Effects of high heeled shoes on limits of stability in young women

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ABSTRACT

High heeled shoes have been associated with the increase of the risk of falls. An experimental study on examining the effects of wearing high heeled shoes on stability limits was conducted. Seven young females participated in the Limit of stability (LOS) test in the NeuroCom PRO Balance Master System. Reaction time, movement velocity, endpoint excursions, maximum excursions and directional control obtained from the LOS test were used to determine the maximum distance a person can lean in a given direction without stepping or losing balance. The experimental results showed that endpoint excursions and maximum excursions, expressed as percentages of the limits of stability, decreased significantly while participants were standing in high heeled shoes. The results suggested that standing in high heeled shoes will lessen an individual's ability to retain a postural control when their balance is destabilized outside area of control, thus decreasing dynamic balance ability.

Keywords: High heeled shoes, Balance, Limits of stability, Fall

1. Introduction

During the Middle Ages, both men and women would wear patten or wooden soles, which are clearly a precursor to high heel (Swann, 1984) in order to satisfy their desire to be more beautiful (Linder and Saltzman, 1998). A survey of 503 women by the American Podiatric Medical Association (2009) revealed that 72% of women wear high heeled shoes. However, there are negative effects of wearing high heeled shoes. Younger women are more likely to encounter blisters and pain in the arches while older women are more likely to encounter corns, calluses, and bunions. Various complaints such as pain, fatigue, and heavy-feeling legs are common results of walking with high heeled shoes (Filho, et al., 2012). Increasing heel height shifted pressure from the heel and midfoot region to the forefoot region and significantly reduced footwear comfort (Yung-Hui and Wei-Hsien, 2005). Cronin, et al. (2012) proved that the fibers in calf muscles of women that habituated to high heeled shoes had shortened since the mechanical strain they put on their calf muscles is much greater than the women who rarely wore high heeled shoes did. Muscle efficiency in walking may compromise with long-term high heeled shoes but high heeled shoes wearers are consistent with reports that they experience discomfort and muscle fatigue frequently, hence the risk of strain injuries may also increase with long-term high-heeled shoes use. Not only that, heel elevation is associated with an increased risk of falling in older people (Gabell, et al., 1985; Tencer, et al., 2004). Fall-related injuries are associated with high financial costs as well as human suffering (Melzer, et al., 2004). Even though most falls do not result in significant physical injury or death, a fall can affect the psychological aspect of a person. If a person has suffered a fall, they are more likely to attempt to reduce their physical activities and mobility, as a result of a fear of further falling (Rogers, et al., 2003; Melzer, et al., 2004). The primary risk factor for falls is reduced balance ability. Balance is a component of a person's ability to perform physical tasks of daily life. Daily activities such as bending, reaching up or to the side while doing housework, climbing stairs, and carrying groceries require shifting the center of gravity (COG) within the base of support (BOS) (Newton, 2001; Islam, et al., 2004). However, there is very limited research has been conducted to investigate the effects of high heeled shoes on dynamic balance ability. To fill this gap, our study utilizes Limits of Stability (LOS) test to determine individual's ability to retain a postural control when their balance is destabilized outside area of control. It is hypothesized that wearing high heeled shoes will decrease individual's dynamic balance ability.

2. Methods

2.1 Participants

Seven young healthy female participants with the range of 18-30 years were participated in this experiment. None of the subjects reported having any musculoskeletal disorders that restrict the range of lower extremity motion that can make the wearing of high heeled shoes painful. Prior to the start of testing, participants were given a detailed explanation of the purpose of the study as well as its procedure. The shoes were women's dress pumps, with identical style and made by the same manufacturer. The only variation was the heel height: flat at 2cm and high at 8cm. The heel height order was randomly assigned to each participant, and the Limits of Stability (LOS) test consists of 8 trials were conducted for each shoe condition. To prevent fatigue, each participant took minimum 5 minutes rest between each shoe condition.

2.2 Limits of Stability (LOS) test

LOS is a measure to determine the maximum distance a person can displace their center of gravity (COG) intentionally by leaning in the given direction without stepping, losing balance or reaching for assistance (Newton, 2001; Goulding, et al., 2003; Islam, et al., 2004). Before the participants stand on the force platform, they wore a safety belt with harness straps that was tight enough to prevent them fall, but loose enough so that their movement was not restricted. During the assessment, participants were asked to stand with their feet centered on the force platform, facing forward to the monitor, as steady as possible with both arms beside their body. In LOS test, the monitor displays a central box with eight targets surrounding the central box in a clockwise manner (Fig. 1). These targets represent the individual's estimated stability limits, based on their statures. In terms of LOS test, each of the targets is considered to be 100% of the theoretical limits of stability, which is the maximum distance an individual can move his/her COG intentionally. Beyond the 100% of theoretical limits of stability, an individual will likely require additional strategies, such as step strategy, to maintain stability (Cordo & Nashner, 1982). The eight targets are displayed on the monitor at 0, 45, 90, 135, 180, 225, 270, and 315 degrees. For each of the trials, the participant was asked to maintain COG centered over the BOS. The participant's COG appears as a human-shaped cursor on the monitor. This cursor moves freely with the participant as they shift their weight. Upon hearing auditory signal from the computer, the participant moves the COG cursor as fast and accurate as possible toward the highlighted target (one of eight targets located on the LOS perimeter) and holds the position 10 s.

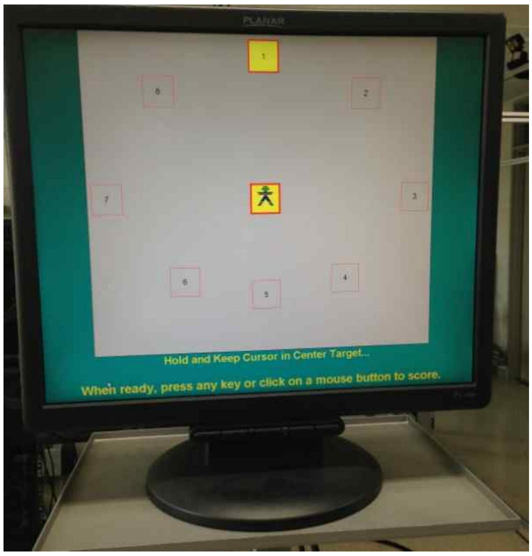

Figure 1. CoG of an individual and 8 tested targets

The measured parameters on the LOS test are reaction time, COG movement velocity, end point excursion, maximum excursion and directional control. Reaction time represents the amount of time from the auditory signal until movement is initiated. Movement velocity represents the speed of movement , while directional control represents a comparison of the amount of movement in the intended direction toward the target and extraneous movement away from the target. Path accuracy shows in straighter path movements and lower time values indicate better performance and control of balance (Rogers, et al., 2003). End point excursion (EXE) represents the distance the COP is displaced toward the target during the primary movement of the participant. EXE is expressed as percentage of the distance to the target. If a participant whose initial movement ends precisely at the target, their EXE will be exactly 100%. Maximum excursion (MXE) represents the maximum distance the COP is displaced toward the target over the entire duration of the trial. Most people initiate additional movement when their initial movements are short of the target. Since the participants initiate additional movement after the EPE is recorded, the MXE, also expressed as a percentage, is usually larger than EPE.

2.3 Statistical analysis

Data analysis was conducted using the statistical software program Minitab 16 for Windows 7 (Minitab Inc., State College, PA, USA). The differences between results of the shoe conditions were performed using a paired t-test. A P value of less than 0.05 was considered statistically significant.

3. Results

Data analysis indicated that the composite score for end point excursion (EPE, P=0.015) and maximum excursion (MXE, P=0.010) were significantly greater for flat than for high heels. Reaction time and movement velocity was not significantly different between two shoe conditions. Directional control was greater for flat heel than high heel, but statistical significance was not achieved for two shoe conditions (Table 1).

Further analysis (Table 2) on which direction in terms of EPE is significantly different between flat and high heels demonstrated that both back (P=0.005) and left (P=0.030) directions showed statistically significant differences for two shoe conditions. The percentages of EPE for back and left directions were greater for flat heel than high heel. Similar pattern was applicable to maximum excursion (MXE), even though only back direction showed statistically significant differences for two shoe conditions (P=0.031) (Table 3).

Table 1 Paired t-test results on LOS parameters

	Mean ± SD	P
Reaction time (s)		0.299
Flat	0.69 ± 0.17	
High	0.75 ± 0.20	
Movement velocity (deg/sec)		0.748
Flat	5.54 ± 1.47	
High	5.39 ± 1.18	
Endpoint excursions (%)		0.015*
Flat	84.14 ± 6.20	
High	74.71 ± 7.61	
Max excursions (%)		0.010*
Flat	94.29 ± 6.55	
High	84.14 ± 4.38	
Directional control (%)		0.150
Flat	74.57 ± 5.68	
High	70.14 ± 10.16	

Table 2 Paired t-test results on end point excursion

	Mean ± SD	P
End point excursion		
Forward		**0.421**
Flat	74.14 ± 12.21	
High	67.86 ± 9.06	
Back		**0.005***
Flat	53.00 ± 7.48	
High	41.00 ± 10.18	
Right		**0.609**
Flat	99.14 ± 12.60	
High	94.71 ± 15.41	
Left		**0.030***
Flat	110.29 ± 12.13	
High	94.71 ± 19.31	

Table 3 Paired t-test results on maximum excursion

	Mean ± SD	P
Maximum excursion		
Forward		**0.250**
Flat	85.14 ± 9.65	
High	76.57 ± 9.62	
Back		**0.031***
Flat	67.71 ± 15.32	
High	47.43 ± 10.94	
Right		**0.243**
Flat	111.71 ± 5.09	
High	105.29 ± 9.93	
Left		**0.165**
Flat	115.43 ± 9.76	
High	107.29 ± 14.43	

4. Discussion

The results supported our hypothesis that wearing high heeled shoes will decrease individual's dynamic balance ability. In this study, all shoes were bought from the same manufacturer, made by the same material and had the same type and style, except the heel height so there were no differences in shoe wear that may affect subjects' comfort and thus affect their assessment. Participants in this study were healthy women aged 18-30 years, which were assumed to have sufficient muscle strengths to support them to do physical tasks in their daily activities.

Significant differences were found in end point excursion (EPE) and maximum excursion (MXE). Wearing high heeled shoes resulted in a reduction in EPE and MXE percentages. EPE is the distance of the first movement toward each of the designated targets, expressed as a percentage of maximum LOS distance, while MXE is the maximum distance achieved during the trial. A reduction on EPE may indicate worsen postural control. Excursions may also be restricted by biomechanical limitations. For example, dizzy, unsteady, and people who are fearful of falling may restrict their excursions artificially. People with lower extremity weakness may not have the strength to attain and/or maintain stable target positions (Rogers, et al., 2003; NeuroCom, 2012). Women wearing high heeled shoes walk with an upward displacement of center of body mass and thus they have a more unstable posture and higher rank of discomfort (Lee, et al., 2001; Yung-Hui and Wei-Hsien, 2005). This unstable posture and higher discomfort while wearing high heeled shoes might results in participants' fearful feeling of falling thus reduced their excursions. Significant difference was also found in back and left directions of EPE. This result partially supports other studies which stated that the directions that are most associated with falls that result in hip fracture are right, left, and back directions (Greenspan, et al., 1988; Rogers, et al., 2003). It indicates that wearing high heeled shoes may either result in restricted movement or a fear in falling in back and left directions.

No significant differences were observed in other three parameters including reaction time, movement velocity and directional control. Reaction time, which represents the amount of time from the auditory signal until the first movement initiated is commonly associated with difficulties in cognitive processing and/or motor diseases (Rogers, et al., 2003; NeuroCom, 2012). This result should be reasonable as wearing high heeled shoes is clearly not related with individual's cognitive skills. Regarding movement velocity, which represents the movement quality and is commonly associated with high-level central nervous system, no significant differences were found for two shoe conditions even though a reduced pattern in movement velocity when participants wore high heeled shoes can be observed. This result was somewhat out of our expectations since previous studies reported that a lower average speed may indicate high-level system deficits such as Parkinson's disease and age-related disorders (Rogers, et al., 2003; NeuroCom, 2012) and women are also reported to walk slower in high-heel dress shoes than in walking shoes during the 10 m walk test (Arnadottir and Mercer, 2000). This inconsistency may be caused by the small sample size (N=7) in our study and the exact reason is worthy of further investigation. Directional control, which represents a comparison of the amount of movement towards the target to the amount of movement away from the target is commonly associated with motor control abnormalities. Straighter path movements are indicator of better performance and control of balance (Rogers, et al., 2003; NeuroCom, 2012). The non-significant difference on directional control between two shoe conditions should be understandable since the participants in our study are healthy and have no motor control abnormalities.

5. Conclusion

The present study showed that wearing high heeled shoes will decrease individual's dynamic balance ability. Reductions were observed for EPE and MXE, especially in back and left directions. Delayed reaction time, slower speed and indirect path were also observed when participants wore high heeled shoes, but not statistically significant. All of these effects reduce women ability to anticipate changes and coordinate muscle activity in response to perturbations of stability. These effects restrict their movements when doing daily activities that need leaning in a specific direction and may cause them to lose their balance, resulting in fall.

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