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WALKING WITH AND WITHOUT HIGH HEELS ON A DECLINED SURFACE

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The purpose of this pilot study was to investigate body segment ROMs while walking with and without high heels on flat and declined surfaces. Eight healthy, active, female college students (BH: 1.67 ± .08 m, BW: 57.8 ± 7.03 kg) were recruited in the study. The participants randomly performed three trials of walking on level ground and a declined surface in both high heels and tennis shoes using 2D motion analysis. Results indicated that the ROMs were significantly decreased on a declined slope, regardless of the type of shoes. Considering shoe types, the body segments' ROMs were reduced during the high heels conditions except for the trunk segment for both surfaces. This enhanced control of locomotion during decline and/or high-heeled walking.

KEY WORDS: gait analysis, high heel, range of motion.

INTRODUCTION: Women of all ages wear high heels for a variety of reasons. While standard shoes have an elevation of around 1 to 2 centimeters, high-heeled shoes can have an elevation anywhere between 3 to 11 centimeters (Stephens, 1992). A vast body of studies have shown that a change in heel height would result in some adjustments to the musculoskeletal system during walking, such as body segmental range of motion (ROM), muscle activation through different walking phases, shifts in weight distribution, etc. (e.g., Sefanyshyn, Nigg, Ficsher, Fishe, & Lui, 2000). These changes regularly correspond with pain and discomfort in the lower back and foot, as well as muscle fatigue (Adrian & Karpovich, 1996).

Studies found that during downhill walking with regular shoes, the hip flexion angle decreased, compared to level walking in early stance to late swing; while greater knee flexion was necessary during stance phase to lower the body downward, compared to level walking (Lay, Hass, & Gregor, 2006). Also, there is a dramatic increase in the hip extension angle during level walking, as opposed to walking downhill which required less extension during heel strike. In the ankle, there was no notable change during heel strike or maximum stance flexion, between level and downhill walking (Lay et al., 2006; Kadaba, Ramakrishnan, & Wootten, 1990).

Many studies have examined the effect of heel height during walking on a flat surface (e.g., Adrian & Karpovich, 1996; Ebbeling, Hamill, & Crussemeyer, 1994; Csapo, Maganaris, Seynnes, & Narici, 2010; Sefanyshyn et al., 2000). While on a declined surface in regular tennis shoes, the ROM changes throughout the body are due to center of mass (CoM) being shifted. While walking on a flat surface, the CoM must be lifted in order to take a step. But as one is walking downhill, the CoM is already significantly above the foot and continues to move in the downward motion due to the decline of the hill (Easton, Micklebrough, & Baltzpoulous, 1995; & Sefanyshyn et al., 2000). The hip and ankle flexors become active when walking downhill, and a major difference in downhill walking compared to walking on a flat surface is that the hip extensor moment switches to a flexor moment earlier in the stance phase (Lay et al., 2006).

Most of the studies have determined the effect of heel height on the kinematics of body movement, but the majority of the studies investigated walking in high heels on a flat surface only. Therefore, the purpose of this pilot study was to examine the body segments' ROM while walking with and without high heels (regular tennis shoes) on a flat and declined surface.

METHODS: Eight healthy female subjects with no lower extremity injuries in the past six months participated in this study (Age: 20.6 ± 1.4 years, BH: 1.67 ± .08 m, BW: 57.8 ± 7.03

kg). During the time of the study, the subjects reported wearing high heels similar to the ones used in the study at least one day a week.

The participants wore form fitting athletic clothing to ensure that the markers used during the experiment would not move. The participants wore two different pairs of shoes: a pair of 10.16 cm high heel stilettos and a pair of tennis shoes. The markers used were placed on the right side of the subjects' body at the acromion process, greater trochanter, lateral condyle, lateral malleolus, and the fifth metatarsal phalangeal joint. A wooden platform with the length of 2.44 meters was set up at a 12-degree angle slope from the floor. A straight line was marked on the level ground and on the ramp to ensure that the subjects walked in the plane of motion. The kinematic variables were recorded at a camera speed of 60 frames per second (Canon, ZR 960).

The participants were asked to walk down the 12-degree decline as well as walk on a flat surface in both tennis shoes and high heels at the individual's comfortable walking pace. The four conditions were done in a random order to prevent practice effect and three trials were performed for each condition. A two-dimensional video analysis (Vicon Motus, 9.2) was performed to obtain the ROM of the body segments in each condition from the sagittal plane of each subject. All the videos were cropped from the 10th field before the right heel contacted the floor to the 10th field after the same heel contacted the floor again. The fourth-order zero-lag Butterworth filter and a cut-off frequency (4 Hz) were performed to filter the kinematic data.

The ROM of each body segment, trunk, thigh, shank, and foot were calculated during the stance phase for downhill and level walking in both high heels and tennis shoes. Two-way ANOVA was applied to examine the differences of ROM for each body segment in the different types of shoes and slopes. Tukey HSD post hoc was performed to determine the difference among the variables. The significance level was set at $P = .05$.

RESULTS: Two-way ANOVAs and Tukey HSD post hoc revealed significant differences ($P < .01$) between shoe and slope types as well as cross differences between the conditions. Overall, walking on a decline reduced the ROM in all body segments whether wearing tennis shoes or high heels. In general (with the exception of the trunk segment), the ROMs were reduced by wearing high heels. Walking downhill in high heels significantly reduced the ROM for all body segments as compared to walking flat in tennis shoes. For the foot and shank segments, walking in high heels on a flat surface decreased the ROM contrasting with ROM when walking on a decline in tennis shoes (Tables 1 and 2). Conversely, when walking with high heels, the thigh and trunk segments exhibited an increased ROM (Tables 3 and 4). Figure 1 indicates the segment angles during the stance phase.

Table 1
Foot ROM in four conditions

Slope/Shoe	Tennis	High Heels
Flat	79.03 ± 6.06*^#	44.58 ± 8.31*^#
Decline	62.42 ± 8.60*^#	31.27 ± 6.61*^#

Table 2
Shank ROM in four conditions

Slope/Shoe	Tennis	High Heels
Flat	69.53 ± 3.46*#	51.28 ± 5.23*^#
Decline	66.11 ± 4.52*#	45.35 ± 6.98*^#

Note: * indicates significant difference between shoe types. ^ indicates significant difference between slope types. # indicates significant cross difference between shoe and slope types.

Table 3
Thigh ROM in four conditions

Slope/Shoe	Tennis	High Heels
Flat	36.92 ± 3.29^#	37.09 ± 4.39^#
Decline	17.50 ± 3.88*^#	14.45 ± 3.50*^#

Table 4
Trunk ROM in four conditions

Slope/Shoe	Tennis	High Heels
Flat	8.18 ± 3.02^#	8.81 ± 4.10^#
Decline	4.33 ± 2.01^#	5.68 ± 2.44^#

Note: * indicates significant difference between shoe types. ^ indicates significant difference between slope types. # indicates significant cross difference between shoe and slope types.

DISCUSSION: The studies conducted by Lay and associates (2006) and Mika and colleagues (2012) found reduced ROMs when walking down a slope using regular shoes. Those findings were mostly confirmed by the results of the present study. The exception was that the shank ROMs between the two slope conditions were comparable while wearing tennis shoes. This research further revealed that all segments exhibited reduced ROMs when participants wore high heels while walking downslope.

Regarding shoe types, significant differences in ROMs were limited to the foot and shank segments while walking on both surfaces. Due to the foot being in a plantar flexed position while wearing high-heeled shoes, the shank would directly affected (decreased ROM) as it is an adjacent segment. For the thigh segment, the only significant difference in ROM was under the declined surface condition, while the ROM of the flat surface locomotion did not change significantly between shoe types. The trunk segment was unaffected by shoe type, which is consistent with previous studies that determined balance and posture are correlated with small trunk ROM (Krebs, Wong, Jevsevar, Riley, & Hodge, 1992; Opila-Correia, 1990). Krebs and colleagues (1992) found that trunk ROM during locomotion was 12° or less, which corroborates with the current results. Therefore, the shank is the major body segment that compensates for shoe types during level walking. When walking downslope, both shank and thigh segments compensate for the change of shoe types.

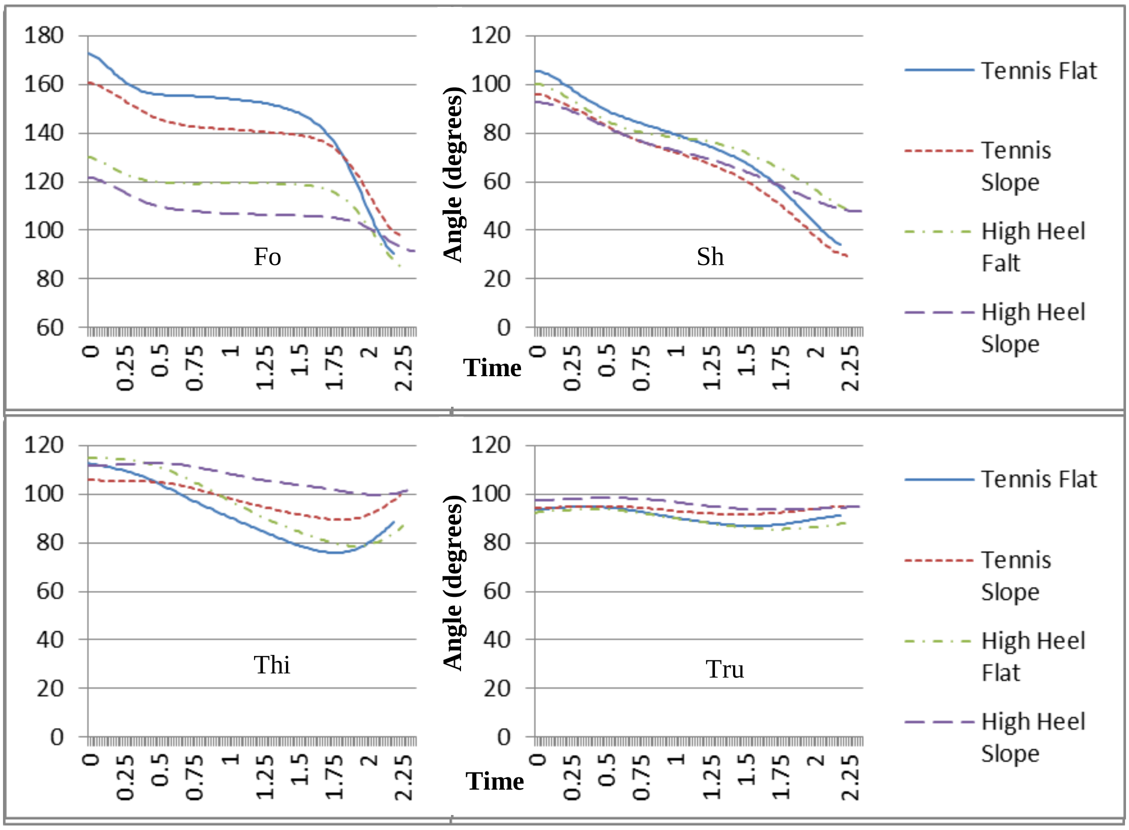

Figure 1: Body segment angles during stance phase.

From the initial heel contact, the foot segment angle was greater for the tennis shoes condition. When approaching toe off, those angles were similar for both shoe conditions, which resulted in greater ROM when walking with tennis shoes. In order to clear the height of the heel while walking downslope, the shank had greater segment angle at toe off, which resulted in less ROM for wearing high heels. For the thigh segment at heel contact, the angles are similar for all conditions. However, the thigh segment exhibited smaller segment angles during late stance phase on level walking surfaces for both shoe types, which resulted in greater ROMs. The trunk segment angles evidenced the least amount of ROM from heel contact to toe off.

There are several limitations of the current study. Subjects utilized their own shoes that met the height characteristics of the experiment; however, the lack of uniformity of the shoe type may have influenced gait kinematics. Second, there was variability in the frequency of wearing high-heeled shoes from each individual. The third limitation is that there was a small sample size used for the study. Finally, the subjects were young females and the results could not be generalized beyond this group to elderly women, for example. Further studies should include kinetics data such as ground reaction force and joint moments.

CONCLUSIONS: The current study found that the ROMs of all body segments were significantly decreased during downslope. Moreover, reductions in ROMs were found when participants wore high-heeled shoes, which were even more pronounced when walking downhill, except for the trunk segment. Overall, the trunk segment ROMs remained unaffected by the shoe type.

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