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Investigation of Bodyweight Distribution on Metatarsophalangeal Joint of Human Foot for Ladies High Heel Footwear

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Abstract

This study aimed to investigate the bodyweight distribution on metatarsophalangeal (MTP) joint of human foot for ladies high heel footwear. Distribution of percentage of bodyweight from rear foot to MTP joint of forefoot observed with varying heel heights. Young healthy women participated in the test and force on MTP joint & leg muscle activities have been recorded with data recording systems. The results of this experiment showed that the increased heel height shifted the force and peak pressure from the rear foot to the MTP joint of the forefoot region. Around 21.37%, 31.45%, 32.67%, 34.05%, and 36.59% of bodyweight is imposed on MTP joint for the heel height of 0cm, 2.54cm, 5.08cm, 6.35cm, and 8.89cm respectively. Semi-high heel results significant imposition of bodyweight on MTP joint only whereas high heel creates more unstable footsteps and imposes less significant additional compressive forces on MTP joint that may increase discomfort, muscle fatigue & pain.

Keywords: high heel, metatarsophalangeal joint, electromyography, bodyweight distribution.

1. Introduction

Footwear is considered one of the basic requirements of a complete costume. There are various types' footwear worn by people but high heels and stilettos are very popular and fashionable among women especially in today's modern society. Since the ancient period high heel shoes have been one of the cornerstones of a woman's wardrobe, most women like wearing high-heeled shoes for the benefit of sensuous attractiveness and self-esteem. Footwear purchase is dictated by fashion and not a sense of comfort; for many people fashion surpasses the need of comfort [1]-[2]. In today's society, fashionable footwear designs are now becoming increasingly complex and incorporating high heels [3]. High heeled shoes not only does it made female look taller but also attractive and prettier when match with favorite dress or gown, hence always become a popular choice among women. Although this fashion is intended to be uncomfortable, few women plan to give up their high heels [4]. According to surveys on footwear, between 39% and 69% of women wear high heels on a daily basis, representing a huge proportion of the female population [5]-[6]. High-heeled shoes (HHSs) are defined as shoes in which the heel is higher than the forepart of the shoe. HHSs often also include a narrow toe box, rigid heel cap and curved plantar region, all of which interfere with natural foot motion [7]. High heeled shoes have come under much speculation as one of the causative factors for forefoot pain and discomfort. A prevalence proportion of foot problems in women were associated with wearing high heeled shoes [8]. A study in Netherlands found that 60% of women suffered foot problems directly caused by shoes. Studies on high heel shoes effect have become a hot issue in biomechanical field [9]. Biomechanical studies showed that walking in high heeled shoes may alter lower-extremity joint function, raise the peak pressure in the fore foot and alter the body weight load distribution on the media foot region [10]-[11]. According to several studies, walking with high heels leads to changes in load distribution beneath the feet, increase of the foot bone internal stress [12]-[13], decrease of the contact area and transfer of the center of pressure from midfoot to forefoot [13]-[14]. Another distinct difference reported is that peak pressure with positive correlation to the heel height shifting from the lateral forefoot to medial forefoot: from the area of 3rd, 4th, and 5th metatarsal head to 1st and 2nd metatarsal head [14]-[16]. These previous findings could be correlated to high heel wearing induced foot pain and uncomfortableness. However, most previous researches focused on the effect of the body weight/pressure on the different regions of the foot but only limited research has been performed regarding the analysis of bodyweight distribution specifically on metatarsophalangeal (MTP) joint of the human foot. Therefore, the aim of the study is to experimentally characterize the body weight distribution on MTP joint of the human foot especially on ladies footwear varying heel heights.

2. Methodology

The methodology of this work can be explained clearly by the following sub-sections:

Subject's specification

In this study, a young healthy female subject free from any physiological disease was enrolled. Subject wasn't smoker and refrained from alcohol and caffeine containing drinks before the study. Food intake was totally restricted to a light meal prior to the test. After being informed about the summary of the study design, the subject gave her written consent. The subject had an initial visit to the experimental laboratory, for a physical examination and a medical history assessment. The age, weight, height, and body mass index (BMI) are listed in Table 1.

Sample development

Correct designs of ladies high heel footwears with various heel height such as 0cm, 2.54cm, 5.08cm, 6.35cm, and 8.89cm were developed and constructed. The design of ladies footwears were developed in such way so that it could compatible with the subject foot and body anatomy. The footwears provided normal walking facilities to the subject. The uppers of the high heel footwear were constructed in such way so that it couldn't bring any bad impact to the subject during the experiment. After identifying the position of MTP joint on the footwear, a channel was made on that position with exact depth and width compared to the dynamometer by which measurment of force or load on footwear was done as shown in Fig. 1(a). Five pairs of footwear with different heel height were constructed in such a way so that it could make exact fitting to the subject's feet. It should be mentioned that footwear was validated with the subject's and experimental setup requirements by minor necessary correction in footwear constructions. The designed and constructed ladies footwears were quite similar to the conventional ladies footwears.

Experimental setup

The study was performed in a quiet room with the temperature kept constant. After putting footwear, at least five minutes were allowed for acclimatization before the measurements were performed on MTP joint and skeletal muscles of leg. Dynamometer was placed just below MTP joint for force measurement as shown in Fig. 1(c). Dynamometer was interconnected to data acquisition unit and computer. For electromyogram (EMG) recording, electrodes were placed on skeletal muscles of leg as shown in Fig. 1(b). EMG recording was performed simultaneously with force measurement on MTP joint to investigate the affects of heel height increment on muscular activity of leg. Using necessary software force and EMG were recorded in computer.

Experimental procedures

Using proper experimental setup and calibration, data recording was done with normal walking of the subject. At first, subject was allowed to make few steps of walking by putting footwear to analyze that the foot was correctly adjusted or not. If foot and footwear is correctly adjusted then subject was allowed to walk freely for few steps and then data was recorded for the load imposed on MTP joint. Besides, EMG signal recording in leg muscle was simultaneously done. Data recording was done with varying heel heights of ladies high heel footwear. The subject was allowed to be rested several times so that the subject can walk smoothly without being tired for next heel height episodes. Results were noted down separately for each heel height to investigate the bodyweight imposed on MTP joint.

Table 1. Subject's specification

Parameters	Value
Age (yr)	21
Weight (kg)	60
Height (cm)	167.64
BMI (kg/m^2)	21.35

3. Data collection and analysis

In this study, force on MTP joint and EMG signal were recorded with few natural footsteps with varying heel heights of ladies high heel footwear. Typical recordings for flat footwear (heel height: 0cm) and semi-high heel footwear (heel height: 5.08cm) are shown in Fig. 2 and Fig. 3 respectively. In Fig. 2, it is observed that the forces on MTP joint for each footstep are nearly constant and the mean force of these footsteps is around 12.82 kg on MTP joint. EMG recording is shown in Fig. 2 also that shows the activity of skeletal muscles in leg for flat footwear. EMG shows irregular muscle contraction and constant muscular contraction is not found due to the poor electrode-skin contact. Poor electrode-skin contact might be resulted for strong muscle tension or electrode slippage.

(a) (b) (c)

Fig. 1. Experimental setup for (a) sample development (b) EMG recording and (c) force recording

In Fig. 3, it is observed that the forces on MTP joint for each footstep are nearly constant and the mean force of these footsteps is around 19.60 kg on MTP joint. EMG recording is shown also in Fig. 3 that shows the irregular contraction of leg muscles for 5.08cm heel height. Analysis of irregular muscle contraction according to EMG is very difficult. The above analysis results increased force on MTP joint with the increase of heel height.

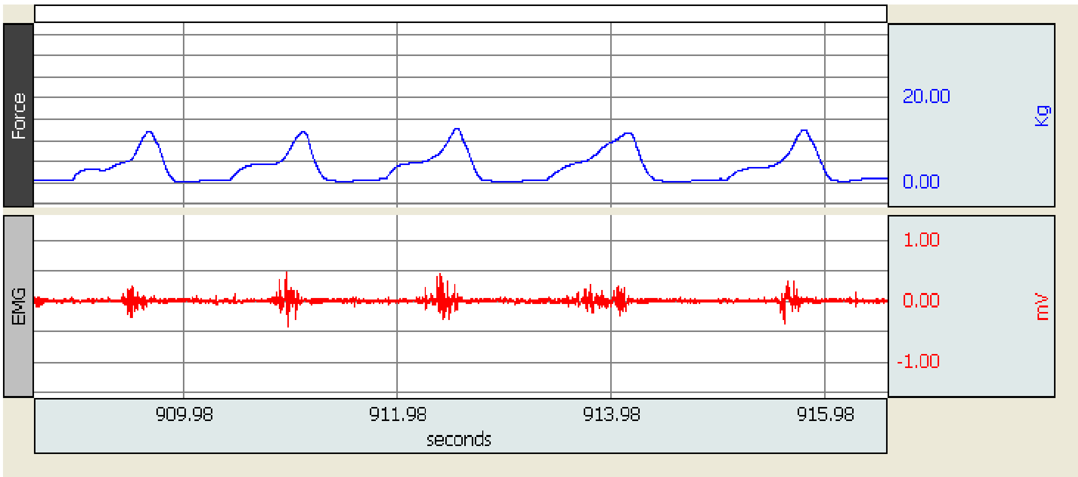

Fig. 2. Force and EMG recording for flat footwear (heel height: 0 cm)

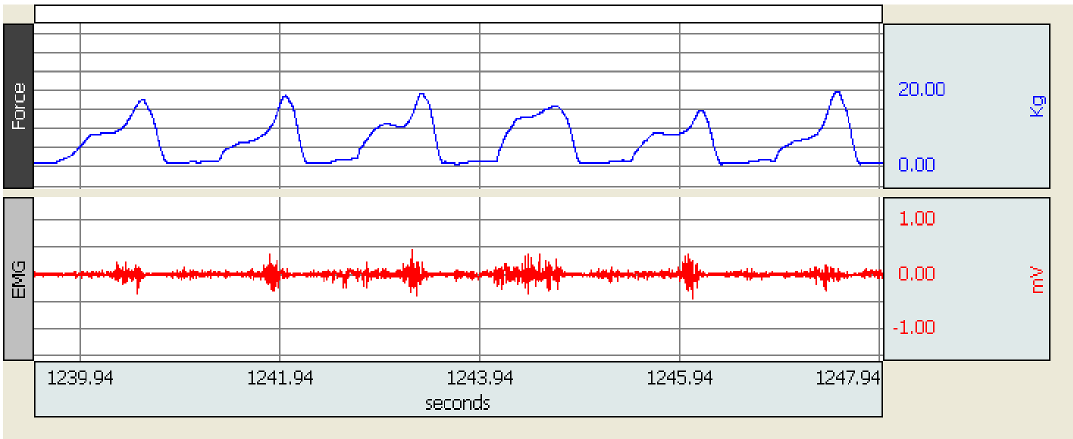

Fig. 3. Force and EMG recording for high heel footwear (heel height: 5.08 cm)

4. Results and discussion

Body weight imposed on MTP joint is investigated by varying heel heights of ladies footwear. Different heel heights and their corresponding forces on MTP joint are listed in Table 2. As the heel height increases the pressure beneath the forefoot surface increases. This phenomenon occurs due to the hips and spine of the body is out of alignment as a result the high heels push the body weight to the forward direction of the foot. As the height of the heel increases the bodyweight concentrates more on MTP joint and the bases of proximal phalanges of foot. From Table 2, it is seen that around 12.82 kg bodyweight is imposed on MTP joint for flat footwear (heel height: 0cm). For 2.54cm heel height the imposed bodyweight on MTP joint is 18.87 kg. As the heel height is increased more, the more bodyweight is imposed on MTP joint. 19.60 kg, 20.43 kg, and 21.95 kg bodyweight is imposed on MTP joint for 5.08cm, 6.35cm, and 8.89cm heel height respectively. Around 6.05 kg bodyweight is imposed more on MTP joint due to the transition from flat footwear (heel height: 0cm) to semi-high heel footwear (heel height: 2.54cm). The largest portion of bodyweight is more imposed for above transition and other transitions (heel height: 2.54cm to 5.08cm, 5.08cm to 6.35cm, and 6.35cm to 8.89cm) result significantly less increment in bodyweight imposition on MTP joint.

Table 2. Body weight imposed on MTP joint with varying heel height

Subject's weight (kg)	Heel height (cm)	Average body weight imposed on MTP joint (kg)*
	0	12.82±0.584
	2.54	18.87±0.610
60	5.08	19.60±0.432
	6.35	20.43±0.545
	8.89	21.95±0.795

*Values are Mean±Standard Deviation

The percentage of bodyweight imposed on MTP joint with varying heel height is shown in Fig. 4. It is found that about 21.37%, 31.45%, 32.67%, 34.05%, and 36.59% of bodyweight is imposed on MTP joint for the heel height of 0cm, 2.54cm, 5.08cm, 6.35cm, and 8.89cm respectively. Around 10.08% of bodyweight is imposed more on MTP joint due to the transition from flat footwear (heel height: 0cm) to semi-high heel footwear (heel height: 2.54cm). The largest percentage of bodyweight is more imposed for above transition and other transitions (heel height: 2.54cm to 5.08cm, 5.08cm to 6.35cm, and 6.35cm to 8.89cm) result significantly less increment about 1.22%, 1.38%, and 2.54% respectively. Analysis shows that 2.54cm heel height results significant imposition of bodyweight on MTP joint but later increment of heel height fails to do so. As the heel height increases more from 2.54cm, the stress on the phalanges of the foot increase that hinders proper functioning and results uncomfortable situations. Long term high heel footwear wearing may create structural damage in foot that would feel severely in old ages.

The limitation of the study is that only one subject is used for this experiment to collect data due to unavailability of the subject. Further research should be conducted to determine the effects of ladies high heel on human foot for different age groups.

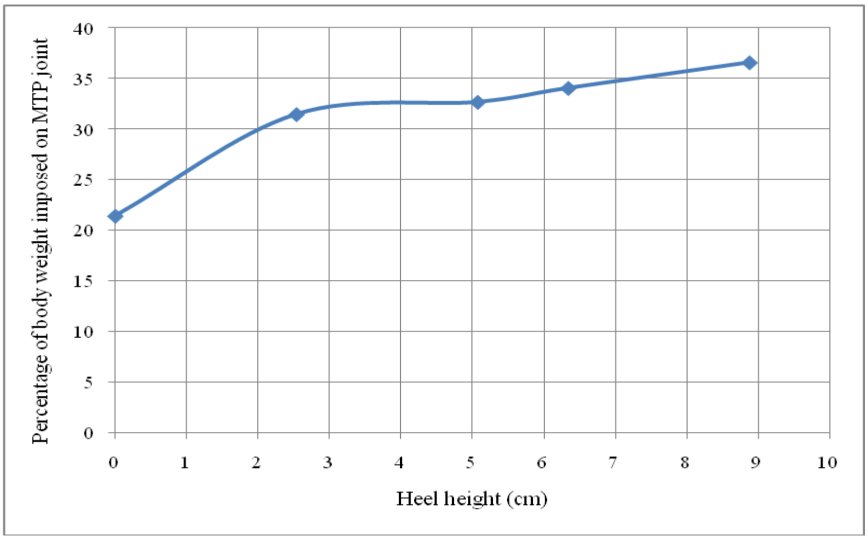

Fig. 4. Percentage of body weight on MTP joint with varying heel heigh

5. Conclusion

The effects of ladies high heel footwear on MTP joint are investigated in this study by bodyweight distribution. The percentage bodyweight imposed on MTP joint increases with the increase of heel height. Semi-high heel results significant percent of bodyweight imposition on MTP joint but high heel can't. High heels not only create a more unstable posture but also impose additional compressive forces on MTP joint that significantly increase discomfort, fatigue level, and foot pain by long term wearing.

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