

EFFECT OF FLOOR SLOPE AND LOAD CARRIAGE ON STANDING POSTURE

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ABSTRACT

Posture has been linked to low back pain and other ailments. While heeled shoes have been investigated, the effect of floor slope and load carriage on posture has received little attention. Therefore, the goal of this investigation was to assess these factors. Twenty-one men and 22 women (all healthy) of college age provided university-approved informed consent prior to participation. After familiarization, subjects stood motionless on the slope (facing up and down at 10° and 20° as well as the level), then bent over picking up a milk crate from the floor (men = 25kg, women = 15kg), and returned to a motionless standing position with the crate at knuckle height. Six trials were performed in each condition with the last three averaged to produce representative results in both standing conditions for each slope. Right sagittal plane kinematics and surface EMG of the erector spinae and middle trapezius were recorded. A static inverse model calculated moments at L5/S1. Significant differences ($p < 0.001$) between standing with and without the load were observed in all variables (torso, hip, knee, and ankle angles, L5/S1 moment, and both muscle activities) except low back curvature ($p = 0.217$). Across the floor slopes, significant trends existed in the low-back, knee, and ankle angles when standing without the load ($p < 0.001$) while the same parameters plus hip angle and L5/S1 moment were significantly different across floor slope with the load ($p < 0.026$). In conclusion, both floor slope and load carriage should be considered when assessing ergonomic factors related to standing posture.

INTRODUCTION

Many occupations and activities of daily living require prolonged periods of standing. Standing duration and posture has been found to be significantly associated with the prevalence of low-back pain [1]. One factor that affects standing posture is shoe heel height. Both positive and negative heels produce modifications in posture at the ankle joint as well as the curvature of the lumbar spine [2]. Standing in heeled shoes in many ways is similar to standing on a sloped floor surface when wearing flat soled shoes. However, the foot and ankle are supported slightly differently, even though the elevation of the heel to the toe might be similar. These differences may affect the ensuing posture that is adopted, since no changes in pelvic alignment were noted while standing on an inclined treadmill [3] even though it is commonly found when studying the effects of high heels [2,4]. Additionally, the range of heeled shoes does not span the range of sloped surfaces that might be encountered at the work place when facing both up as well as down a slope are considered.

While the majority of standing activities most likely occur on a level floor surface, occupations exist where significant slopes would be encountered on a regular basis. Working on a roof, loading ramp, or construction site are examples where sloped surfaces would be encountered on a regular and prolonged basis. Under these working conditions, standing while holding an object of considerable weight would also be expected. Since low-back pain is a common injury in workers that encounter sloped floor conditions both on a regular basis as well as to those exposed on limited occasions [5], two distinct groups may develop; one with chronic adaptations and one without. The goal of this investigation was to evaluate the effect of floor slope on standing posture both with and without load carriage on a group that has not been chronically exposed to sloped surfaces.

METHODS

Subjects were selected from the general college population, limiting age from 18-24 yrs so that a relatively homogeneous group could be analyzed in an age range that would normally be employed in manual labor intensive jobs. Subjects were not employed in jobs that required significant standing or time spent on a sloped surface. An equal representation of each gender was included in the sample population with women holding 15 kg and men 25 kg based on strength differences between genders [6]. Prior to participation, a health-history questionnaire and university-approved informed consent form were completed.

All standing was performed in the center of a 1.23 x 1.23 m wooden platform hinged at one end and outfitted with screw jacks to alter floor slope (Figure 1). For the load carriage trials, a standard cubic milk crate was held at knuckle height. The 3D motion of retro-reflective markers was captured with a six-camera (60 fps) optical capture motion analysis system (Motus 7.0, Peak Performance Technologies Inc., Englewood, CO). Electromyography (EMG) was sampled simultaneously at 1,200 Hz through a tethered Noraxon 1200 system (Scottsdale, AZ). Both the coordinate data as well as the zero-measured and rectified EMG data were low-pass filtered at 5 Hz (4th-order recursive Butterworth).

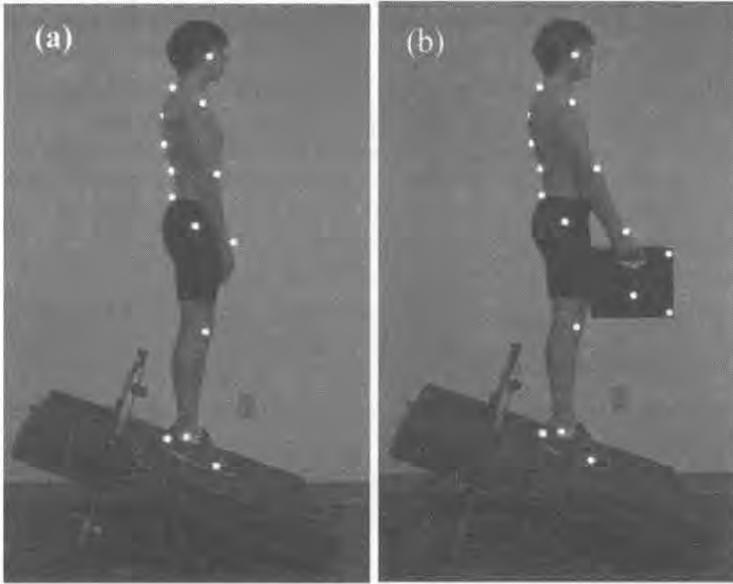


Figure 1: Demonstration of standing conditions and reflective marker placement facing downhill on a 20° slope both (a) without and (b) with load carriage.

All data were collected from each subject in a single visit lasting ~1.5 hrs. A 30 min familiarization session was followed by data collection. Subjects wore their preferred shoe and sock and a dark-colored, tight-fitting spandex type short. Men wore no shirt and women an exercise bra. Reflective markers were placed on the skin/clothing over the right temple (approximating head center of mass), joint centers of the shoulder, elbow, wrist, hip, knee, ankle, and toe (base of 5th metatarsal), and heel as viewed in the sagittal plane. Five reflective markers were also placed on the spine at L5/S1, C7, and 1/4, 1/2, and 3/4 the distance between L5/S1 and C7. The box was tracked by placing markers on the right side at an estimated center of mass, and on both the top and bottom of the leading vertical edge to show orientation (Figure 1). Bi-polar surface electrodes with 2.54 cm inter-electrode distance were placed symmetrically over the muscle bellies of the right and left erector spinae and middle trapezius after cleaning and debrading of the skin.

Lifting conditions of facing down the slope at 20° (-20°) and 10° (-10°), level (LVL), and up the slope at 10° (+10°) and 20° (+20°) were presented to each subject in a randomized order. A symmetric, non-staggered stance, with feet wider than the box, was required. After standing motionless with arms

by their sides for collection of the load free standing posture, the subject picked up the crate, returning to a motionless erect standing position with arms extended and crate resting in front of the their hips (knuckle height). After settling on foot placement to ensure comfort, six trials for record were performed with one minute rest between each.

Torso angle was calculated from the shoulder and hip relative to vertical such that 0° was upright. Hip and knee angles were defined as the included angles between the shoulder, hip, and knee and hip, knee, and ankle, respectively, such that 180° was full extension. Ankle angle was the included angle between the lines created by the ankle to the knee and the heel to the toe such that 180° was full plantar-flexion. Lower back curvature of the spine was defined as the angle produced by three reflective markers outlining the lumbar region of the back. The angle was defined such that a value less than 180° was lordotic in nature.

A four segment model (head and neck, trunk (without pelvis), upper arm, and forearm and hand) based on the reflective markers was constructed. Motion of the left side of the body was assumed symmetric to that of the right and incorporated into the mass distribution of segments. Gender specific anthropometric values were utilized based on the work of Plagenhoef et al. [7]. The L5/S1 joint location was calculated using the procedure outlined by Chaffin et al. [8]. The net muscular moment about L5/S1 was calculated by summing the torque created by the weight of each body segment superior to L5/S1 and that of the crate.

Instantaneous parameter values were extracted prior to any downward motion to pick up the crate for the load free condition and after all motion had stopped after picking up the crate for the load carriage condition. EMG was normalized to the free standing condition on the level surface and then averaged across sides of the body. The last three standing postures of each subject in each condition were averaged and analyzed to create a representative stance for each condition for further comparison. Before combining the men and women into one single group, analyses were performed to ensure that trends across conditions were not significantly different between genders ($p > 0.05$). Statistical analysis was conducted with SPSS 12.0 (Statistical Package for the Social Sciences, Chicago, IL) with $p < 0.05$ set for determination of significant differences. A 2×5 within subjects repeated measures ANOVA was utilized to compare the load and no load carriage posture results across floor slope.

RESULTS

Forty-three healthy men ($n=21$) and women ($n=22$) successfully completed the research protocol. While age was not significantly different between the men and women ($p=0.517$), the men were significantly heavier ($p<0.001$) and taller ($p<0.001$) than the women. The average combined age, height and mass of the subjects were 22.3 ± 1.6 yrs, 173.2 ± 8.2 cm, and 67.5 ± 10.2 kg, respectively.

Ankle, knee, hip, and torso angle along with low-back curvature, L5/S1 moment, and erector spinae and middle trapezius muscle activities are summarized in Table 1. Comparing free standing to load carriage conditions, position for position, significant differences existed in every position and posture related parameter ($p\leq 0.019$) except for the low-back curvature in all four sloped conditions ($p\geq 0.094$). Ankle and knee angles were more extended while the hip more flexed when standing with the load. The torso was slightly more bent forward when standing with the load and the L5/S1 moments and muscle activations also greater when standing with the load. In the only position where low-back curvature was significantly different, the LVL, there was increased lordosis when standing with the load.

Across floor slope, significant trends existed in the ankle and knee angles as well as the low-back curvature when free standing ($p<0.001$). In addition to these three parameters continuing to exhibit significant trends when standing with the load, significant trends also existed in the hip angle and L5/S1

moment ($p \leq 0.030$). The ankle angle decreased 45° and 43° as floor slope increased from -20 to $+20$ in the free standing and load carriage conditions, respectively. This slight difference was large enough to create a significant interaction between the two ($p=0.013$). While the knee angle exhibited a significant trend in both conditions, the magnitude of the differences was only on the order of 3° with no clear pattern across floor slope. Again, a significant interaction existed between standing conditions ($p=0.006$). Hip angle when standing with the load possessed a significant trend across slope even though the difference was only 2° and the interaction was not significant ($p=0.537$) with the free standing condition that did not have a significant trend ($p=0.120$). Low-back curvature became significantly more lordotic as floor slope increased in both standing conditions. However, the difference was only on the order of 3° as well. The response in the low-back curvature was slightly greater when standing with the load, resulting in a significant interaction ($p < 0.001$). The L5/S1 moment significantly increased as floor slope increased when standing with the load. However, the increase was only 3 Nm and there was no significant interaction ($p=0.329$) with the free standing condition which did not have a significant trend ($p=0.492$).

Table 1: Kinematic, kinetic, and muscle activity results standing with and without load across floor slopes.

	Free Standing					Standing with Load				
	-20°	-10°	LVL	+10°	+20°	-20°	-10°	LVL	+10°	+20°
Ankle Angle	111 (4)	100 (4)	89 (5)	79 (4)	66 (5)	117 (4)	107 (4)	96 (4)	85 (5)	74 (4)
Knee Angle	174 (5)	175 (5)	174 (4)	174 (4)	172 (5)	176 (5)	178 (4)	178 (4)	177 (4)	176 (4)
Hip Angle	180 (5)	181 (6)	181 (6)	182 (6)	182 (5)	172 (7)	173 (6)	174 (5)	174 (5)	173 (6)
Torso Angle	1 (3)	1 (3)	1 (3)	1 (3)	1 (3)	6 (5)	7 (5)	7 (4)	7 (4)	8 (4)
Low-Back Curve	167 (8)	167 (8)	167 (8)	166 (8)	165 (8)	168 (8)	166 (7)	165 (7)	165 (7)	165 (7)
L5/S1 Moment	8 (7)	8 (7)	8 (8)	8 (7)	9 (7)	74 (25)	74 (25)	75 (23)	75 (24)	77 (25)
Erector Spinae	1.12 (0.75)	1.21 (0.69)	1.00 (0.00)	1.13 (0.62)	1.28 (0.77)	20.07 (10.49)	19.04 (11.68)	19.23 (13.55)	18.47 (11.90)	18.91 (12.97)
M. Trapezius	1.25 (0.68)	1.29 (0.87)	1.00 (0.00)	1.16 (0.65)	1.28 (0.86)	14.05 (14.21)	12.02 (11.06)	12.26 (11.82)	13.12 (13.81)	11.65 (14.35)

Angles in degrees, Moment in Nm, and EMG normalized to free standing level condition
() indicates standard deviation

DISCUSSION

The subjects that participated in this study portrayed similar anthropometric characteristics to the general population [9]. However, it should be noted that these participants were not accustomed to standing on sloped surfaces for extended periods of time. While this would place their postural responses to the slope in the same category as others without this experience, it may differ from those who work on a slope on a regular basis. Based on the observed differences between the sloped and level standing conditions, muscles, tendons and ligaments at the ankle may adapt to chronically being placed in relatively extended positions if the work requires facing down the slope and flexed positions if facing up the slope. As a result, the findings from this investigation may be limited to people unaccustomed to sloped surfaces and further research may be warranted on a group with chronic adaptations.

The differences in kinematics, kinetics, and muscle activity between free standing and load carriage were not completely unexpected. In order to stay upright, the center of mass must stay over the base of

support. When holding a weight in front of the hips, the center of mass of the person must be displaced posteriorly relative to standing without the load. This was accomplished by plantar flexing at the ankle and extending the knees slightly when holding the load. In order to bring the mass of the upper body forward and make the load carriage stance a bit more comfortable, the hip was then flexed more than when free standing. The increased hip flexion resulted in a greater forward lean of the torso when standing with the load.

With the load in front of the hips, an increased extensor moment was created at L5/S1. The moment was increased further relative to free standing due to the greater forward torso lean which would increase the moment arm of the upper body musculature about the low back. The increased L5/S1 moment was accompanied by increased activity of the erector spinae, a muscle heavily responsible for generating this action. Even though there was increased hip flexion, forward torso lean, extensor torque at L5/S1, and activity of the erector spinae when standing with the load, it only affected the low-back curvature in the LVL position. The response was to increase lordosis when holding the load, which has been purported to be protective of this region [10]. The middle trapezius also exhibited increased activity when holding the load, due to the stabilizing requirement of this muscle to hold the shoulder girdle in place against the resistance created by gravity pulling the load downward.

As floor slope increased, the most consistent response was at the ankle joint. A systematic response at the ankle joint was expected, since it is the first major joint superior to the foot. The foot interacts directly with the floor, adopting an orientation similar to it. The remainder of the body then must remain upright keeping the center of mass over the base of support. As a result, the ankle angle responded with changes of $\sim 10^\circ$ for every 10° change in the floor slope. The response at the ankle was not exactly 10° for several reasons. First, the person may not place their foot completely flat on the floor, especially in the more extreme slopes. Due to flexibility and balance requirements, the heel or toe may potentially be raised slightly from the floor. Second, postural responses at knee, hip, spine, etc. will influence the magnitude of change at the ankle joint.

While significant changes occurred in other parameters across slope, only two were consistent: low-back curvature regardless of loading condition and the L5/S1 extensor moment when holding the load. Lordosis increased slightly with floor slope as did the L5/S1 extensor moment. While the magnitude of the increases were relatively low (3° and 3 Nm, respectively, over a slope change of 40°), their consistency indicates that they should be considered when assessing the affect of floor slope on posture. The increased lordosis was most likely a response to both the increased extensor moment generated by muscles in the region as well as postural demands of the altered kinematics, since the L5/S1 moment did not increase significantly with floor slope when free standing. Even though these increases were relatively small, with sufficient exposure the increased lordosis may cause back pain due to the increased compression created on the posterior regions of the spine and increased tension on the anterior regions. Additionally, the increased extensor moment required when holding the load may change the rate of fatigue, making it more difficult to stand for extended periods of time when facing up the slope. The fact that the erector spinae muscle activity did not increase with the extensor moment suggests that other muscles may be responding to this increased demand or that the change in the muscle length accompanied by the change in low-back curvature altered force production in such a way that increased activity was not necessary.

Leroux et al. [3] observed that the pelvis maintained its orientation with the line of gravity regardless of slope during quiet stance. This was maintained when both facing up and down slopes of 10° . This is consistent with the present finding that torso angle was not affected by floor slope, since the person was keeping themselves consistently aligned with gravity. However, it does not explain the observed

increase in lordosis with slope. The increased lordosis was consistent with studies examining the effect of heel height on posture [2,4]. The discrepancy with Leroux et al. [3] may be due to a limited number of subjects (n=8), different marker configuration, and limited range of floor slope.

CONCLUSIONS

In summary, both floor slope and load carriage effect standing posture. Load carriage mainly increases the musculoskeletal demand as indicated by increased extensor moments at L5/S1 and increased muscle activity in the erector spinae and middle trapezius. Floor slope had the greatest effect on changes in ankle angle. However, consistent changes in the low-back curvature and L5/S1 moment (during load carriage) were also recorded. As floor slope increases, so does the amount of lumbar lordosis, potentially changing the stress distribution across the vertebral discs in the region in such a manner as to influence the risk for injury. The extensor moment also increases with floor slope when standing with the load. This may increase the risk for injury as well as affect fatigue rates if the posture is maintained for extended periods. Finally, caution should be taken when applying these results to other populations, since chronic exposure to slopes may induce changes not observed in this group.

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