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Is static balance affected by using shoes of different height?

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Summary

Study aim: to investigate the impact of heels of different height on static balance of teenagers and young women not accustomed to high heels.
Material and methods: The study involved 71 young women aged 21.09 ± 2.91 years. We used a stabilometric platform to take measurements barefoot and with heels: of 4 cm and of 10 cm. Two types of measurements were taken: with eyes open and with eyes closed.
Results: Statistical analysis revealed a significant increase in values of the measured stabilographic parameters with 4 cm and 10 cm heels, in comparison to measurements taken with bare feet. Measurements with eyes closed revealed significantly greater distortions to static balance than measurements with eyes open. A comparison of measurements – both with eyes open and with eyes closed – barefoot, with 4 cm heels and with 10 cm heels revealed statistically significant differences.
Conclusions: High heels in the population of young women significantly worsen static balance. Heel height and the exclusion of visual control are important factors diminishing static balance.

Key words: Heel height – Static balance – Stability

Introduction

Women wear high-heeled shoes for their role in beauty, class and elegance [24]. However, the basic function of footwear is to protect the feet, to absorb shocks, as well as to make the gait natural and easy [23]. There are numerous hypotheses on the effect of high heel footwear on human static balance and on the activity of separate muscle groups responsible for postural control. High-heeled footwear negatively affects load imbalance, increases joint stress and diminishes postural stability, and increases the risk of falls and the degree of probability of suffering from injuries and even fractures of the lateral malleolus [25].

Balance is the dynamic state of the postural system, in which the resultant of all the forces affecting the body and its torques balance each other out [17]. The process of maintaining balance in the standing upright position consists in constant losing and regaining balance. The ability to maintain balance is understood as keeping the projection of the centre of gravity within the support plane outlined by the feet; and it is the resultant of a complex system of neuromuscular coordination comprising the vestibular system, the visual system, proprioceptors which serve as stimuli receptors, the nervous system as the transducer of the signal, and muscles as effector systems [30]. Distortions to this complex system result in stability loss and in falls. Maintaining body balance may be distorted both by intrinsic factors, such as body movement, and by extrinsic forces acting on the body in a particular environment. Boisgontier et al. [4] used a research protocol which combined brain structural imaging and standing balance analyses to investigate the effect of whole-brain grey matter density and white microstructural organisation on the balance instability. Many physical tests are used when assessing body balance, but care must be taken when choosing balance tests to best match the test to the purpose of testing [12]. Depending on the source of distorting factors, body balance is measured under static or dynamic conditions; for example, multidirectional stance perturbations were measured by a moveable platform [7]. Most of the measurements of balance maintenance are taken on one or two platforms, with the subjects standing on one or on both legs, with eyes open or eyes closed

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depending for example on the subject's age and disability [32, 34]. Sometimes more complex tests, e.g. elements of sport performance, are performed, which incorporate two stabilographic platforms, a movement recorder and mathematic modelling systems [15]. The most important role in maintaining balance in the standing position is played by a vertical component of the ground reaction forces, and the path of the point of application of its resultant, described as the centre of pressure of the feet on the ground (COP), is the main measure of the performance efficiency of the balance system [18, 22]. Kaewkaen et al. [16] examined the immediate effect of balance training with high-heeled shoes on cognitive processing speed of non-regular high-heeled shoe wearers. Wearing high-heeled shoes increases the risk of ankle sprain [29], development of lower limb pain, knee and low back pain [20, 33, 36], shortening of the Achilles tendon [31] and shortening of the gait [9]. Hapsari and Xiong evaluated static balance on different high-heeled shoes, but only included in the study 10 experienced and 20 inexperienced high-heeled shoe wearers [14]. The is a lack of information in the literature regarding the influence of high-heel wearing on the static balance of young women not accustomed to such shoes.

The aim of this study was to determine the impact of high-heeled footwear of different height on static balance parameters of young women not accustomed to wearing high-heeled shoes. We assumed that stability would worsen while standing an high heels with eyes closed and would depend on heel height.

Material and methods

We obtained the consent to conduct the study from the Senate Commission on Ethics of Scientific Research of the Józef Piłsudski University of Physical Education in Warsaw. The study population consisted of 71 healthy women aged 18 to 28 years (21.09 ± 2.91 years). Table 1 presents their biometric data. They were informed of the aim of the study and the organisation of the measurements.

The criteria for subject inclusion in the study were: consent to participate, not using high-heeled shoes regularly (less than once a week), lack of neurological disorders (no vestibular disorders), no prior history of lower limb or spinal injuries.

Table 1. Anthropometric data of the studied female population (n = 71)

	Median	±SD
Age [years]	22.0	2.91
Body height [cm]	167.0	4.68
Body mass [kg]	57.2	8.32

The criteria for subject exclusion from the study were: neurological and orthopaedic disorders, frequent wearing of high-heeled shoes.

The measurements were taken using the CQStab two-plate stabilometric platform produced by Swierc, Poland. The platforms is equipped with three sensors which analyse the movement of the projection of the centre of foot pressure onto the ground, which, under static conditions, is identical to the centre of body mass of the subject. The equipment can register global movement of the body, as well as movement of each of the lower limbs separately. The changes of the COP path are registered on the x axis and on the y axis in the form of statokinesiograms and stabilograms, in which the COP position is the function of time. The antero-posterior and medio-lateral sways were measured separately. According to Błaszczyk [3] the sway vector (SV) may be recommended as a useful measure in both the laboratory and clinical assessment of postural control.

The measurements were taken in accordance with the applicable norms. The measurement equipment is presented in fig. 1.

We analysed the following parameters:

- SP – the total sway path on both the x-axis and the y-axis (2D) [mm];
- SPAP – the sway path along the y-axis [mm];
- SPML – the sway path along the x-axis [mm];
- MA – the mean amplitude of COP (2D) [mm];
- MAAP – the mean amplitude of COP in the anterio-posterior direction [mm];
- MAML – the mean amplitude of COP in the medio-lateral direction [mm];
- MaxAP – the maximum sway of the COP in the anterio-posterior direction [mm];
- MaxML – the maximum sway of the COP in the medio-lateral direction [mm];
- MV – the mean COP velocity in both directions (2D) [mm];
- MVAP – the mean COP velocity in the antero-posterior direction [mm/s];
- MVML – the mean COP velocity in the medio-lateral direction [mm/s];
- SA – the surface area of COP during the test [mm^2];
- MF – the mean frequency of COP [mm^2].

Prior to the test, the subject chose the right size of the footwear, then had 5 minutes to walk and become familiarized with them, and then rested for 2 minutes in a sitting position. Then, the tested persons stepped on the platform and assumed a natural standing position on both feet, positioned at the distance of the hips, with the upper limbs hanging along the body, head straight, looking forward. Then, six measurements were taken: 1: barefoot with eyes open, 2: barefoot with eyes closed, 3: wearing 4 cm heels with eyes open, 4: wearing 4 cm heels a b c

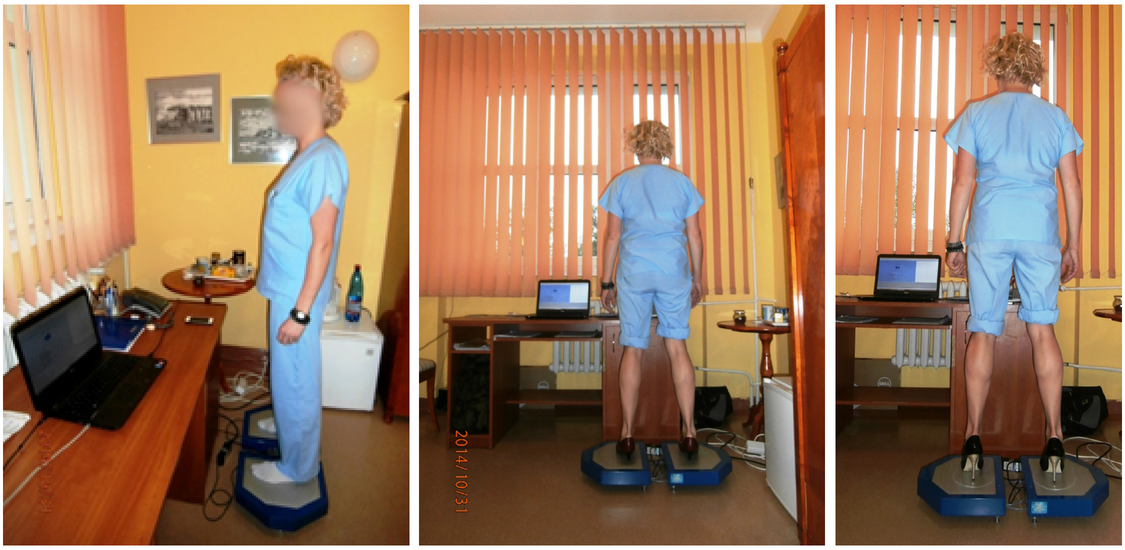

Fig. 1. The measurements equipment with a subject barefoot (a), wearing 4 cm (b) and 10 cm heels (c)

with eyes closed, 5: wearing 10 cm heels with eyes open, 6: wearing 10 cm heels with eyes closed. Each measurement lasted 30 seconds.

Statistical analysis

We used Student's t-test to calculate the significance of differences between the analysed parameter values: stability parameters without shoes, and with 4 cm and 10 cm heels. The statistical significance was set at $p < 0.05$. For most of the variable analysis, we used non-parametric methods, as there was lack of normal distribution – we confirmed this with the Kolmogorov test. We characterized distribution with mean values, median and range. We assessed the statistical significance of differences between tests with the Mann-Whitney U-test.

Results

Tables 2 show the results of the analysed parameters in measurements with eyes open.

Tables 3 shows the results of the analysed parameters in measurements with eyes closed for heels of different height.

Table 2. Analyzed variable values in bare feet and on heels measured with eyes open

Eyes open		Bare feet	4 cm	10 cm	Friedmann Chi	Significance
	Variable	Median	Median	Median	(df = 2)	
1	SP [mm]	152.0 ± 30.3	172.0 ± 50.4	262.0 ± 92.0	118.4	<0.001
2	SPAP [mm]	108.0 ± 24.2	133.0 ± 39.0	223.0 ± 81.7	120.9	<0.001
3	SPML [mm]	80.0 ± 18.4	84.0 ± 28.9	98.0 ± 38.7	71.9	<0.001
4	MA [mm]	1.8 ± 1.1	1.7 ± 1.1	2.4 ± 1.4	24.7	<0.001
5	MAAP [mm]	1.5 ± 1.0	1.5 ± 0.9	2.2 ± 1.1	22.0	<0.001
6	MAAML [mm]	0.5 ± 0.5	0.5 ± 0.6	0.7 ± 1.0	20.5	<0.001
7	MaxAP [mm]	5.6 ± 3.2	5.1 ± 2.9	7.4 ± 4.1	23.2	<0.001
8	MaxML [mm]	2.2 ± 1.3	2.1 ± 2.1	2.8 ± 3.8	31.6	<0.001
9	MV [mm/s]	5.1 ± 1.0	5.7 ± 1.7	8.7 ± 3.1	119.5	<0.001
10	MVAP [mm/s]	3.6 ± 0.8	4.4 ± 1.3	7.4 ± 2.7	120.9	<0.001
11	MVML [mm/s]	2.7 ± 0.6	2.8 ± 1.0	3.3 ± 1.3	73.0	<0.001
12	SA [mm^2]	76.0 ± 81.0	81.0 ± 132.6	253.0 ± 302.9	60.7	<0.001

Table 3. Analyzed variable values measured with eyes closed

Eyes closed		Bare feet	4 cm	10 cm	Friedmann Chi	Significance
	Variable	Median	Median	Median	(df = 2)	
1	SP [mm]	170.0 ± 54.7	205.0 ± 68.2	414.0 ± 220.6	124.5	<0.001
2	SPAP [mm]	130.0 ± 45.1	169.0 ± 61.8	372.0 ± 210.5	123.1	<0.001
3	SPML [mm]	81.0 ± 27.2	86.0 ± 21.2	115.0 ± 52.8	98.2	<0.001
4	MA [mm]	1.9 ± 1.5	2.0 ± 1.6	3.7 ± 1.9	73.2	<0.001
5	MAAP [mm]	1.7 ± 1.3	1.9 ± 1.5	3.3 ± 1.8	65.0	<0.001
6	MAAML [mm]	0.5 ± 0.7	0.5 ± 0.5	0.8 ± 0.6	50.2	<0.001
7	MaxAP [mm]	6.4 ± 4.3	7.7 ± 3.9	14.5 ± 8.4	80.8	<0.001
8	MaxML [mm]	1.9 ± 1.9	2.3 ± 1.8	3.4 ± 3.3	51.6	<0.001
9	MV [mm/s]	5.7 ± 1.8	6.8 ± 2.3	13.8 ± 7.4	125.7	<0.001
10	MVAP [mm/s]	4.3 ± 1.5	5.6 ± 2.1	12.4 ± 7.0	124.3	<0.001
11	MVML [mm/s]	2.7 ± 0.9	2.9 ± 0.9	3.8 ± 1.8	97.4	<0.001
12	SA [mm^2]	81.0 ± 140.4	101.0 ± 117.8	306.0 ± 525.9	88.3	<0.001
13	MF [Hz]	0.5 ± 0.2	0.5 ± 0.2	0.6 ± 0.2	18.8	<0.001

When we compared postural stability variable values for bare feet and for 4 cm heels we found statistically significant differences regarding SP, SPAP, SPML, MV, MVAP, MVML and MF. When we compared parameter values for bare feet and for 10 cm heels we found statistically significant differences for all variables. When we compared variable values for 4 cm heels and for 10 cm heels we also found a number of statistically significant differences.

When we compared postural stability variable values for bare feet and for 4 cm heels we found statistically significant differences regarding SP, SPAP, SPML, MA, MAAP, MaxAP, MV and MVAP, MVML and SA.

When we compared postural stability variable values for bare feet and for 10 cm heels, and when we compared postural stability variable values for 4 cm heels and for 10 cm heel, we found statistically significant differences for all variables. Measurements with eyes closed revealed significantly greater distortions to static balance than measurements with eyes open.

Discussion

Static posturography, measuring spontaneous postural sway, in which global descriptive sway parameters (e.g. sway amplitude and sway velocity) are measured in different sensory conditions (e.g. standing with eyes open or closed) could provide information to determine whether a patient's postural control deviates from what is normal [35].

In our research we used most postural variables, which are based on the standard spatiotemporal metrics of the centre of foot pressure (COP) recorded during quiet stance. In our study young women swayed more under eyes-closed conditions than under eyes-open conditions in all measurements. We confirmed our hypothesis. This finding is in agreement with the study performed by Agostini et al. on healthy subjects. The role of central and peripheral vision in the maintenance of upright stance is debated in the literature, and different theories can be found. This study supported the theory that central and peripheral vision have functionally different and complementary roles in upright stance. It argues that peripheral vision is predominant in antero-posterior (AP) postural control, while central vision is predominant in the medio-lateral (ML) one [1].

Our results showed that static balance worsened in females wearing high heels, and that wearing the higher heel resulted in more significant stability distortions, which confirms our second hypothesis. Mika et al. chose these same heel height and age group but studied the impact on the tension of antigravity muscles. The subjects were asked to perform a trunk forward flexion and return task. Three measurements were taken, i.e. with footwear with flat heels, 4 cm heels and 10 cm heels. The results showed that higher heels resulted in increased activity of the spine and hip extensors, which in consequence may lead to muscle and joint overload and to pain [26]. Mika et al. also studied the activity of the erector spinae and the kinematic parameters of the pelvis. The study population consisted of 31 women aged 20 to 25 years and of 15 women aged 45 to 55 years. The measurements were taken in gait with bare feet, and when wearing footwear with the same heels as in our study. The group of younger women showed a significant increase in bioelectric activity of the erector spinae in the early and final phases of single support. In both groups, the researchers found an increase of bioelectric activity of the erector spinae with higher heels. In gait with high heels they found an increase of pelvis inclination in the sagittal plane [27]. Mika et al. [28] also studied the impact of high heels on the kinematics and activity of the lower limb muscles in gait. They observed an increase of bend at the knee and of eversion at the ankle related to an increase in heel height. These changes may suggest that a compensation mechanism that decreases the ground-reaction forces may negatively affect the gait in high heels. These results suggest that frequent use of high-heeled shoes may lead to muscle overload and repeated sprain of the ankle [28].

In his study on defining paraspinal muscle activity in a standing task in footwear with heels of different height, Han studied 28 healthy young women. His results showed that the paraspinal muscle activity in the standing task in each studied type of footwear was significantly higher in the cervical and lumbar spine in comparison to measurements taken in barefoot subjects. Han concluded that the increase of paraspinal muscle activity results from the heel height, not the heel width. He also suggested that wearing high heels is not advised for patients with cervical or lumbar spine problems [13]. High heels also significantly increase tension of other lower limb muscles – gastrocnemius medialis, rectus femoris, tibialis anterior and rectus abdominis – and causes longer participation of these muscles during the gait cycle [10].

Gerber et al. took measurements of changes to postural stability resulting from wearing high-heeled shoes, but in women accustomed to wearing high-heeled shoes. Balance measurements were taken under static conditions on a dynamometric platform. Centre of gravity projection sways in the medio-lateral and antero-posterior dimensions were measured in a standing task barefoot, and with a heel 7 cm high and 1 cm wide, with both eyes open and eyes closed. Statistical analysis revealed significant differences between measurement with and without footwear and between eyes open and eyes closed. Centre of gravity sway in the medio-lateral dimension with eyes closed was also statistically significant. The studies showed that using shoes with a 7 cm heel negatively affected balance of young women in that it increased the centre of gravity projection sways, regardless of limitations related to lack of visual control [11].

Chien et al. studied the issue of centre of mass (COM) projection movement control in relation to the centre of pressure (COP) in gait in high-heeled footwear. Their studies aimed to determine the impact of surface area of the high heel as well as its height on the COM movement, in relation to the inclination angle (IA) of COM-COP and the rate of changes of the inclination angle (RCIA). The study population consisted of 15 women aged 24.4 ± 3.4 years who wore high-heeled footwear regularly. 39 markers were put on their bodies, while they had to walk both barefoot and, subsequently, in shoes with 3.9 cm, 6.3 cm and 7.3 cm on a walking path that registered the ground reaction forces. The registered values were then used to calculate the COM and COP. A decreased surface area of the heel base turned out to be the main factor that decreased the velocity and the range of sways in the sagittal plane during the gait cycle. This was mainly achieved because of RCIA control during double-leg stance (DLS). The heel height influenced mainly the top value of RCIA during the double-leg stance phase, but it was not high enough to have influenced the IA value [6].

Ko and Lee studied the changes of centre of foot pressure in shoes with flat and with high heels. They conducted measurements of 15 women, whom they randomly assigned shoes with flat heels (0.5 cm), medium heels (4 cm) or high heels (10 cm). They conducted two COP measurements with FDM-S equipment (Zebris Medical GmbH Germany): the first one immediately after putting the shoes on, and another one after an hour of wearing the shoes. They proved that the COP path was longest after standing with flat or high-heeled shoes, while the medium heels seemed to be the most beneficial for the human postural stability [21].

Lee et al. studied 200 women aged 20-30 years who regularly wore high-heeled shoes for more than a year. They found that 58% of women suffered from low back pain, and 55% had the greatest discomfort while walking in shoes with 6-9 cm heels [23]. Lee et al. conducted another study, in which they took measurements in the standing task and then walking in shoes with flat heels and with heels of 4.5 cm and 8 cm. The study population consisted of 5 women aged 20 years. The subjects were asked to walk twice with the speed of 4 km/h along a measurement path, with a 10-minute break between the measurements. Lee at al. collected measurement data from 8 points and conducted movement analysis using the ME3000 System. They also measured the electromyographic signal (EMG) of the erector spinae at the L1/L2 and L4/L5 levels, as well as the vastus lateral and tibialis anterior. Inclination angles at the lumbar region of the spine were measured on the basis of images taken in the standing task. It turned out that with an increase of the heel height the inclination angle of the trunk decreases significantly. The EMG of the tibialis anterior and the erector spinae in the lumbar region of the spine, as well as the vertical changes of COM, significantly increased while walking in high-heeled shoes. Experimental results show while the heel height increased to 10 cm, the standing balance also becomes worse. Experienced high-heeled shoe wearers do not show significantly better overall performance in standing balance, even though they have better directional control [23].

Chien et al. analysed the effects of long-term wearing of high-heeled shoes on the COM and COP movement control in gait. Their study involved 30 women aged 24.4 ± 3.4 years, divided into groups of 15 subjects: 15 women who had had experience of using high-heeled shoes, and 15 women who formed the clinical control group. The study population subjects had 39 markers placed onto their bodies, which enabled kinematic analysis. The subjects were asked to walk on the measurement path of 8 metres length in shoes with 7.3 cm heels. The path measured the ground reaction forces. When compared to the clinical control group, the women who had regularly used high-heeled shoes has significantly decreased IA values (rate of changes) in the sagittal plane. They also found increased values of foot pronator torques in the single support phase. During the double support phase (DLS), they observed a significant increase in the RCIA values in the sagittal plane in the last stage of propulsion (toe-off) with contralateral heel strike, decreased time of double support DLS and no changes to the RCIA and DLS ratio value. In the sagittal plane of the high-heel experienced women, a significant increase in the RCIA was found ($p < 0.05$) and statistically significant differences of the RCIA in the last stages of propulsion (toe off) with the contralateral heel strike. The hip flexor torques and knee extensor torques significantly increased. These muscles are involved in the forward movement of the limb swinging forward. This study found changes in postural control in women who used high-heeled shoes in the long term, and they provided a basis for future projects on strategies for minimizing risks of falls in gait in high-heeled shoes [5]. According to Kim et al., heel height has the potential to induce muscle imbalance during the standing task [20].

Zhang and Li suggested that a heel made of materials with good support and elastic properties might be more appropriate to improve footwear comfort and medial–lateral motion control [37].

In the opinion of Bae et al., revised high-heeled shoes (by making use of tunnel technology with excellent shock absorption and a rearward decrease in the wedge angle) produce significantly higher rearfoot pressure and lower forefoot pressure and have a greater positive effect than standard high-heeled shoes on static balance [2].

Another aspect of high-heel wearing is increase of lumbar lordosis, which might in certain circumstances cause low back pain [7].

Value of the study

Despite numerous studies on postural balance reported in the literature, only a limited number of them concerned postural balance and static balance measurements in inexperienced women wearing high heels. This small number of studies concerned inter alia the bioelectric potential of postural muscles, gait analysis, and biomechanical changes in the body both in gait and in maintaining static positions. Our measurements focused on the analysis of the impact of the heel height and of excluding visual control on female static balance. The results we collected may provide a basis for subsequent, more comprehensive studies on e.g. the impact of balance training on postural stability, or preventing falls and injuries.

Limitations of the study

In this study, during the assessment of each woman, the six different sensory conditions were non-randomised. Lack of randomisation of the test conditions could systematically induce fatigue in the more difficult (10 cm heels) conditions and thus influence their performance [35].

We tested only one type of shoes, that is stilettos – narrow heels with sharp endings, with the heel height of 4 cm and 10 cm.

Conclusions

Higher values of the heel height significantly decrease static balance, especially on 10 cm heels. Visual control exclusion significantly decreases static balance, which may increase the risk of injury in that group of women, especially in the darkness.

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