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Measurement of lumbar lordosis in static standing posture with and without high-heeled shoes

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Abstract

Objective: Some doctors and therapists believe that wearing high-heeled shoes causes increased lumbar lordosis and that this may be a cause of low back pain. The purpose of this study was to evaluate whether high-heeled shoes increase lumbar lordosis and to do so with more reliable methods and a larger sample size than used in previous studies.

Methods: Fifty participants from a chiropractic university were included in a test group (32 female and 18 male) and 9 in a control group (3 female and 6 male). A Spinal Mouse was used to measure lumbar lordosis in test participants barefoot and then again with 3- or 4-in high-heeled shoes after a 10-minute adaptation period of walking and sitting and standing while wearing the shoes. Reliability of the testing conditions was evaluated with 9 barefoot control participants before and after an identical adaptation period, and intra- and interexaminer reliability of Spinal Mouse measurements was tested by use of a wooden model built to mimic the proportions of a human spine.

Results: Both groups showed non-significant decreases in lordosis between the first and second scans (high heels: 23.4° to 22.8°, $P = .17$; control: 18.8° to 17.6°, $P = .16$). Scans of the wooden spine model were highly reliable (intra- and interexaminer intraclass correlation coefficients > .999).

Conclusions: Consistent with most previous studies, high-heeled shoes did not affect lumbar lordosis in most people while standing. Future research could investigate the effect of shoes during dynamic conditions or identify affected subgroups.

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Introduction

It is believed by some that low back pain (LBP) can be caused by wearing high-heeled shoes. Some doctors and therapists advise that the wearing of high-heeled shoes causes an increased lumbar lordosis and that the increased curve causes LBP.[1-4] de Lateur[5] described this belief as "firmly ingrained in clinical folklore." The heels-cause-increased-lordosis way of thinking has been reflected in press releases from professional groups, such as the American Chiropractic Association, "Essentially, wearing high heels for any length of time increases the normal forward curve of the back and causes the pelvis to tip forward,"[6] and, at one time, the American Physical Therapy Association, "Walking in high heels forces the back to arch and the chest to thrust forward. Basically, high heels cause the neck and back to hyperextend."[7] A more thorough discussion of popular beliefs and previous studies may be found in a recent narrative review.[8]

However, prior studies of this topic have found either a decreased lordosis or no significant difference with heels as compared with barefoot standing.[1-3,5,9-11] There is some discrepancy, as some studies have found increased lordosis with heels,[4,12] although in some cases only with certain subgroups.[9,13] Further confusing the issue, many of the prior studies used small groups; and in some cases, the validity of assessment methods may be questionable.

Remaining uncertainty about the relevance of high heels to lumbar lordosis may be a problem for clinicians, considering that both LBP and the wearing of high-heeled shoes are common. The primary purpose of this project was to evaluate whether high-heeled shoes increase lumbar lordosis and to use a reliable method and larger sample size than had been used in previous studies.

Methods

Participants

Recruitment of 61 students, staff, and faculty from the Life University campus was conducted for the high-heels group (HH) through personal requests by the investigators and announcements in classes and the student newspaper. For eligibility, participants were required to be 18 years of age or older, to be able to read and understand English, and to have no known structural or neurological abnormalities that would prevent them from standing and walking in a pair of high-heeled shoes for 10 to 15 minutes. Participants were to be excluded if they did not meet those criteria, if they could not tolerate the shoes, or if there were no shoes available in an appropriate size. Men were included in addition to women, as had been done in some previous studies, with the premise that the effect of heels might be independent of sex. At a later time, 11 participants were recruited for a control group (CG) through personal requests by the investigators and met the same criteria except that they were not asked to wear high-heeled shoes. Participants provided information for age, height, and weight; and HH participants also provided frequency per week and number of years wearing high-heeled shoes, and whether the shoes caused them LBP. All participants signed an Informed Consent form after explanation of procedures, and all were given a campus bookstore gift card as compensation for their time. Plans for recruitment, assessment, and use of information were approved by the Life University Institutional Review Board.

Measurement

Values for lumbar lordosis were obtained by using a Spinal Mouse (SM) (idiag AG, Fehraltorf, Switzerland), which has been shown to be reliable for sagittal plane assessment of the spine.[14,15] The SM is a hand-held device with small wheels that roll along the spine (Fig 1); it contains accelerometers and functions as an electronic inclinometer.[14] In measuring sagittal spinal contours, rotation around its medial-lateral axis generates positive angular values in areas of kyphosis ("thorac" and sacral regions), as seen in Fig 2 for one participant, and negative angular values in areas of lordosis (lumbar region and intersegmental angles, Fig 2). The lumbar angle (T12 to S1) was the main outcome measure in the present study, with sacral angles and scan length of secondary interest. The SM also reported thoracic regional angles and spinal inclination angles ("inclin," Fig 2; amount of anterior-posterior lean from upright vertical), but these were not used in this study.

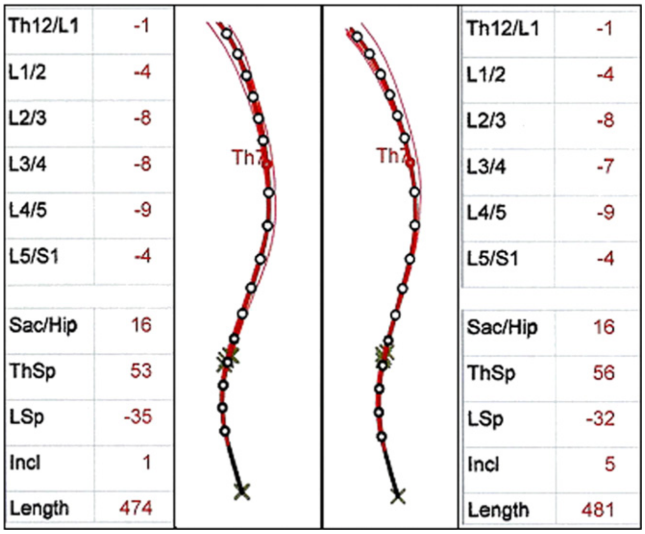
The bold lines in Fig 2 are mean values of 4 individual paraspinal scans (thin lines). The mean value of 4 scans was intended to minimize the effect of, for example, different SM calculations made for the left and right sides for any participants with surface contour variations related to asymmetry in spinal structure or muscle mass or inconsistencies in lateral-to-medial SM positioning. In addition, the SM software interprets locations of segments based upon scan length; so any inconsistency in starting and stopping points would affect the calculated measurements. The sacral angle

Fig 1. The SM in use by the second author.

and scan length also were monitored for consistency between conditions. For the SM, *sacral angle* represents the natural kyphotic curve of the sacrum, which should remain constant from one scan to another. The *scan length* represents the distance the SM traveled from C7 to S3, and inconsistent start-stop points could be a source of measurement variability.

Participants were asked to change into a patient gown; men were given the option of simply removing their shirts, and women were asked to leave bras unhooked to allow access to the paraspinal area. Participants were allowed to wear pants or skirts; fleece pants were available for anyone whose clothing did not allow for easy access to the sacral area. An eyeliner pencil was used to mark the C7 and L1 spinous processes and the second sacral tubercle. A set of scans of the spine was done with each participant barefoot or while wearing stockings or socks. A set consisted of 4 scans—2 each on the left and right of the spinous processes from C7 to the S3 tubercle. Participants were instructed to look at a vertical column of numbers on the wall and to gaze at the number closest to eye height until the scans were finished. Each person in the HH group then put on a pair of high-heeled shoes and performed a 10-minute adaptation exercise following a prescribed course within a hallway: walking, sitting down and standing back up, and picking up and carrying a light box, all repeated a total of 4 times, followed by a few minutes of standing. During this time, they were allowed to wear additional clothing. At the end of this adaptation period, another set of scans was performed as before. Most participants wore shoes supplied by the investigators, which had 7.5-cm heel heights (approximately 3″), all of the same model in a variety of sizes (women's 5-14). Two male participants required larger sizes and wore a different model with 10-cm heels (women's sizes 15 and 16). One potential male participant was not enrolled in the study because the investigators did not have men's size 15 shoes. Participants were allowed to wear their personal shoes of 7.5-cm heel heights, but only 2 did so. Control group participants followed the same protocol above, except that they remained shoeless during the adaptation period and second set of scans.

Little training is required to learn how to use the SM; the authors watched a short video, read the device's operation manual, and practiced handling it. For the HH group, the second author (KM) performed all scans except 2 done by the principal author (BR); the fourth author (CD) conducted all scans of the CG.



Th12/L1	-1
L1/2	-4
L2/3	-8
L3/4	-8
L4/5	-9
L5/S1	-4
Sac/Hip	16
ThSp	53
LSp	-35
Incl	1
Length	474

Th12/L1	-1
L1/2	-4
L2/3	-8
L3/4	-7
L4/5	-9
L5/S1	-4
Sac/Hip	16
ThSp	56
LSp	-32
Incl	5
Length	481

Fig 2. Excerpts from SM reports for a participant of the HH group. The numbers and spine image on the left are from the barefoot condition; those on the right were after 10 minutes wearing high-heeled shoes. The bold lines are mean values of 4 individual paraspinal scans (thin lines). Positive numbers for the thoracic region ("ThSp") indicate kyphosis; negative numbers for the lumbar region ("LSp" and individual levels) indicate lordosis. The absolute value of the lumbar angle is decreased with heels, which indicates decreased lordosis. The increased "incl" angle, although not analyzed in this study, indicates that the participant had a slightly increased forward lean with heels.

Construction and use of a wooden spine model for verification of measurements

In addition, for the control group only, a flexible measuring tape was used to manually measure distances between the C7 and T12 spinous processes, and between T12 and the second sacral tubercle. The ratio of mean thoracic length to mean lumbar length was used in the construction of a wooden model of a spine, using 2″ × 2″ lumber cut into segments to represent vertebral bodies and glued together (Fig 3). This model was intended as a way to check the validity and reliability of the particular SM device used in the study, with the premise that the model could be built with angular measurements determined independently of the SM and also that the flat, hard surfaces could be measured multiple times, more than would likely be tolerable by most people, without human sources of variability such as postural sway or subcutaneous irregularities. Three of the authors (BR, KH, CD) and another student from the chiropractic program (TT, in the Acknowledgment) each made practice scans of the model; then 4 consecutive scans were recorded. Ultimately, the construction methods of the wooden spine model proved too crude to be able to test validity because of lack of precision in cutting intersegmental angles. However, the measurement data were analyzed for intra- and interexaminer reliability.

Fig 3. The wooden spine model used for evaluating intra- and interexaminer reliability.

Statistical analysis

Data were entered into an Excel document by the principal author, a second person verified the entries, and the files were imported into SPSS version 17.0 (now IBM SPSS Statistics, Chicago, Illinois). The preadaptation period scans were compared with the postadaptation scans with paired, 2-tailed *t* tests for HH and CG lumbar lordosis, sacral angle, and scan length. The HH group participants were also separated into 2 subgroups, according to increased or decreased lordosis with shoes; and the subgroups were examined for differences in age, body mass index (BMI), frequency of wear, years of experience of wear, number of participants in each sex, and self-report of back pain related to wearing heels.

Participant exclusions

One HH group participant with a lumbar kyphosis was excluded from analysis, and equipment malfunction caused the loss of data for another 3 participants. On the assumption that scan length inconsistency could have a detrimental effect on lordosis comparisons, 7 participants whose differences between the first and second scan lengths were more than 3.25% were excluded from analysis. One CG participant was excluded a priori as a training and practice session for the fourth investigator, and another was excluded for scan length inconsistency.

For measurements of the wooden spine model, intra- and interexaminer reliability was calculated using intraclass correlation, 2-way random effects—although the object being measured did not change between scans, the examiners are expected sources of variability in that scan-to-scan consistency is affected by start and stop points and variations in side-to-side movement.

Results

For the 50 participants included in the HH group, the mean barefoot (first scan) lordosis was 23.4°, decreasing slightly to a mean value of 22.8° with high-heeled shoes (second scan); the difference was statistically not significant (Table 1). For the 9 participants included in the CG, the mean lordosis was 18.8° for the first set of scans (Table 1), decreasing to 17.6° for the second set of scans; the difference was statistically not significant. Fig 4 illustrates the lordosis values for the HH group for the barefoot condition (range, 7°-40°) and the changes resulting from the heels. Although not included in the table, there were no statistical differences between the HH and CG in their first scan values for lordosis ($P = .19$, 95% confidence interval [CI] = −2.6 to 11.9), sacral angle ($P = .74$, 95% CI = −4.9 to 6.8), or scan length ($P = .69$, 95% CI = −37.3 to 25.8).

For the HH group, there was a slight decrease in sacral angle (Table 1) from the barefoot condition (10.3°) to the heels condition (10.1°); this was not statistically significant. Comparisons in scan lengths from the barefoot condition to the heels condition were not significantly different (472 vs 475 mm, respectively; Table 1). Similarly, the sacral angles and scan length measurements were quite stable for the control group. As mentioned above, 7 HH participants and 1 CG participant had been excluded from analysis for scan length differences. However, the magnitudes of the differences were only a few millimeters; and the exclusion of those few had a negligible effect on lordosis mean values and their comparisons.

The sex mix was different (HH group, 64% female; CG, only 33.3% female). Only 6 of the female HH participants reported previous wear of high-heeled shoes as a source of LBP. The HH group was similar to the CG group in age (32.7 [HH] vs 32.4 [CG], Table 2) but had a smaller BMI (25.3 [HH] vs 30.7 [CG], Table 2); because the variances for the groups were so different (Levene test: F = 2.5, $P = .12$), the difference in BMI was not statistically significant.

Although the HH group had no mean change in their barefoot-to-heels response, the individuals can be categorized as to whether they had an increase or a decrease in lordosis, as has been done in Table 3. From these subgroups, a post hoc decision was made to identify those individuals who had a change of 5° or more, of either increased or decreased lordosis, as having a "clinically significant" change. The amount of 5° was somewhat arbitrary, but the reasoning was that smaller changes would likely not be detectable by visual or manual examination; also, 5° is approximately equal to the subgroups' mean change plus one standard deviation (Table 3). As seen in Table 4, the 3 participants with increased lordosis who met this criterion were somewhat younger, and reported a shorter history of wear and less frequent wear, than those 4 participants with a clinically significant decreased lordosis. None of these 7 female participants attributed LBP to high-heeled shoes.

For the wooden spine model, the examiners found a mean thoracic angle of 48.4°, a mean lumbar angle of 40.6°, a sacral angle of 23.1°, and a mean scan length of 587 mm (Table 5). The angular and linear measurements of the model do not closely match those of human participants, as a limitation of the construction methods; but the ratio of the lengths of the thoracic and lumbar regions was similar to that of the CG participants. As stated above, the model was used only for testing reliability of the SM unit. Intraclass correlation coefficients (ICCs) were calculated for the 4 measurement values and 4 examiners; intra- and inter-examiner measurements were highly reliable, with all ICCs greater than .999.

Discussion

Like many of the other studies on this topic, these results contradict some popular beliefs. Whatever weaknesses there might be in the body of research on

Table 1 Lumbar lordosis measurements and other characteristics of the HH group and the CG

		HH (n = 50: 32 F,18 M)		CG (n = 9: 3 F, 6 M)	
Lumbar lordosis, mean value (SD)	1st scan	23.4° (7.5)	$P = .173$,	18.8° (9.3)	$P = .163$,
	2nd scan	22.8° (7.1)	CI = −.298 to 1.62	17.6° (9.9)	CI = −.61 to 3.06
Sacral angle, mean value (SD)	1st scan	10.3° (6.3)	$P = .554$	9.4° (7.4)	$P = .855$
	2nd scan	10.1° (6.0)	CI = −.523 to .963	9.3° (8.6)	CI = −1.25 to 1.47
Scan length, mean value (SD)	1st scan	472 mm (34)	$P = .064$	480 mm (40.1)	$P = 1.00$
	2nd scan	475 mm (35)	CI = −4.08 to .121	480 mm (37.1)	CI = −6.07 to 6.07

"1st scan" was done barefoot before a 10-minute adaptation period of walking, sitting, and standing. For the "2nd scan," the HH participants wore high-heeled shoes during the adaptation period and subsequent SM measurement; the CG remained barefoot during the adaptation period and subsequent measurement. Degrees of lordosis are reported in absolute values (the SM reports negative numbers for lordosis.) Confidence intervals are for the 95% level.

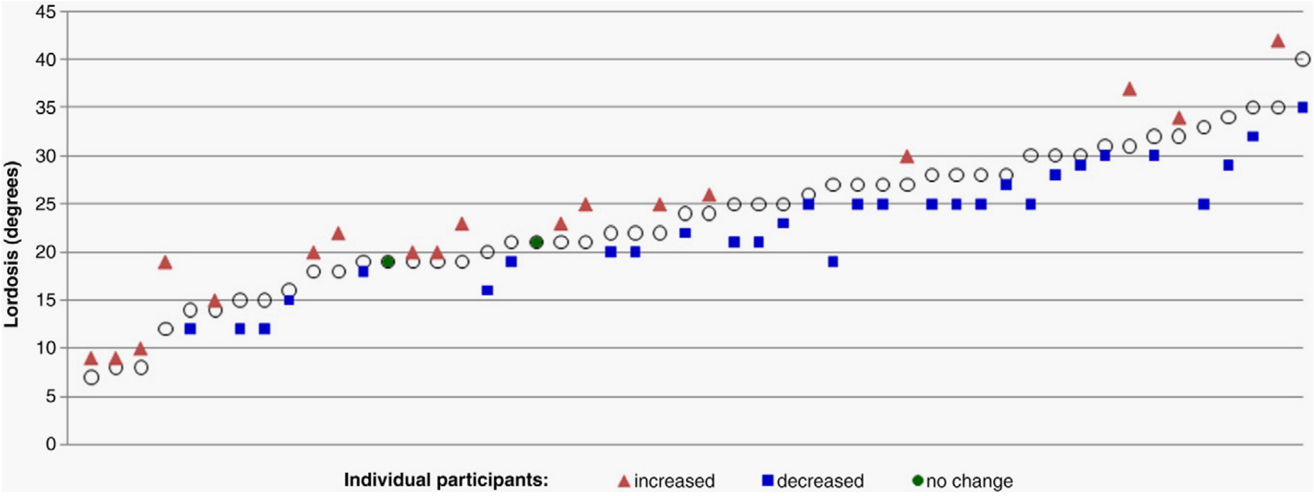


Fig 4. Lumbar values for participants of the HH group, barefoot and with heels, as measured by the SM. Open circles rank individual participants (from 1 to 50 on the horizontal axis) according to magnitude of lumbar lordosis while barefoot. The vertical axis corresponds to amount of lordosis in degrees. A triangle above an open circle indicates increased lordosis with shoes, a square below an open circle indicates decreased lordosis, and solid dots indicate no change (only 2 participants).

this topic (including those of this present study), the findings have usually been the same. Low back pain attributed to heels may be caused by some factor other than increased lordosis. In the present study, it was found that, overall, high-heeled shoes did not cause an increased lumbar curve. Yet, a few individuals had increases in lordosis of 5° or more. Perhaps, practicing clinicians notice this phenomenon in a few patients and assume that the same effect applies to everyone.

The measurements in this study appear to have been reliable, as evidenced by the consistency of sacral angles and scan lengths from first to second scans, the high ICCs for the wooden spine model, and the stability of measurements for the CG from first to second scans. Other investigators have also found SM measurements to be reliable. Mannion et al[14] obtained ICCs for lumbar lordosis measurement ranging from .90 to .92 for intraexaminer reliability and .87 to .93 for interexaminer reliability; Miyazaki et al[15] reported SM ICCs of .939 over skin and .883 over clothing.

The validity of SM sagittal plane measurement, on the other hand, has not been established. One concern is that the mean value for lumbar lordosis in the present study was much smaller than the 32° of Mannion et al.[14] However, there have been differences in the lordosis measurements reported by other authors using an SM: Liebig et al[16] found a mean lordosis of about 15°; Keller et al,[17] about 27°; Takihara et al,[18] just under 20°; and Miyazaki et al,[15] 19° on skin and 20° over clothing. It is not clear whether the discrepancies can simply be blamed on differences in the participant samples. Mannion et al[14] felt that there was no "suitable gold standard" for validity but found its measurements comparable to other surface contour devices and reported that they verified their device's measurements by comparison to an "object of known angles." The SM device in the present study very closely matched a simple test of a clipboard set at a 45° slope between a wall and floor, but the attempt to create a more sophisticated validation method with a wooden spine model suffered from inadequate construction methods. Ulti-

Table 2 Age and BMI for the HH group and the CG

	HH (n = 50)	CG (n = 9)	Group differences
Age: mean value (SD), range	32.7 y (10.4), 21-62 y	32.4 (8.0), 25-52 y	*P* = .94; CI −6.3 to 6.8
BMI	25.3 (3.7)	30.7 (8.4)	*P* = .088; CI −6.3 to 6.8

Confidence intervals are for the 95% level.

Table 3 The HH participants sorted by increased (↑) or decreased (↓) lordosis

	Increased (n = 18: 11 F, 7 M)	Decreased (n = 30: 19 F, 11 M)
Mean change (SD)	↑ 3.1° (1.9)	↓ 2.9° (1.8)
Age	29.7 y (9.8)	33.8 y (10.6)
BMI	25.4 (3.5)	25.2 (3.9)

The subgroups total, n = 48, omits 2 participants who had no lordosis change with shoes. There were no significant differences in age (*P* = .18) or BMI (*P* = .89).

Table 4 The HH participants with likely “clinically significant change” (change in lordosis of ≥ 5°) from barefoot condition to heels

	Increased ≥ 5° (n = 3: 3 F)	Decreased ≥ 5° (n = 5: 4 F, 1 M)
Degrees of change	↑ 6.7° (0.6)	↓ 6.2° (1.6)
Age	23.7 y (2.3)	37.0 y (15.4)
	21-25	21-55
Wear per week	1.3/wk (0.6)	2.7 /wk (2.0)
	1-2 ×/wk	0.25-3 ×/wk
Years of wear	9.3 y (1.2)	18.25 y (12.8)
	8-10 y	8-37 y

The sole male participant was included in the calculation of degree of change and age but omitted for findings for wear per week and years of wear.

mately, the investigators feel that the measurements of the present study were consistent across the various study conditions but do not know whether the values can be compared with those of other studies.

The SM was chosen for its ease of use, for its previously reported reliability, and as an alternative to the use of radiographs as a method of lordosis assessment; the study was intended to evaluate a general population and was not designed to select only participants with clinical indications that would have justified exposure to ionizing radiation. However, the authors’ use of the SM device should not be seen as a commercial endorsement. There are other nonradiographic methods of lordosis assessment, some of which could have been appropriate for this present study, which future investigators could consider. For example, several studies have analyzed lumbar lordosis from photographs [11,13,19-21]; and Kuo et al [22] used still images from videotape. More sophisticated methods are available: Crawford et al [23] used rasterstereography before and after spinal surgery; Singh et al [24] used a Polhemus Fastrak (Polhemus, Colchester, VT) electromagnetic tracking device.

Table 5 Spinal Mouse measurements for wooden spine model recorded by each of the 4 examiners

Examiner	1	2	3	4
Thoracic (°), mean value (SD):	48	49	48	48
48.4 (0.8)	48	48	49	49
	48	49	51	48
	48	48	48	48
Lumbar (°), mean value (SD):	39	42	41	41
40.6 (1.4)	38	41	42	41
	41	43	42	39
	40	40	40	39
Sacral (°), mean value (SD):	22	24	24	24
23.1 (0.9)	21	23	24	24
	23	24	22	23
	22	23	23	23
Scan length (mm), mean value (SD):	593	584	585	590
587 (7.3)	594	580	582	582
	592	580	567	593
	594	588	589	592

Degrees of lordosis are reported in absolute values (the SM reports negative numbers for lordosis.). *Scan length* is the actual distance of excursion of the SM’s measuring wheel. All intra- and interexaminer comparisons were very high, with ICCs greater than .999.

Limitations

One limitation was that many participants were chiropractic students and faculty already familiar with the popular heels-cause-increased-lordosis belief. The authors of this study were careful during their interactions with participants not to suggest a desired outcome, and there were no indications of anyone attempting to influence the results.

The control group was small. The original plan was to simply assume that that the SM’s reliability and validity would be acceptable, as appears to have been done in some other studies. [18,25-27] The CG and the wood spine model were late additions to the project and were used to check the testing conditions of this particular study. A larger group of control participants would make those results more certain.

Furthermore, one could question whether the length of time of the adaptation activity (10 minutes) was adequate. In other words, if someone unaccustomed to wearing high-heeled shoes is scanned after only a few minutes of wear, would the measurements be different after several hours? Previous studies used adaptation periods ranging from 1 minute to 3 hours and did not produce any evidence that longer adaptation makes a difference. Ten minutes was chosen as a longest period possible that would still be convenient for participants, in the circumstances of the present study, in that only 30 minutes of their time was required for all procedures. It also may be relevant to note that a previous study did not find differences in lordosis between women who were experienced wearers of heels and women with less experience [9]; and in the present study, those women with a decreased lordosis had a longer history of wear. In contrast, a recent study by de Oliveira Pezzan et al [13] found a 2° increase in lordosis in their group of experienced adolescent wearers, whereas their “nonuser” adolescent participants showed a 17° decreased lordosis when wearing high-heeled shoes.

Some might question the inclusion of male participants in the present study. That decision was made on the assumption that any effect might be sex independent. Two other prior studies[2,5] have also included men. Opila et al[2] stated, in their 1988 study, "It was decided to include men … because this research was intended firstly to analyze barefoot postural alignment on a basic science level, and secondly to evaluate the postural adaptations to a raised heel as a potential clinical intervention for particular disabilities affecting either gender."[2] In any case, there was no obviously different response from men than women in the present study.

This study only evaluated lumbar lordosis in static standing posture, and the findings should not be extrapolated to other anatomical locations or to dynamic conditions of gait. As well, this study did not measure the presence of back pain. There may be other factors related with back pain and possible association with high heels that were not measured in this study. There are numerous other possible questions about the effects of high-heeled shoes on the health of women who wear them; for more information, the interested reader might start with a recent review by Cowley et al.[28]

In the future, more research could be done to investigate the effect of shoes during walking or other dynamic conditions, or to further identify affected subgroups.

Conclusions

This study showed that high-heeled shoes did not have a significant effect on lumbar lordosis, in static standing posture, for study participants.

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