A preliminary study on dynamic balance performances during normal walking with high-heeled shoes

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ABSTRACT

A preliminary study on investigating the effects of high-heeled shoes on wearers’ dynamic balance performances during normal walking was conducted with 5 healthy female adults. Motion capture and F-scan systems were used to record the biomechanical data and several parameters including vertical position of center of body mass (COM), ankle joint angles and knee joint angles were calculated afterwards. The experimental data at flat shoes and high-heeled shoes were compared and the results showed that wearing high-heeled shoes would result in significantly smaller RMS of time series COM height and restrict the flexibility of lower limbs. This suggested human dynamic balance performance became worse with high-heeled shoes.

Keywords: Dynamic balance, Center of body mass (COM), Motion capture, High-heeled shoe

1. Introduction

 Millions of women wear high-heeled shoes to fulfill their desire of appearing more beautiful and attractive (Linder et.al, 1998). However, previous studies have found that high-heeled shoes cause negative effects on wearer’s health in different aspects, such as sprained ankles (Nieto et. al, 1975), leg pain (Yoe, 1994), lower back pain (Hyun et. al, 1994), change of gait pattern (Merrifield, 1971) and other negative biomechanical effects (Lee et al., 2001). However, only a few of these studies have attempted to examine the effects of wearing high-heeled shoes on balance performance during walking. This is an important issue to be considered, since fall is one of the leading causes of the burden of disease in the world for all age groups (World Health Organization, 1999).

 Therefore, the purpose of this study was to evaluate the dynamic balance performance during normal walk with high-heeled shoes. In this study, vertical positions of center of body mass (COM), ankle joint and knee joint angles were used to measure balance performance.

2. Method

2.1 Subjects and Apparatus

 Five female volunteers from the university with the range of 21-31 years were participated in this experiment. All subjects have no previous history of foot and musculoskeletal disorders.

 F-scan system (Tekscan) was used to measure in-shoe plantar pressures and motion capture system (OptiTrack) with eighteen cameras was used to collect the position data of optical markers. Motion capture and F-scan systems were synchronized to collect the data at a sampling frequency of 100Hz.

2.2 Data collection and analysis

 The participants were asked to walk on treadmill with the speed of 4 km/h under two shoe conditions: (1) flat shoes; (2) high-heeled shoes with heel height at 7cm. Each condition took three minutes and was repeated three
times for each participant. The time series vertical positions of COM were derived by the add-on function of F-scan software. Four markers were used to define and calculate the ankle joint angle and knee joint angle (Figure 1). Position data of these optical markers were collected by the motion capture system during normal walking.

![Figure 1 Measurements of ankle joint and knee joint angles](image1.png)

The root mean square (RMS) of time series vertical position of COM was calculated based on the F-scan data. The mean and standard deviation (SD) of the ankle joint and knee joint angles were used to evaluate the joint movements. Paired t-test was applied to analyze the parameter differences between flat shoes and high-heeled shoes conditions.

### 3. Results

#### 3.1 Vertical position of COM

As shown in figure 2 for a typical experimental subject, the time series vertical positions of COM describes the variation of COM height in each walking cycle. Figure 3 showed that wearing high-heeled shoes induced significantly smaller (p=0.0079) RMS of time series vertical position of COM when compared with the flat shoes.

![Figure 2 Vertical position of COM for a typical subject at two shoe conditions](image2.png)

![Figure 3 Paired t-test of RMS of COM height at two shoe conditions](image3.png)

#### 3.1 The mean and SD of ankle joint and knee joint angles

Figures 4 and 5 showed the box-plots on mean and SD of ankle joint angles respectively under flat shoes and high-heeled shoes conditions. Further paired t-test showed that there was a significant difference (P=0.017) on mean ankle joint angles between two shoes conditions, where the mean for high-heeled shoes was significantly larger (Figure 4). Even though figure 5 showed only marginally significant difference (P=0.096) on SD of ankle joint angle between two shoes conditions, a detailed analysis on SD of each individual in figure 6 clearly showed the SD was smaller at the high-heeled shoe condition for each experimental subject. Figure 6 also showed that considerable variations among different subjects, which may result in marginal significant difference between two shoe conditions due to small sample size (N=5) in this preliminary study.

![Figure 4 Box-plot of mean ankle joint angles](image4.png)

![Figure 5 Box-plot of SD ankle joint angles](image5.png)

![Figure 6 Box-plot of SD ankle joint angles](image6.png)
4. Discussion

This study showed that the RMS of time series COM height was significantly decreased during walking with high-heeled shoes (Figure 2 and Figure 3) when compared with flat shoes. Merrifield (1971) found that due to less stability from the higher COM when wearing high-heeled shoes, the wearer’s step length and stride length were significantly decreased in order to compensate for less stable position on the sagittal plane. Smaller step length and stride length will induce a narrower range of up-and-down COM movements and thus, a smaller RMS of COM height.

Regarding the movements of ankle and knee joints, our study showed that the mean ankle joint angle was significantly increased in the high-heeled shoes condition (Figure 1 and Figure 4), indicating the restriction of ankle joint when wearing high-heeled shoes. This result was consistent with Snow (1994), who reported larger ankle angles in plantar-flexion

Figures 7 and 8 showed the box-plots on mean and SD of knee joint angles respectively under flat shoes and high-heeled shoes conditions. Further paired t-test showed that there was no significant difference (P=0.19) on mean knee joint angles between two shoes conditions, even though SD of knee joint angles was significantly different (P=0.035) between two shoes conditions.

Figures 4, 5, and 6 illustrate the paired t-test of mean ankle joint angles, SD of ankle joint angles, and SD of each individual’s ankle joint angles at two shoe conditions, respectively.
throughout the gait cycle with the increased heel height. Interestingly, there was no significant difference on mean knee joint angles (Figure 7) between two shoe conditions, which may be due to human body could control knee joint flexibly comparing with ankle joint even wearing high-heeled shoes. Furthermore, SDs of ankle joint and knee joint angles when wearing high-heeled shoes were significantly smaller (Figures 5, 6 and 8). This result may be explained by gait changes when wearing high heeled shoes (Merrifield, 1971). The heel height causes a walking step to be modified by shorter, quicker steps with less range of ankle and knee motions during the swing phase of walking, thus, inducing smaller variances on ankle joint and knee joint angles.

5. Conclusion

A preliminary study on changes of vertical positions of COM, ankle joint and knee joint angles during normal walking with high-heeled shoes was conducted. Experimental results showed that wearing high-heeled shoes would result in smaller RMS of time series COM height and restrict the flexibility of lower limbs, inducing the worse dynamic balance performance. More extensive experimental study with a large sample size should be carried out in the near future to check the generalization of the results.

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