JOINT MOMENT OF LOWER LIMBS DURING WALKING WITH HIGH-HEELED SHOES AND ASYMMETRIC LOAD CARRYING IN YOUNG FEMALES

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The objective of the study was to examine the effects of walking in high heeled shoes and asymmetrical carrying a load on joint kinetics of lower extremity in 15 young females. The moment of force of the hip, knee, and ankle in sagittal and frontal planes during walking in flat, 3 cm, and 9 cm heights of high-heeled shoes while asymmetrically carrying a load of 0%, 5% and 10% of weight BW was studied. Results showed that hip extensor moment significantly increased with the heel height increase but not the load weight increase. Walking in high-heeled shoes and carrying a load increased knee extensor moment and diminished ankle plantarflexor moment. When high-heeled shoes and asymmetrically carried load are combined, the changes of joint kinetics at each joint are much greater than that caused by the high-heeled or load carriage alone.

KEYWORDS: gait, load carriage, joint kinetics

INTRODUCTION: A load carriage is widely performed in our daily lives. Most of the research about the effect of carrying bags in adults focuses on use of backpacks for recreation or heavy load carriage in military personnel. In these studies, different load weights were often compared to find a threshold point or optimum weight to be put into the backpack while minimize biomechanical stresses to carrier's musculoskeletal structure. Studies in backpack carrying found significant biomechanical changes made to posture and gait patterns. Results from these studies showed significantly increased ground reaction force as a load in backpacks increased (Tilbury-Davis &Hooper, 1999). However, in general female population, backpack carriage is not the most popular load carrying methods. Other carrying method such as asymmetrical load carrying method is implemented by women. Thus, it is not reasonable to apply such conclusions from backpack researches directly to asymmetrical load carrying in woman. Furthermore, when footwear changes from flat or low heeled shoes to high-heeled shoes the body must compensate any changes caused by load and shoes. Increased complaints about back and foot pain and increased incidents of falls and discomfort from wearing high-heeled shoes are evident among women (Tencer, Koepsell, Wolf, Frankenfeld, Buchner, Kukull, LaCroix, Larson, & Tautvydas, 2004). Both asymmetrical load carriage and high-heeled shoes are frequently encountered during walking and in turn, problems have raised concerns among women. Both high-heeled shoes and load carriage are important factors on stability in the dynamic environments such as during simple locomotion or balancing on a moving bus. Although numerous efforts have been undertaken into investigating the effects of high-heeled shoes (Esenyel, Walsh, Walden, & Gitter, 2003; Cowley, Chevalier, & Chockalingam, 2009) or load carriage alone (DeVita., Hong & Hamill, 1991) on neuromuscular stress and walking stability, the combined effect has not yet been studied. Therefore, the purpose of the current study was to examine the combined effects of asymmetrical load carriage and high-heeled shoes on lower extremities joint kinetics during walking in young healthy habitual high-heeled shoes wearers. The study would add the understanding to gait and posture adaptation to the combined conditions.

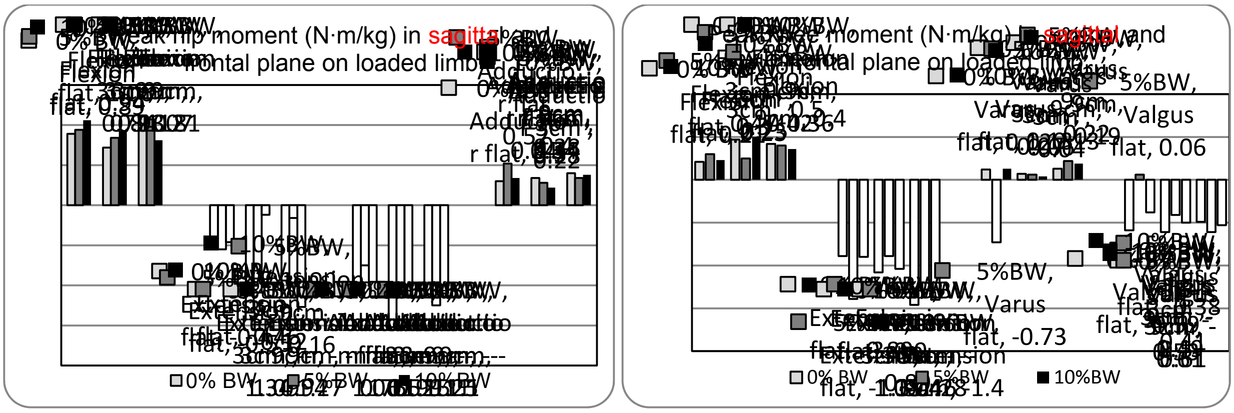
METHODS: A total of fifteen females volunteered to participate in the study (24.67 ±3.54 y; 54.96 ±6.67 kg; 162.2 ±3.91 cm). All of the participants were in good health conditions. They wore high-heeled shoes at least three times a week for three years. Kinematics and kinetics data were collected and analyzed using Vicon Motion Analysis System (Vicon MX-13, Oxford Metrics, Oxford, UK) with nine infrared cameras recording three dimensional motion at 200 Hz, coupled with three force plates (models 9286AA, Kistler Instruments Corp, Winterhur, Swtz; FP 4060-08, Bertec Corporation, Columbus, OH, USA) recording ground reaction force at 1000 Hz. Three-dimensional trajectories of 45 retro-reflective markers (14 mm diameter) at various landmarks of the subject were captured according to a Plug-in-Gait marker set (Kadaba, Ramakrishnan, Wootten, Gainey, Gorton, & Cochran, 1989, Davis, Ounpuu, Tyburski, & Gage, 1991). The force plates were embedded on the ground in the middle of walkway. The kinematics and ground reaction force data were collected for each subject walking across the testing area of 8 m in their comfortable speed at three loads (0%, 5%, and 10% of each subject's body mass) and three heel heights (flat shoes and 3 cm and 9 cm stiletto high-heeled shoes) conditions. Metal weights were put into a woman's one strap nylon shoulder purse measured as 26.7 cm (L) x 3.8 cm (W) x 16.5 cm (H) (model: 7606 Lulu, Le Sportsac Inc.) to build 5% and 10% load conditions. The purse was asymmetrically carried between the trunk and the upper arm. One pair of flat shoes with 1.1 cm heel height (Vans Inc., California, USA) and two pairs of stiletto high-heeled shoes (Jones Apparel Group Inc., NY, USA) were used. The base tip of the stiletto heels was 0.9 cm^2. A total of 9 conditions (3 loads and 3 heel heights) were randomly assigned to each participant. In each condition, five trials were measured.

One full gait cycle per each foot was analyzed. VICON Nexus software (v1.3) along with the Plug-in-Gait marker set was used to obtain joint angles of hip, knee, and ankle in sagittal and frontal planes. Computed joint angles were then employed to calculate joint moment using inverse dynamics based on linear and angular Newtonian equations. The data was normalized to a stride period of 100% by using Polygon software (VICON, Oxford, UK). All data were normalized by body weight and presented as 100% of gait cycle. The peak moments at stance phase were compared using two-way repeated measures of ANOVA (3 heel heights x 3 load weights) at a 95% confidence level. If any difference was found between the independent variables, Tukey's post hoc test was performed for further detection. Effect of heel height and asymmetrical load as well as the interaction between the independent variables were found from the statistical testing. Paired sample *t*-tests were implemented for all dependent parameters to find a significant difference between loaded and unloaded limb.

RESULTS: All participants carried an asymmetrical load on their right shoulders, therefore loaded limb indicates right limb in this paper. Mean and standard deviations of peak moment for hip, knee, and ankle in sagittal and frontal planes are illustrated in Figure 1. No significant difference was found between loaded and unloaded limb in lower extremity joint moment during walking with no load. Interestingly, significant differences in joint moment between the two limbs were found only during high-heeled gait with load. In high-heeled walking with a load of 5% and 10% BW, loaded limb demonstrated a lower ankle adductor moment than unloaded limb.

Shoes Effect During walking with no load, no significant change in peak hip flexor moment was found but there was an increase in peak hip extensor moment with high-heeled shoes. High-heeled shoes, regardless of heel height, significantly increased peak hip extensor moment. A larger peak knee extensor moment was found with the increase in heel height ($p = 0.033$, flat-heeled vs. 3 cm high-heeled; $p = 0.008$, flat-heeled vs. 9 cm high-heeled). Moreover, a significant difference in peak knee extensor moment was showed between 3 cm and 9 cm high-heeled shoes walking ($p = 0.036$). A larger peak knee varus moment was found with 9 cm high-heeled shoes than with 3 cm high-heeled shoes ($p = 0.001$). Peak ankle plantarflexor moment was reduced with 9 cm high-heeled shoes comparing to the flat shoes with the same load ($p = 0.000$, flat-heeled vs. 9 cm high-heeled; $p = 0.001$, 3 cm high-heeled vs. 9 cm high-heeled). Peak inversion moment increased and eversion moment decreased significantly with the increase in heel height at the condition without load carrying.

Load Effect Carrying a load of 10%BW significantly increased hip flexion moment during walking in flat shoes and 3 cm high-heeled shoes. However 10% BW load carrying significantly decreased hip flexion moment when walking in 9 cm high-heeled shoes. Load carrying didn't change hip extension moment significantly when walking in flat shoes. However when carrying a load and walking in high-heeled shoes, hip extension moment showed significant change: decreased with 3 cm high-heeled shoes and increased with 9 cm high-heeled shoes. Hip adduction moment wasn't influenced significantly by load carrying during walking in all shoes conditions. Load carrying significantly influenced hip abduction moment when walking in high-heeled shoes. Both load conditions significantly decreased hip abduction moment during walking in 3 cm high-heeled shoes. In 9 cm high-heeled shoes walking, hip abduction moment increased significantly when load of 5%BW was carried. Load carrying didn't cause significant change in knee flexion moment, but had significant impact on knee extension moment. Carrying a load of 10% BW significantly decreased knee extension moment when walking in high-heeled shoes. Knee varus and valgus moment were significantly increased by load carrying during walking in high heeled shoes compared to same load condition during walking in flat shoes. Compared to no load condition dorsiflexion moment and plantarflexion moment were significantly increased by carrying a load of 10% BW when walking in 9 cm high-heeled shoes. Carrying a load of 10% BW significantly increased inversion moment and decreased eversion moment during walking in high-heeled shoes.



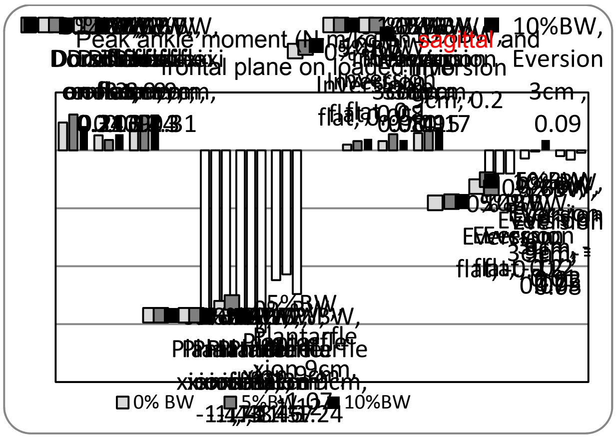


Figure 1 Peak moment of the hip, knee, and ankle joint of stance phase in sagittal and frontal plane on the loaded limb.

DISCUSSION Esenyel et al. (2003) and Hwang et al. (2006) reported that peak hip extensor moment increased during walking with high-heeled shoes. The result of this study showed similar change in hip extensor moment when walking in high-heeled shoes. The evidences suggested that high-heeled shoes and load together decrease limb acceleration during swing phase and cause hip flexor muscles to work harder. Knee, as an adjacent joint to the ankle that undergoes most prominent changes in joint kinetics, must be altered to compensate for the exaggerated plantarflexed posture and minimize the impact to transfer to proximal joints. Knee during high-heeled gait demonstrated larger extensor moment. Moreover, varus moment of knee increased when carrying a load during high-heeled shoes walking. The result of this study further confirms the findings that with high-heeled shoes, knee adduction was increased during stance contributing to medial shift in the location of the center of pressure (Esenyel et al., 2003). Ankle undergoes most significant changes in joint angle in walking with high-heeled shoes due to the raised heel height. As previously reported (Esenyel et al., 2003), an excessive increase in plantarflexion resulted in decrease in ankle moment since smaller propulsive moments were required at take-off. Although magnitudes of the joint moment varied between the different loaded conditions, a decrease in ankle moment was showed in all conditions of high-heeled shoes walking in this study. Therefore, the reduced ankle plantar flexor moments may hinder it to carry out its function as suggested by previous studies (Sutherland, Cooper, & Daniel, 1980; Winter, 1980).

CONCLUSION: The findings of this study indicated that the walking with high heel shoes and asymmetrical load carrying alters the lower extremity kinetics. These changes represented adaptive strategies that maintain limb stability as the ankle is forced into an exaggerated plantarflexed posture with the asymmetrical load carrying. Asymmetical load carriage affected the loaded limb differently from unloaded limb in lower extremity kinetics interestingly only during high-heeled walking. Hip extensor moment increased with heel height increase but not with load weight increase. Knee extensor moment was affected by both high-heeled shoes and load carriage. Ankle plantarflexor moment decreased with high-heeled shoes but increased with load weight. As a result of high-heeled shoes and load carriage, knee extensor moment exaggerated and ankle plantrarflexor moment diminished. These changes might associate to the proximal joint pain complaints of high-heeled shoes users. Furthermore, an additional load carried on one shoulder only exacerbates the alterations, therefore consideration is necessary when when high-heeled shoes and load carriage combined are utilized for prolonged period.

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