels, Pain and Their Influencing Factors - A Cross-Sectional Study

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## 1. Abstract

**Purpose:** High heels have been a fashion mainstay for women for 100s of years despite the well-known fact that wearing them often causes pain in the feet, legs and back. The cause of this pain is complex and the root cause of it has not been determined because a study exploring the biomechanical effects on the vertebral torsion moment on wearers has not been undertaken.

**Methods:** Using video raster stereography, 140 women were measured while in bare foot and while wearing high heels. The collected parameters formed the basis for biomechanical model calculation in order to make more accurate statements about the torsion moment and muscle strength. In addition, a multivariate regression analysis was carried out to evaluate influence factors on pain that occurred while wearing high heels.

**Results:** One hundred and thirty-six women (97 %) aged 18 to 79 years finished the study. The comparison between the measurement points showed a significant difference in the torsion moment. In the regression analysis, the heel height and the frequency of wearing high heels were significant factors influencing the occurrence of pain.

**Conclusion:** Wearing high heels is associated with changes in the posture parameters. The torsion moment is reduced but it does not influence the development of pain which is mainly affected by the height of the heels and the frequency of wearing high heels. In the present study especially, the wearer's feet were affected.

## 2. Keywords: Women; High heels; Biomechanic; Pain

## 3. Introduction

Wearing high heels is common in the modern society. Approximately, 78% of all women regularly wear high heels [1]. For many women, they are an important part of their gender identity, they increase the perception of attractiveness and lead to psycho-sexual advantages [2]. At the same time, wearing heels is associated with discomfort [3], musculoskeletal [1,4-7] and patellofemoral [8] pain.

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The causes of this pain are complex and to date, it has not been fully clarified. There is agreement that there is a change in posture and balance as a result of wearing high heels [6,9] and this increases the risk of falling [10,11]. There are contradictory opinions on extent and exact localisation of the cause of the pain. Some authors point to an enhanced static lumbar lordosis [1,4,12,13] and others consider it to be caused by a reduced lumbar lordosis [14,15]. There are also contradictory statements on the shift of the gravitational line, the head posture and the pelvic inclination of women wearing high heels [13,15-17].

Links in the biomechanical adjustment processes, caused by changes in posture due to wearing high heels, have not been considered in the biomechanical models in this study. The objective of this study is to verify a biomechanical model by collecting torque data within the spine. An assessment has also been made to determine if pain occurring while wearing high heels is caused by the total change of the vertebral statics or due to other influencing factors.

## 4.Methods

The aim of this study is to examine the effect of wearing high heels on women’s posture and biomechanics. At the same time, factors influencing the associated pain will be evaluated.

### Study design and recruitment

The study design corresponds to a monocentric, clinical examination of a treatment group in cross-sectional design. The recruitment of the test subjects was carried out by the clinic. A flyer campaign also attracted female test subjects.

### Inclusion and exclusion criteria

Exclusion criteria of the clinical examination were females under 18, growth retardation, anatomical deformities of the spine, previous spinal surgery and psychiatric diseases. Participants who did not meet any of the exclusion criteria were included in the clinical trial.

### Imaging examination methods - Video raster stereography (VRS)

In order to document changes in the posture of the test subjects, we used the method of photogrammetric measurement of the back using raster stereography. A grid of parallel lines is projected onto the back surface of the test subjects and deformed by the body's own surface contour [18,19]. Each of the 81 transverse lines consists of light points that are captured by a

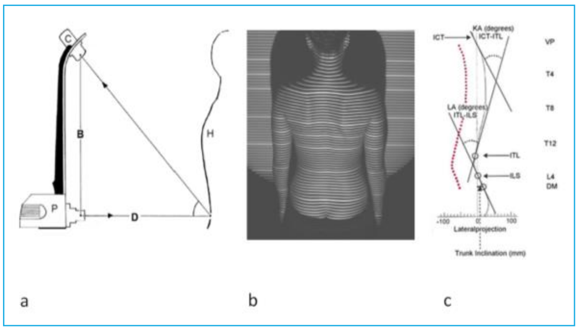


**Figure 1:** Schematic representation of the video raster stereography (according to Drerup), video camera (C), strip projector (P), human back surface (H), base distance (B) between camera and projector, distance (D) to the patient a; Sagittal profile with kyphosis angle (KA), lordosis angle (LA), trunk inclination (TI), inflectional point cervicothoracal (ICT), inflectional point thoracolumbar (ITL), inflectional point lumbosacral, dimple middle (DM) correspond to kyphosis angle, lordosis angle, trunk inclination, turning points and lumbar pit center c.

camera system [20]. In a medium sized person, 25,000 measuring points are recorded initially and afterwards reduced by interpolation for reasons of smoothing and data reduction. This results in a homogeneous distribution of 8,000 points with a depth resolution of 0.2 mm [21]. Via fixed points (Figure 1c; spinous process symmetry line, vertebra prominens, left and right dimple, sacrum point) a reference system corresponding to the body is formed from space coordinates (x, y, z). Triangulation automatically generates mathematical parameters for the calculation of the frontal and sagittal planes and for surface rotation. Accordingly, statements can be made about the kyphosis angle (in degree, ˚), the lordosis angle (in degree, ˚) and the forward leaning of the trunk (in degree, ˚) (Figure 1d). The maximum kyphosis angle results from the surface tangent of the upper inflectional point cervicothoracic (ICT) at the vertebra prominens (VP) and the inflectional point thoracolumbar (ITL). The maximum lordosis angle describes the angle formed by the surface tangent the points ITL and the inflectional point lumbosacral (ILS). The trunk inclination is the difference in height between VP and dimple middle (DM) related on the vertical plane (sagittal section) (Figure 1d).

With the used DIERS® for metric 4D system it took six seconds to record the back surface for the static analysis of the standing posture. Two pictures per second were generated, so in the end there were 12 pictures of the posterior trunk available for the measuring system. In order to define single shape parameters from the image series, an algorithm calculates averages from the complete scan. In line with the data reduction, the algorithm chooses one out of 12 images which is closest to the average results and reports these parameters to the spine scanner [22]. In the present investigation, three shots were taken while barefoot and three shots were taken while wearing high heels. These images were included in the evaluation. The method of VRS was already applied in different studies [18,19,23-25] and achieved very good results for the intratester as well as the intratester reliability for ka, la and ti. Raster stereography is a dependable method for a non-invasive and three-dimensional assessment of the spinal alignment in normal non-scoliotic individuals in the sagittal plane [26]. VRS can also help patients with scoliosis or other constitute deformities to record and monitor the disease progression [20,27,28]. Being free of ionising radiation might be the major advantage of VRS compared to radiological examinations [21].

The x and y coordinates of the sagittal profile served, among other aspects, as a basis for the biomechanical model of the spine described in the following (Figure 1c).

## Biomechanical model of the spine

For many years, research has focused on the biomechanics of the spinal column and has produced models that provide valuable insights into the effects of force and stabilization. The model developed by Bergmark [29] represents the basis of this study and has already been successfully applied to pregnant and osteoporotic women [18, 19] (Abb. 2).

The symbols, units and indices used here are shown in the supporting table. Furthermore, the following values are significant.

**Trunk length:** It is the perpendicular connection between the seventh cervical vertebra (C7) and the middle of the lumbar grove (LG), is associated with the y coordinate and was measured with the aid of VRS.

**Vertebral body height:** This was taken from the investigation of Berry et al. [30]. The existing X-rays of the patients were used to evaluate the theoretical model by performing our own measurements and calculations.

**Body mass:** The percentages of body mass from C7 to the first sacral vertebra (S1) are based on Duval-Beaupere's study [31]. The suggested percentage distributions are reflected in the calculation of actual body mass.

**Intervertebral disks:** A quasilinear adjustment of intervertebral disk height was performed for the model. In order to consider differences in the patients' trunk length, a percentage compression factor was introduced. When no compression factor was available, we refer to the original values stated by Berry et al. [30] and our assumed values. **Compression was calculated according to the following formula:**

Reference height = Original height ´ (1 –Compression factor).

With the aid of the compression factor, one can adjust the trunk length of the model to the actual trunk length (VRS). For instance, according to Berry et al. [30] the vertebral body height of L5 is 27 mm and for a patient with a trunk length of 508 mm the vertebral body height of L5 is 22.2 mm. This is equivalent to a compression factor of 17.8 percent.

**X-coordinate:** The x-coordinate (Figure 1c) is derived graphically from lateral VRS images.

**Weight force:** The weight force acting on each section of a segment is calculated as the product of the mass of this section and gravity (9.81 $m/s^2$).

**Gravitational line:** On average it runs about 1 cm before the mid-point of the ventral-most lumbar vertebra. According to Asmussen [32] it is the fourth lumbar vertebra.

**Muscle strength:** A global epicenter of the trunk is assumed for the calculation of muscle strength (erector spinae muscles). The following equations are important for the calculations:

$M_G = F_G x\ h$

The resulting moment must be equivalent to the moment arising from muscle strength and the lever arm c.

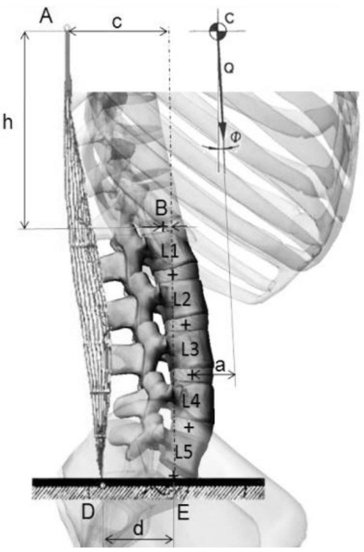


**Figure 2:** The geometrical parameters used to describe posture and position of the gravity line A: insertion of the global erector spinae muscle, B: T12-L1 disk-midpoint C: the combined center of gravity of upper body weight and the weight that constitutes the outer load (Q), D: origin of the global erector spinae muscle, E: L5-S1 disk-midpoint, a: distance from the most anterior disk-midpoint to the gravity line. The coordinates of the global muscle insertions on the thoracic cage are given by c and h. c = 59 + 21 mm and h = 100 mm. The coordinates of the origin D are given by d = 60 mm. Φ trunk inclination (according to Bergmark).

The corresponding muscle strength can be calculated there from.

$M_G = M_{MK}$

$F_{MK} = M_G / c$

**Lever arm:** It is the horizontal projection of the distance between the epicenter of the observed section and the midpoint of the vertebral body in this section. The lever arm consists of several components. The first is distance a (Figure 2). The second is the sagittal shift of the midpoint of the vertebral body in the most ventral location. The third results from the x-shift due to trunk inclination (change in the Φ angle). This is selected so that the measured point (C7) coincides with the model point. The fourth component is the respective averaged x-value of the corresponding section. The lever arm is calculated by the following formula:

$h_n = a + x_{(max.LWK)} + x_{(\Delta\Phi)} - x_n$

**Symbols and units used:**

a [mm]: distance between the most anterior disc centre and the line of gravity.

c [mm]: distance between the global back muscles and the line of gravity.

F [N]: Force

h [mm]: Lever arm

M [Nm]: Torque

x [mm]: x-coordinate

Φ [°] Angle

**Indices:**

G: Weight force

max. LWK: maximum deflection of the lumbar vertebrae towards ventral

MK: Muscular strength

N: Single component

n: Run index of the individual levels

**Heel height, plateau height, heel width**

We determined the heel height, plateau height and heel width with help of a ruler with a graduation of one tenth of a centimetre.

For the examination the women wore their personal footwear and preferred heel. The choice of using personal footwear resulted also from the age span of the study group. We assumed that older women would be more challenged to maintain their posture control in standardised or higher heels than younger women. The somatosensory changes coming with higher heels would have increased the risk of falling of older women [33,34] and secondly, negative effects on sagittal posture parameters should be avoided.

The height of the heels without the platform height is classified as follows: flat heels up to 5 cm, medium heels up to 7.5 cm and high heels 10 cm and over.

### Shoe types

### Following types of shoes were differentiated:

- Sandals - light and usually flat shoe made of straps or pierced leather.
- Wedge heel - wide and straight shoe that uses most of the posterior foot section as a walking surface.
- Pumps - wide cut or closed low shoes without tying and flat soles.
- High heels - shoes with heels higher than 10 cm and over.

### Numerical rating scale

The numerical rating scale (NRS) was used in the present clinical investigation. This is a one-dimensional pain scale based on 11 grades, where 0 means no pain and 10 means the strongest pain imaginable. Within this range, the subjects selected the number relating to their pain perception. The advantage of this system is the low error rate of the results and at the same time a high acceptance among the test persons [35].

### Statistics

The collected data was analyzed with the statistical software package SPSS, version 23.0 (SPSS Inc., Chicago, USA). The first step involved a descriptive analysis. The quantitative characteristics were each described as mean, standard deviation, minimum, maximum and number of observations available and were represented using the interval mean ± standard deviation. Absolute and percentage frequencies specify the individual characteristics and their instances.

For comparisons between the measurement points, the Wilcoxon-test for two depending samples was used. The selection was made in dependence of the result of the Kolmogorow-Smirnow-test for normal distribution. In the case of a normal distribution, the independent t-test was used. For testing qualitative characteristics and analysing categorical frequencies the Chi$^2$-test was used. Having statistically significant results in the Chi$^2$-test, an analysis using the Mann-Whitney-U-tests was carried out between two independent samples. Second, the effect strength was calculated by the ratio of the amount of the test value (z) and the square root of the amount of test person (n). The return value between 0.1 and 0.3 was interpreted as a weak effect, a value between 0.3 and 0.5 as a moderate effect and values greater that 0.5 as a strong effect. Furthermore, a successive multivariate Cox analysis (backward logistic regression) was carried out to identify independent predictors on pain while wearing high heels. All variables in the univariate analysis that differed with p-values $<0.05$ were included in multivariate models.

All p-values were a result of bilateral statistical tests and in general $p \leq 0.05$ was considered to be statistically significant.

## 5. Results

### Test subjects and basic characteristics of the study population

The clinical study started with 140. One woman was excluded before the initial examination because she underwent a surgery on her spine. A second woman reported severe pain during the VRS-recordings while standing on her high heels and as a result these images where incomplete and could not be analysed. The VRS-evaluation failed for two other participants due to significantly increased BMI.

The participants were aged between 18 and 79 years (35.7 ± 13.0) and 136 completed the clinical examination (97.1 %). Table 1 summarises the basic characteristics of the study population.

**Table 1:** Basic characteristics of the study population (n=136).

| General anamnesis | M ± SD (min.-max.) |
|---|---|
| Age (years) | 35.7 ± 13.0 (18-79) |

| | |
|---|---|
| Height (cm) | 168.4 ± 6.0 (155.0-184.0) |
| Weight (kg) | 67.7 ± 12.7 (44.3-132.0) |
| BMI (kg/m$^2$) | 23.9 ± 4.2 (17.2-43.1) |
| Waist-to-hip ratio | 0.8 ± 0.1 (0.7-1.0) |
| Waist-to-hightratio | 0.5 ± 0.1 (0.4-0.7) |
| **Back painhistory** | |
| Yes/no (%) | 69.1/30.9 |
| **Frequency of pain** | |
| Daily (%) | 16.2 |
| Occasional (%) | 52.9 |
| Never (%) | 30.9 |
| **Painintensity** | |
| NRS (0 bis 10) | 2.9 ± 2.4 (0-10) |
| **Localisation** | |
| Cervical spine (%) | 25.5 |
| Thoracic spine (%) | 9.6 |
| Lumbar spine (%) | 56.4 |
| Entire back (%) | 8.5 |
| Regular pain medication Yes/no (%) | 5.9/94.1 |
| **Musculoskeletal disorders** | |
| Rheumatic disorders yes/no (%) | 5.1/94.9 |
| Orthopedic disorders yes/no (%) | 23.5/76.5 |
| **Activity profile** | |
| Sitting (%) | 37.5 |
| Standing (%) | 9.6 |
| Mixed (%) | 52.9 |
| Activities requiring back muscles yes/no(%) | 39/61 |
| **Sports activity** | |
| yes/no(%) | 66.9/33.1 |
| **Characteristics of shoes** | |
| Shoe size (D) | 38.7 ± 1.4 (35-44) |
| Wearer (years) | 19.0 ± 12.3 (3-63) |
| **Frequency of wearing** | |
| Daily (%) | 5.1 |
| Occasional(%) | 94.1 |
| Never (%) | 0.7 |
| Heel height (cm) | 7.9 ± 2.1 (1.4-13.4) |
| Plateau height (cm) | 0.7 ± 0.8 (0-4) |
| Heel width (cm) | 2.2 ± 1.3 (0.7-6.2) |
| **Shoe type** | |
| Pumps (%) | 39.0 |
| High heels (%) | 33.1 |
| Cuban heels (%) | 19.9 |
| Boots (%) | 4.4 |
| Sandals(%) | 3.7 |

Data expressed as mean value ± standard deviation (M±SD) and percentage (%).

## Biomechanics

### Baseline characteristics

Wearing high heels affects the posture and therefore the biomechanics of the wearer.

### Group

### Global torque

The global torque was significantly changed by wearing high heels (p=0.032). Altogether this effect was weakly defined (r=0.130).

### Global muscle strength

The results of calculations on muscle strength of the m. erector spinae indicate that changes of the global torque accompany changes in muscle strength. This stands out as a statistical trend (p=0.072).

### Local torque

The local torque is the added up torques which affect every single vertebral body. Therefore, by contrast to the global torque, single centres of gravity were considered that resulted from the shift of the x-coordinate. The local torque wasn't significantly different between measurement points (p>0.05).

### Torque range

Values between -2.5 bis +2.5 Nm were defined as physiological (group PT), values outside of this range were defined as unphysiological (group UT). The median body weight of both groups was (PT 63.5 kg *vs.* UT 66.6 kg, p=0.009) and the effect cause by size was medium-strong (r=0.225). A comparison of the BMI was also very significant with the medium effect size (p=0.005, r=0.243). With regards to the plateau height and heel width, very significant differences were found in both parameters (p=0.004) and the effect was moderate for the plateau height (r=0.244) and heel width (r=0.249). The group comparison of trunk inclination showed a very significant difference (p=0.004). Here, too, the effect was moderate (r=0.247).

In contrast, the parameters of age, body height, years of wearing, shoe size, NRS, kw and lw it was found that there were no significant differences between the measurement points (p>0.05). Table 2 gives an overview of the influencing factors on characteristics of the torque.

**Table 2:** Comparison of groups: torque.

| Parameter | Physiological torque* (n=67) | Unphysiological torque (n=69) | Z-value | p-value$^M$ | Effektsize r |
|---|---|---|---|---|---|
| Age (years) | 30 | 33 | -1.349 | 0.177 | ---------- |
| Weight (kg) | 63.5 | 66.6 | -2.625 | 0.009 | 0.225** |
| Height (cm) | 168.0 | 170.0 | -0.829 | 0.407 | ---------- |
| BMI (kg/m$^2$) | 22.2 | 23.9 | -2.834 | 0.005 | 0.243** |
| Wearer (years) | 14 | 16 | -1.031 | 0.303 | ---------- |
| Shoesize (D) | 39.0 | 39.0 | -0.689 | 0.491 | ---------- |
| Plateau height (cm) | 0.0 | 1.0 | -2.841 | 0.004 | 0.244** |
| Heelwidth (cm) | 1.5 | 2.2 | -2.903 | 0.004 | 0.249** |
| NRS (0-10) | 3 | 3 | -0.801 | 0.423 | ---------- |
| Kw (degree angle) | 53.3 | 53.0 | -0.618 | 0.536 | ---------- |
| Lw (degree angle) | 43.0 | 45.7 | -1.659 | 0.097 | ---------- |
| Rn (degre | 2 | 3.7 | -2.882 | 0.004 | 0.247** |

| | | | | | |
|---|---|---|---|---|---|
| e angle) | | | | | |

*defined as the range between +2.5 und -2.5 Nm, data expressed as median, [M]Mann-Whitney-U-test, *weak, **moderate, ***strong.

### Pain while wearing heels

In total, 57.4% of the group reported pain while wearing heels. The feet were most frequently affected at 47.8% and 5.9% of the participants reported pain in buttocks and legs. Just 3.7 % experienced back pain, less than in the general anamnesis (Table 1). Comparing the groups with and without pain a statistically significant difference regarding the age was noticeable (p=0.030). Participants older than 50 years were affected less frequently (≥50 y 36.4 % *vs.* <50 y 61.4 %). There was also a significant difference between those recording pain and the shoe type (p<0.001) as well as a significant difference regarding the frequency of wear (p=0.016). The level of education was also significant different between both groups (p=0.023). It was found that 69.1% of the participants with higher education and just 49.4% of the participants with secondary school qualifications reported pain when wearing heels. Comparing the global torque between both groups, there was a difference in the statistical trend (p=0.053). N statistical differences could be determined for the other included parameters (Table 3).

**Table 3:** Group comparison regarding back pain while wearing heels.

| Parameter | Pain | No pain | p-value [c] |
|---|---|---|---|
| Age<50/ ≥50 years | 70/8 | 44/14 | 0.030 |
| BMI normal/not normal | 56/22 | 33/24 | 0.124 |
| Education ≥12/≤10 years | 38/40 | 17/41 | 0.023 |
| Activity profile active/inactive | 24/54 | 21/37 | 0.505 |
| Sedentary work yes/no | 29/49 | 22/36 | 0.929 |
| Activities requiring back muscles yes/no | 31/47 | 22/36 | 0.830 |
| Shoe type high heels yes/no | 46/32 | 14/44 | <0.001 |
| Frequency of wearing frequently/rarely | 7/71 | 14/44 | 0.016 |
| Sports yes/no | 51/27 | 40/18 | 0.661 |
| Rheumatic disorders yes/no | 4/74 | 3/55 | 0.991 |
| Orthopedic disorders yes/no | 16/62 | 16/42 | 0.336 |
| Regular pain medication | 3/75 | 5/53 | 0.242 |
| Global torque physiological/unphysiological | 44/34 | 23/35 | 0.053 |

Data expressed as amount n, [c]Chi²-test.

The height of the heels was significantly different between both groups and it was found that the group experiencing pain wore higher heels (8.2±2.0 cm *vs.* 7.4±2.2 cm, p=0.024).

### Influencing factors on the pain

Independent predictors on pain while wearing high heels should be identified by a gradual multivariate logistic regression analysis.

All variables that differed with a p-value <0.05 in multivariate analysis were integrated in multivariate models.

It was found that there was a statistically significant value regarding the frequency of wearing (p=0.045) and a statistically very significant value regarding the shoe type (p=0.002).

All the other parameters included in the analysis did not reveal statistically relevant results (p>0.05) (Table 4).

**Table 4:** Influencing factors on back pain while wearing heels (n=136).

| Parameter | p-value c | OR | 95.0% CI for OR | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Age (years) | 0.962 | 0.997 | 0.900 | 1.105 |
| Years of wearing | 0.640 | 1.026 | 0.921 | 1.144 |
| Frequency of wearing (frequently/rarely) | 0.045 | 3.128 | 1.026 | 9.538 |
| Shoe type high heels >7.5cm | 0.002 | 7.234 | 2.045 | 25.587 |
| Heel height (cm) | 0.130 | 1.235 | 0.940 | 1.622 |
| Heel width (cm) | 0.737 | 1.061 | 0.752 | 1.497 |
| Group torpue heels | 0.980 | 1.011 | 0.445 | 2.294 |

Omnibus test p=0.001 (needs to be significant to continue the regression).

## 6. Discussion

This study explored the impact of wearing high heels on women's body posture from a biomechanical perspective and looked at factors influencing pain while wearing high heels. Our results showed changes in the vertebral torque. It was complicated to classify those changes however because there are limited studies on this topic to compare. The available studies used different research methods or patient groups. Our study found much lower torques while in barefoot as well as on high heels compared to a study focusing on women with osteoporosis. That study showed global torques between 4 Nm and 5 Nm [18]. One reason is the pathology of osteoporosis itself. The KA is unphysiologically increased by forming wedge vertebrae and influencing the trunk inclination. The test subjects in this study were also much old than in our study.

The ranking-test performed in our study showed predominantly negative rankings, therefore we expected a torque-reduction and a concomitant straightening of the trunk, which correlates to data already published. Bendix et al. [14] reported a decreasing lumbar lordosis and pelvic inclination with increasing height of the heels and constant gravitational line and activity of back and abdominal muscles. Opila et al. [15] noticed a flattening of the lumbar spine in their test subjects. Iunes et al. [16] report, however, that neither the frequency of wearing or the shoe type influences the static posture.

We assumed that the body's centre of gravity is constantly balanced, regardless the height of the heels. However, results from Ko and Lee [3] suggest otherwise. The objective of their investigation was to determine the optimum height of heels by shifting the contact centre point and changing the distribution of foot pressure after walking with different heel heights. They found that both flat (0.5 cm) and high (9 cm) heels impact negatively on the body. Consequently, shoes with medium heels (4 cm) should be preferred to low (0.5 cm) and high (9 cm) heels for health and comfort of the feet.

Besides the body posture, the associated pain of the wearer was of major significance. On this point, the shoe type and frequency of wearing high heels was found to be an independent influencing factor and the participants reported the presence of pain more often when they rarely wore high heels. A study by Pratihast et al. [36] showed that wearing heels caused an increase in muscular synchronisation and this change reduces the lower shoes are and the less frequently high heels are worn. At the same time, it is possible to deduce that the height of the heels is an influencer. In our study, the heels of the high heels were significantly higher in the pain-group than in the group without pain. Hong et al. [37] reported that that higher heels significantly restrict the feeling of comfort and the biomechanics whereby the latter is setting directly on the feet by the heel lift. Weidemeijer and Otten [12] expect in their review that raising the plantar flexion results in an increased knee flexion. As a result, the knee needs to compensate for the loss of strength in the ankle by increasing strength in the knee. At the same time, the increased in knee flexion improves shock absorption, which is partly lost in the ankle and also allows an early stress on the forefoot that improves balance. According to the authors, the described knee flexion requires an anterior pelvic inclination which again increases the lordosis and lumbar muscle activity. The results relate to the gait of the person wearing high heels, the dynamic situation and it can only be compared to some extent with present static surveys. But it does provide valuable information on the interaction of the kinematic chain.

A final evaluation of wearing high heels is not possible and needs additional investigation. Studies indicate that wearing high heels can have a negative impact the quality of health in general and especially the feet [38]. Apart from that, unsuitable shoe sizes have significant adverse effects on foot health and the wearer's quality of life.

## 7. Limitations

The cross-sectional design and the limited group size, especially within the age groups, are limitations of the present study. In addition, the missing normal distribution of some parameters is to be mentioned. More complex statistical methods could not be applied, so that the available results cannot be generalised easily. The posture is interindividual different and is also subject to daily fluctuations. A measurement at the same time of day was not logistically feasible. Furthermore, the lack of blinding of both the test person and the investigator should be mentioned as a further limitation.

## 8. Conclusion

- Wearing high heels changes the acting vertebral torque
- The body's centre of gravity is always balanced regardless the heel height
- Heels higher than 7.5 cm are an independent influencing factor on associated pain
- The frequency of wearing is an independent influencing factor on associated pain

## 9. Declaration

### Ethical Approval

We declare that this study with human subjects is in accordance with the Helsinki Declaration of 1975 as amended in 2000 and that it has been approved by the competent institutional ethics committee (Trial registration No. A 2018-0095).

### Consent to participate

All subjects were informed comprehensively about the methods, purposes and risks of the study protocol and also received a written declaration of informed consent.

### Consent for publication

CD agreed in writing to the publication of the illustration.

### Competing interests

We certify that there is no competing of interests with any financial organization regarding the material discussed in the manuscript. All authors in this study declare that they have no competing interests.

### Authors' contribution

HCS led the investigation and is co-responsible for the clinical trial concept. He also participated in the recruitment of the test subjects. GS organized the cooperation with the company DIERS® and designed the data preparation concept. CD carried out the survey, measurement and documentation of the data. She also participated in the recruitment of the test subjects. RB participated in the data preparation and correction of the typesetting. DW developed the biomechanical model. SR implemented it. VB was responsible for the translation of the journal article and the recruitment of the test subjects.

AH carried out the statistical data evaluation. DW developed the biomechanical model. SR implemented it.

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## 11. References

1. Baaklini E, Angst M, Schellenberg F, Hitz M, Schmid S, Tal A, et al. High-heeled walking decreases lumbar lordosis. Gait Posture. 2017; 55: 12-14.
2. Barnish MS, Barnish J. High-heeled shoes and musculoskeletal injuries: A narrative systematic review. BMJ Open. 2016; 6: e010053.
3. Ko DY, Lee HS. The Changes of COP and Foot Pressure after One Hour's Walking Wearing High-heeled and Flat Shoes. J Phys Ther Sci. 2013; 25: 1309-1312.
4. Dai M, Li X, Zhou X, Hu Y, Luo Q, Zhou S. High-heeled-related alterations in the static sagittal profile of the spino-pelvic structure in young women. Eur Spine J. 2015; 24: 1274-1281.
5. Mika A, Oleksy L, Mika P, Marchewka A, Clark BC. The effect of walking in high- and low-heeled shoes on erector spinae activity and pelvis kinematics during gait. Am J Phys Med Rehabil. 2012; 91: 425-434.
6. Hapsari VD, Xiong S. Effects of high heeled shoes wearing experience and heel height on human standing balance and functional mobility. Ergonomics. 2016; 59: 249-264.
7. Lee C-M, Jeong E-H, Freivalds A. Biomechanical effects of wearing high-heeled shoes. International Journal of Industrial Ergonomics. 2001; 28: 321-326.
8. Ho K-Y, Blanchette MG, Powers CM. The influence of heel height on patellofemoral joint kinetics during walking. Gait Posture. 2012; 36: 271-275.
9. Wan FKW, Yick K-L, Yu WWM. Effects of heel height and high-heel experience on foot stability during quiet standing. Gait Posture. 2018; 68: 252-257.
10. Hyun S-H, Kim Y-P, Ryew C-C. Effect on the parameters of the high-heel shoe and transfer time of ground reaction force during level walking. J Exerc Rehabil. 2016; 12: 451-455.
11. Chien H-L, Lu T-W. Effects of shoe heel height on the end-point and joint kinematics of the locomotor system when crossing obstacles of different heights. Ergonomics. 2017; 60: 410-420.
12. Wiedemeijer MM, Otten E. Effects of high heeled shoes on gait. A review. Gait Posture. 2018; 61: 423-430.
13. Oliveira Pezzan PA de, Joao SMA, Ribeiro AP, Manfio EF. Postural assessment of lumbar lordosis and pelvic alignment angles in adolescent users and nonusers of high-heeled shoes. J Manipulative Physiol Ther. 2011; 34: 614-621.
14. Bendix T, Sorensen SS, Klausen K. Lumbar curve, trunk muscles and line of gravity with different heel heights. Spine (Phila Pa 1976). 1984; 9: 223-227.
15. Opila KA, Wagner SS, Schiowitz S, Chen J. Postural alignment in barefoot and high-heeled stance. Spine (Phila Pa 1976). 1988; 13: 542-547.
16. Iunes DH, Monte-Raso W, Santos CB, Castro FA, Salgado HS. Postural influence of high heels among adult women: analysis by computerized photogrammetry. Rev Bras Fisioter. 2008; 12: 454-459.
17. Silva AM, Siqueira GR de, da Silva GAP. Implications of high-heeled shoes on body posture of adolescents. Rev Paul Pediatr. 2013; 31: 265-271.
18. Schröder G, Knauerhase A, Willenberg HS, Kundt G, Wendig D, Schober H-C. Biomechanics of the osteoporotic spine, pain and principles of training. Arch Orthop Trauma Surg. 2017; 137: 617-624.
19. Schröder G, Kundt G, Otte M, Wendig D, Schober H-C. Impact of pregnancy on back pain and body posture in women. J Phys Ther Sci. 2016; 28:

1199-1207.
20. Drerup B, Hierholzer E. Back shape measurement using video raster stereography and three-dimensional reconstruction of spinal shape. Clin Biomech (Bristol, Avon). 1994; 9: 28-36.
21. Drerup B. Raster stereographic measurement of scoliotic deformity. Scoliosis. 2014; 9: 22.
22. Degenhardt B, Starks Z, Bhatia S, Franklin G-A. Appraisal of the DIERS method for calculating postural measurements: An observational study. Scoliosis Spinal Disord. 2017; 12: 28.
23. Schröder G, Knauerhase A, Kundt G, Schober H-C. Trunk stabilization with sling training in osteoporosis patients-a randomized clinical trial. Eur Rev Aging Phys Act. 2014; 11: 61-68.
24. Schröder J, Stiller T, Mattes K. Referenzdaten in der Wirbelsäulenformanalyse: Annäherung an eine Majoritätsnorm und Abweichungen bei unspezifischen Rückenschmerzsyndromen. Manuelle Medizin. 2011; 49: 161-166.
25. Yang DJ, Park SK, Kim JH, Heo JW, Lee YS, Uhm YH. Effect of changes in postural alignment on foot pressure and walking ability of stroke patients. J Phys Ther Sci. 2015; 27: 2943-2945.
26. Schroeder J, Reer R, Braumann KM. Video raster stereography back shape reconstruction: A reliability study for sagittal, frontal and transversal plane parameters. Eur Spine J. 2015; 24: 262-269.
27. Schulein S, Mendoza S, Malzkorn R, Harms J, Skwara A. Rasterstereographic evaluation of interobserver and intraobserver reliability in postsurgical adolescent idiopathic scoliosis patients. J Spinal Disord Tech. 2013; 26: E143-149.
28. Mohokum M, Schulein S, Skwara A. The Validity of Raster stereography : A Systematic Review. Orthop Rev (Pavia). 2015; 7: 5899.
29. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. Acta Orthop Scand Suppl. 1989; 230: 1-54.
30. Berry JL, Moran JM, Berg WS, Steffee AD. A morphometric study of human lumbar and selected thoracic vertebrae. Spine (Phila Pa 1976). 1987; 12: 362-367.
31. Duval-Beaupere G, Robain G. Visualization on full spine radiographs of the anatomical connections of the centres of the segmental body mass supported by each vertebra and measured in vivo. Int Orthop. 1987; 11: 261-269.
32. ASMUSSEN E, Klausen K. Form and function of the erect human spine. Clin Orthop. 1962; 25: 55-63.
33. Gabell A, Simons MA, Nayak US. Falls in the healthy elderly: Predisposing causes. Ergonomics. 1985; 28: 965-975.
34. Menant JC, Steele JR, Menz HB, Munro BJ, Lord SR. Optimizing footwear for older people at risk of falls. J Rehabil Res Dev. 2008; 45: 1167-1181.
35. Basler H-D. Akutschmerz therapie in Pädiatrie und Geriatrie – Schmerzmessung: Welche Schmerzskala bei welchen Patienten? Anästhesiol Intensivmed Notfallmed Schmerzther. 2011; 46: 334-342.
36. Pratihast M, Al-Ani A, Chai R, Su S, Naik G. Changes in lower limb muscle synchronisation during walking on high-heeled shoes. Healthc Technol Lett. 2018; 5: 236-238.
37. Hong W-H, Lee Y-H, Chen H-C, Pei Y-C, Wu C-Y. Influence of heel height and shoe insert on comfort perception and biomechanical performance of young female adults during walking. Foot Ankle Int. 2005; 26: 1042-1048.
38. Lopez-Lopez D, Maranon-Medina J, Losa-Iglesias ME, Calvo-Lobo C, Rodriguez-Sanz D, Palomo-Lopez P, et al. The influence of heel height related on quality of life on the foot in a sample of women. Rev Assoc Med Bras (1992). 2018; 64: 324-329.

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