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ORIGINAL

Effect of Modified High-heels on Metatarsal Stress in Female Workers

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Objective: The purpose of this study was to identify the effect of high-heels (HH) modification on metatarsal stress in female workers.

Method: Seven females who work in clothing stores (heights = 160.4±3.9 cm; weights = 47.4±4.1 kg; age = 31.3±11.1 yrs; HH wear career = 8±6.5 yrs) wore two types of HH (original and modified). The modified HH had been grooved with 1.5 cm radius and 0.2 cm depth around the first metatarsal area inside of the shoes using the modified shoe-last. Participants were asked to walk for 15 minutes on a treadmill and to stand for 10 minutes with original and modified HH, respectively. Kinetics data were collected by the F-scan in-shoe system. After each test, participants were asked to rate their perceived exertion using the Borg's 15-grade RPE scale and interviewed about their feeling of HH. Nonparametric Wilcoxon signed-rank test and effect size (Cohen's d) were used to determine the difference of the variables of interest between the original and modified HH.

Results: In the present study, modified HH of the peak contact pressure of 1st metatarsal (PCP) left, PCP right, pressure time integral (PTI) left, peak pressure gradient (PPG) left during standing and PPG right during walking are greater than original HH. And even it didn't show statistically significant, the average in all pressure values of modified HH showed bigger than original HH. It surmised to be related to awkward with modified HH. Even though they said to feel the comfortable cause of big space inside of HH in the interview, they seemed to be not enough time to adapt with new HH. So their walking and standing postures were unstable.

Conclusion: Modified the fore-medial part of HH can reduce the stress in the first metatarsal head and big toe area during standing and walking.

Keywords: Modified high-heels, Kinetics, Metatarsal stress

INTRODUCTION

Women are usually wearing high-heels (HH) for pretty posture demonstration. Nevertheless, they cannot tolerate prolonged standing and walking with shoes because of following reasons; HH interrupts the natural foot motion because of a narrow toe box, a rigid heel cap, and a curved plantar region (Cronin, 2014). Human's bipedalism posture is inherently unstable because two-thirds of people's body mass is located two-thirds of body height from the ground, and a gait makes the posture more unstable (Winter, 1995). Walking with HH makes the center of body mass forwards and upwards. It contributes to compensatory changes of the body such as the increased knee flexion and increased lower limb muscle activity, and is likely also to contribute to the higher energy cost (Cronin, 2014).

Previous researchers have indicated that the knee is more flexed not only during the stance phase but also at the initial contact of a gait in HH, and the knee flexion appears to be increased with the incremental heel height (Blanchette, Brault & Powers, 2011; Cronin, Barrett & Carty, 2012; Ebbeling, Hamill

& Crussemeyer, 1994; Ho, Blanchette & Powers, 2012; Mika, Oleksy, Mika, Marchewka & Clark, 2012; Simonsen et al., 2012). Moreover, the weight of the body was shifted further medially relative to the foot and imposes increased knee varus moment during HH walking (Barkema, Derrick & Martin, 2012; Esenyel, Walsh, Walden & Gitter, 2003; Simonsen et al., 2012). The increased varus moments may cause the compensation on the lateral muscle forces around the knee, further increase the tibiofemoral compressive forces and have long-term functional relevance to injuries of the lower extremity (Cronin, 2014).

The increased heel height leads to the earlier onset of the erector spinae activity (Barton, Coyle & Tinley, 2009; Bird, Bendrups, & Payne, 2003). This may cause to balance maintenance by counteracting the anterior lumbar displacement, along with the increase in lumbar-abdominal co-activation (Barton et al., 2009; Lee, Jeong & Freivalds, 2001). As well as increasing the energy requirements of the muscles, sustained, large-amplitude activation of lumbar muscles may increase spinal compression, ultimately contributing to muscle fatigue and low back pain (Bendix, Sørensen & Klausen, 1984; Lee et al., 2001; Mika, Oleksy, Mikołajczyk, Marchewka & Mika, 2011). In fact, lumbar muscle contraction at intensities as low as 2% of maximal strength can reduce tissue oxygenation, and prolonged isometric contraction at this intensity has been linked to lumbar repetitive strain injury (McGill, Hughson & Parks, 2000). Therefore, even low levels of lumbar muscle activity maintained over long, uninterrupted periods may result in negative tissue adaptations (Cronin, 2014).

Habitual HH use has been linked with not only foot pain but also foot deformities such as partly reduced foot length and increased arch height (Gefen, Megido-Ravid, Itzchak & Arcan, 2002; Ricci and Karpovich, 1964). The pain was commonly reported in the toes, ball of the foot, heel, and arch (American Podiatric Medical Association, 2003). Furthermore, HH are associated with sprained ankles, probably due to decreased lateral ankle stability (Ebbeling et al., 1994; Nieto and Nahigian, 1975).

The increase in plantar flexion caused by HH leads to smaller peak plantar flexor moments and ankle range of motion during walking (Cronin et al., 2012; Esenyel et al., 2003; Simonsen et al., 2012). HH increased coactivation around the ankle joint such as muscle activity of the soleus, tibialis anterior, medial gastrocnemius and peroneus longus muscles (Cronin et al., 2012; Joseph, 1968; Simonsen et al., 2012; Stefanyshyn, Nigg, Fisher, O'Flynn & Liu, 2000). And it may cause joint stiffness, and presumably somewhat compensates for the decreased stability caused by HH (Ebbeling et al., 1994; Joseph, 1968). To use of HH long time leads to a shortening of the gastrocnemius muscle fascicles and an increase in Achilles tendon size and stiffness, contributing to a reduction in ankle range of motion. Achilles tendon hypertrophy in habitual HH wearers may be an adaptation to the larger triceps surae muscle forces when walking in HH (Csapo, Maganaris, Seynnes, & Narici, 2010).

When we walk on the sand, we could find that the first metatarsal head has shown the deepest part of the footprint. It might be explained it had more depression than the other metatarsal parts (Figure 1). The modified last allows larger space for the first metatarsal head, ie. there would a pit for the first metatarsal head in the modified HH.

Figure 1. The first metatarsal head sink deeply observed on sand and soft surface.

In general gait, foot pressure distribution pattern follows the heel, lateral side of the foot, and the big toe in sequence. The main influence of shoes is modifying the behavior of the forefoot by changing the pressure distribution across the metatarsal heads and increasing the contact times for the toes (Soames, 1985). The major concern of hallux valgus is family history, however, people without family history and often wore HH to develop hallux valgus (Wu & Louie, 2010). The main cause of hallux valgus is such as shoes that do not fit properly, shoes that are too narrow or too tight, or shoes that are too small. It might be assumed that providing more space for the first metatarsal part in the shoes may prevent foot's forward slide and curtail first metatarsal stress. As mentioned before, women won't give up to wear HH for their beauty even it has many uncomfortable. So the present study has curious that is it possible to make fashion and comfort in the same shoe? Is it still room for the manufacturers and designers of shoes to improve the details of the design? Could shoe-last modification of ball-of-foot region satisfy the needs?

Our hypotheses were metatarsal head part grooved inside of HH occurs stuck the foot. And it will prevent foot sliding forward. Then it could be avoid deformed such as hallux valgus. Thus, the purpose of this study was to identify the effect of HH modification on metatarsal stress in female workers.

Figure 2. Side view (left) and bottom view (right) of HH

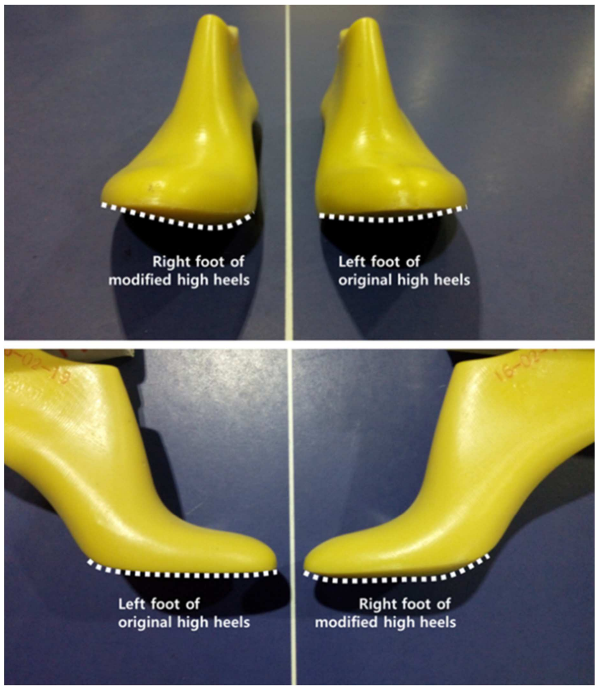

Figure 3. Front view (top) and side view (bottom) of shoe-last

METHODS

1. Participants

Participants were sorted who were customers of the footdisc medium arch support insoles which is normal arch heights (Footdisc Proactive Med Arch, Footdisc Inc., Taipei, Taiwan). The arch index was calculated by the narrowest foot width divided by the widest foot width from the footprint (Forriol & Pascual, 1990) using a footprint device (Footdisc Inc., Taipei, Taiwan) at the store before purchase insoles. Seven females who work in clothing stores voluntarily participated in the study (heights = 160.4±3.9 cm; weights = 47.4±4.1 kg; age = 31.3±11.1 yrs; HH wear caree = 8±6.5 yrs). All participants' informed consent was received and the 'rights of the participants' was protected for participation in this study. The study protocol was approved by the ethics committees of a university for the use of human subjects in research. They were wearing HH every day at least the past two years. Participants were excluded if they had previous trauma or surgery, and current injuries to the body.

2. Procedure

Two types of HH (original and modified) were used in the study. Both HH were characterized by 2 cm height forefoot outsole and 9 cm height heel with 1.5 cm^2 contact area of the heel (Figure 2). The modified HH had been grooved with 1.5 cm radius and 0.2 cm depth around the first metatarsal area inside of the HH using the modified shoe-last (Figure 3).

Walking and standing were chosen for the present research design which are general movements with HH in participants working place. Participants were asked walking for 15 minutes on a treadmill with their comfortable speed and standing for 10 minutes with original and modified HH, respectively (Figure 4). HH were chosen randomly for the tests (walking and standing). There were 15 minutes seated rest between the tests. Before and after each treadmill test, there were 30 seconds walking on a treadmill for collecting the foot pressure data.

After each test, subjects were asked to rate their perceived exertion using the Borg's 15-grade RPE scale and interviewed about their feeling of HH.

3. Data analysis

1) Kinetic data analysis

An F-scan in-shoe system (Tekscan Inc., Boston, MA) was used

Figure 4. Experimental procedure - walking (left) and standing (right)

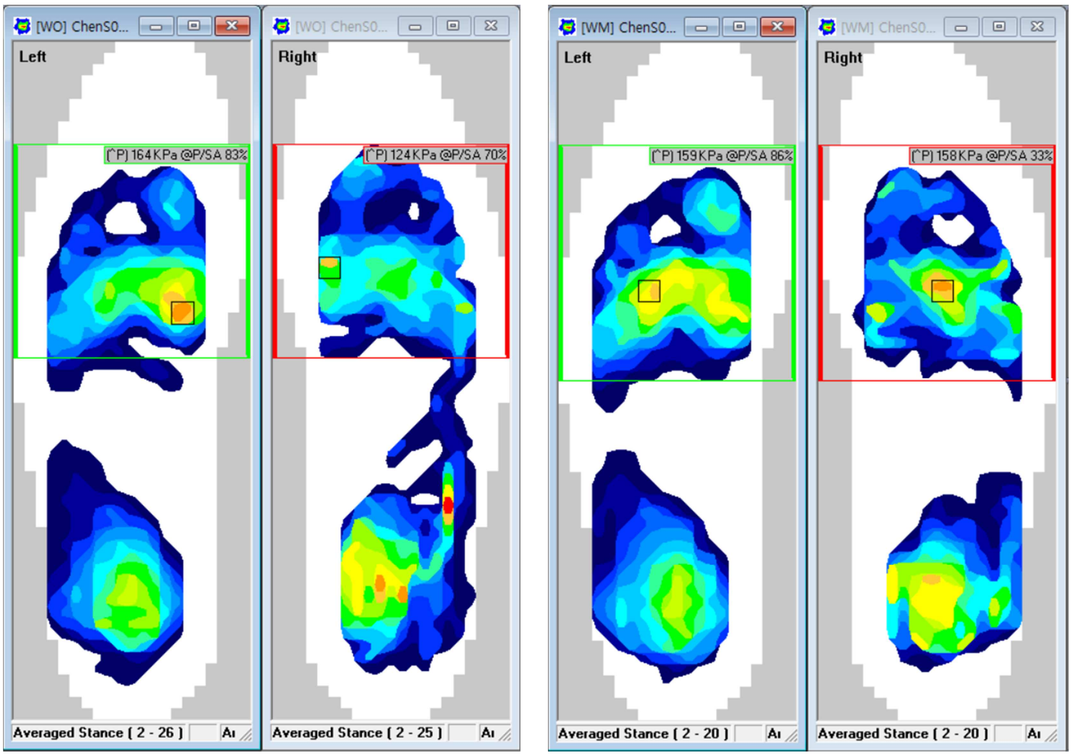

Figure 5. Foot pressure of original HH (left) and modified HH (right)

to collect the foot pressure data. The distance from the point of peak contact pressure to the medial edge of 1st metatarsal (PCPd) (Figure 5), peak contact pressure of 1st metatarsal (PCP), pressure time integral (PTI), peak pressure gradient (PPG), and force time impulse (FTI), pressure time integral (PTI), contact pressure (CP), contact area of forefoot (CA) were calculated using the F-scan software (F-Scan Research 7.0, Tekscan, Boston, USA). The PTI was a measure representing the amount of pressure relative to the time that the pressure is present (KPa*sec). The PPG was a measure representing the spatial change in pressure around the location of the peak pressure (KPa/centimeters).

2) Statistical analysis

The statistical analyses were performed using SPSS 18.0 for Windows (SPSS, Inc., Chicago, IL, USA). Nonparametric Wilcoxon

Table 1. Foot pressure data (Mean ± SD)

			Original	Modified
Standing	Left foot	PCPd	2.14±1.1^{L}	3.76±0.3^{L}
		PCP	125.60±44.4^{*,S}	139.43±42.7^{*,S}
		PTI	134.32±35.7^{*,M}	171.94±71.2^{*,M}
		PPG	100.40±46.5^{*,M}	142.43±70.6^{*,M}
		FF_CA	39.54±5.0	40.39±4.2
		FF_CP	40.00±12.3	41.14±8.4
		FF_FTI	388.82±219.6^{*,L}	1059.87±1015.8^{*,L}
		FF_PTI	86.08±45.4^{*,L}	139.24±80.5^{*,L}
	Right foot	PCPd	2.94±1.3^{M}	3.56±0.1^{M}
		PCP	95.40±19.1^{*,L}	135.14±25.0^{*,L}
		PTI	129.00±47.3	129.83±60.4
		PPG	146.40±49.4^{S}	183.71±125.4^{S}
		FF_CA	37.38±5.7^{L}	41.81±4.0^{L}
		FF_CP	33.60±5.4^{S}	35.43±2.9^{S}
		FF_FTI	393.48±309.1	427.42±273.7
		FF_PTI	90.61±65.7^{S}	69.94±70.8^{S}
Walking	Left foot	PCPd	1.73±0.9^{L}	3.04±1.2^{L}
		PCP	236.43±81.5	246.29±114.0
		PTI	95.40±50.3	103.24±44.3
		PPG	360.14±170.8^{M}	477.43±229.4^{M}
		FF_CA	49.73±7.8^{S}	46.97±3.6^{S}
		FF_CP	66.86±17.5^{*,S}	74.71±23.5^{*,S}
		FF_FTI	912.34±1844.5	1001.38±2036.8
		FF_PTI	42.89±9.8^{*,S}	47.05±11.3^{*,S}
	Right foot	PCPd	1.81±1.4^{*,L}	3.53±0.0^{*,L}
		PCP	215.00±73.7^{S}	240.86±67.9^{S}
		PTI	91.33±17.0^{S}	96.66±33.6^{S}
		PPG	576.00±276.7^{*,M}	418.00±324.9^{*,M}
		FF_CA	48.77±3.7	48.70±3.0
		FF_CP	65.86±14.6	67.71±15.1
		FF_FTI	1096.16±2385.5	1171.45±2632.9
		FF_PTI	40.56±8.3	41.83±7.2

PCPd = peak contact pressure distance from medial part of 1st metatarsal, PCP = peak contact pressure, PTI = pressure time integral, PPG = peak pressure gradient, FF_CA = forefoot contact area, FF_CP = forefoot contact pressure, FF_FTI = forefoot force time impulse, FF_PTI = forefoot pressure time integral; *Significant between original and modified HH ($p<.05$). L = large effect size (≥0.8), M = medium effect size (≥0.5), S = small effect size (≥0.2) between original and modified HH signed rank test and effect size (Cohen's d) were used to determine the difference of the variables of interest between the original and modified HH. *p* value was set at 0.05. The effect size was classified as *small* (d = 0.2), *medium* (d = 0.5), and *large* (d ≥ 0.8).

RESULTS

The PCP left, PCP right, PTI left, PPG left during standing and PCPd right, PPG right during walking had significant differences by Wilcoxon signed-rank test (Table 1). It means modified HH of PCP left, PCP right, PTI left, PPG left during standing and PCPd right, PPG right during walking are greater than original HH.

In case of effect size, large effect size showed on PCPd left, PCP right during standing and PCPd left, PCPd right during walking. Medium effect size showed on RF, PCPd right, PTI left, PPG left during standing and PPG left, PPG right during walking (Table 1).

The result of RPE, original and modified HH showed 11.4±2.4, 10.9±1.8 for walking and 11.6±2.5 and 11.6±1.8 for standing, respectively. And there was small effect size for walking in RPE. It looks like similar but all subjects mentioned on the interview that they felt comfortable with modified HH because shoe inside had more space (Table 2).

Table 2. RPE (Mean ± SD)

	Original	Modified
Standing	11.6±2.5	11.6±1.8
Walking	11.4±2.4^{S}	10.9±1.8^{S}

L = large effect size (≥0.8), M = medium effect size (≥0.5), S = small effect size (≥0.2) between original and modified HH

DISCUSSION

The present study found that PCP left, PCP right, PTI left, PPG left during standing and PCPd right, PPG right during walking had significant differences by Wilcoxon signed-rank test. It means modified HH of PCP left, PCP right, PTI left, PPG left during standing and PCPd right, PPG right during walking are greater than original HH. In case of effect size, Large effect size showed on PCPd left, PCP right during standing and PCPd left, PCPd right during walking. Medium effect size showed on RF, PCPd right, PTI left, PPG left during standing and PPG left, PPG right during walking. The result of RPE, original and modified HH showed 11.4±2.4, 10.9±1.8 for walking and 11.6±2.5 and 11.6±1.8 for standing, respectively. It looks like similar but all subjects mentioned on interview that they felt comfortable with modified HH because shoe inside had more space.

Kim et al. (2004) compared plantar pressure between sneakers and 4 cm HH in 20 female during walking. In their results, the center of force trajectory of HH showed more supination compared with sneakers. They mentioned that it occur negative effect on ankle's stability because it doesn't have enough pronation movement (Kim et al., 2004). Furthermore, HH had more peak pressure and longer landing phase than sneakers. They were deemed unstable gait pattern will lead those results (Kim et al., 2004).

In present study, modified HH showed greater PCPd right than original HH during walking. It can be considered modified HH had more pronation pattern than original HH.

An, Eom & Lee (2005) compared plantar foot pressure and impulse of 7 kinds of shoes (i.e. sports shoes, 5 cm HH, 8 cm HH, 13 cm HH, platform shoes, inline, and heelys shoes) during static and dynamic movement in 20 females. Compared with those of sports shoe, greater pressure and impulse were shown on the 1st phalange and the 1st metatarsal head and greater impulse on the medial tarsal bone in HH. It was because the subject's center of mass moved forward when they wore HH compare with sports shoes (An et al., 2005).

In our study, modified HH of PCP left, PCP right, PTI left, PPG left during standing and PPG right during walking are greater than original HH. And even it didn't show statistically significant, the average in all pressure values of modified HH showed bigger than original HH. It surmised to be related to awkward with modified HH. Even though they said to feel the comfortable cause of big space inside of HH in the interview, they seemed to be not enough time to adapt with new HH. So their walking and standing postures were unstable.

The present study had not enough subject to verify efficacy. Further study needs to recruit more subjects and investigate the relationship between the depth of the medial-inside groove and foot pressure or joint kinematics such as the ankle, knee, pelvic as well.

CONCLUSION

The modified fore-medial part of HH can reduce the stress in the first metatarsal head and big toe area during standing and walking.

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REFERENCES

American Podiatric Medical Association. (2003). High heel survey. Bethesda (MD): *American Podiatric Medical Association*.

An, E. S., Eom, G. M. & Lee, S. H. (2005). Comparison of Plantar Foot Pressure and Impulse in Various Shoe Types. *Journal of the Korean Society for Precision Engineering*, *22*(8), 174-181.

Barkema, D. D., Derrick, T. R. & Martin, P. E. (2012). Heel height affects lower extremity frontal plane joint moments during walking. *Gait & Posture*, *35*(3), 483-488.

Barton, C. J., Coyle, J. A. & Tinley, P. (2009). The effect of heel lifts on trunk muscle activation during gait: a study of young healthy females. *Journal of Electromyography and Kinesiology*, *19*(4), 598-606.

Bendix, T., Sørensen, S. S. & Klausen, K. (1984). Lumbar curve, trunk muscles, and line of gravity with different heel heights. *Spine*, *9*(2), 223.

Bird, A. R., Bendrups, A. P. & Payne, C. B. (2003). The effect of foot wedging on electromyographic activity in the erector spinae and gluteus medius muscles during walking. *Gait & Posture*, *18*(2), 81-91.

Blanchette, M. G., Brault, J. R. & Powers, C. M. (2011). The influence of heel height on utilized coefficient of friction during walking. *Gait & Posture*, *34*(1), 107-110.

Cronin, N. J. (2014). The effects of high heeled shoes on female gait: A review. *Journal of Electromyography and Kinesiology*, *24*(2), 258-263.

Cronin, N. J., Barrett, R. S. & Carty, C. P. (2012). Long-term use of high-heeled shoes alters the neuromechanics of human walking. *Journal of Applied Physiology*, *112*(6), 1054-1058.

Csapo, R., Maganaris, C. N., Seynnes, O. R. & Narici, M. V. (2010). On muscle, tendon and high heels. *Journal of Experimental Biology*, *213*(15), 2582-2588.

Ebbeling, C. J., Hamill, J. & Crussemeyer, J. A. (1994). Lower extremity mechanics and energy cost of walking in high-heeled shoes. *Journal of Orthopaedic & Sports Physical Therapy*, *19*(4), 190-196.

Esenyel, M., Walsh, K., Walden, J. G. & Gitter, A. (2003). Kinetics of high-heeled gait. *Journal of the American Podiatric Medical Association*, *93*(1), 27-32.

Forriol, F. & Pascual, J. (1990). Footprint analysis between three and seventeen years of age. *Foot & Ankle*, *11*(2), 101-104.

Gefen, A., Megido-Ravid, M., Itzchak, Y. & Arcan, M. (2002). Analysis of muscular fatigue and foot stability during high-heeled gait. *Gait & Posture*, *15*(1), 56-63.

Ho, K. Y., Blanchette, M. G. & Powers, C. M. (2012). The influence of heel height on patellofemoral joint kinetics during walking. *Gait & Posture*, *36*(2), 271-275.

Joseph, J. (1968). The pattern of activity of some muscles in women walking on high heels. *Rheumatology*, *9*(7), 295-299.

Kim, Y. J., Ji, J. G., Kim, J. T., Hong, J. H., Lee, J. S., Lee, H. S. & Park, S. B. (2004). A comparison study for mask plantar pressure measures to the difference of shoes in 20 female. *Korean Journal of Sport Biomechanics*, *14*(3), 83-98.

Lee, C. M., Jeong, E. H. & Freivalds, A. (2001). Biomechanical effects of wearing high-heeled shoes. *International Journal of Industrial Ergonomics*, *28*(6), 321-326.

McGill, S. M., Hughson, R. L. & Parks, K. (2000). Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work. *Ergonomics*, *43*(4), 486-493.

Mika, A., Oleksy, Ł. U. K. A. S. Z., Mikołajczyk, E., Marchewka, A. & Mika, P. (2011). Changes of bioelectrical activity in cervical paraspinal muscle during gait in low and high heel shoes. *Acta of Bioengineering and Biomechanic*, *13*(1), 27-33.

Mika, A., Oleksy, Ł., Mika, P., Marchewka, A. & Clark, B. C. (2012). The influence of heel height on lower extremity kinematics and leg muscle activity during gait in young and middle-aged women. *Gait & Posture*, *35*(4), 677-680.

Nieto, E. & Nahigian, S. H. (1975). Severe ankle injuries while wearing elevated "platform" shoes. *Ohio State Medical Journal*, *71*(3), 137-141.

Ricci, B., & Karpovich, P. V. (1964). Effect of height of the heel upon the foot. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *35*(3), 385-388.

Simonsen, E. B., Svendsen, M. B., Norreslet, A., Baldvinsson, H. K., Heilskov-Hansen, T., Larsen, P. K. ... & Henriksen, M. (2012). Walking on high heels changes muscle activity and the dynamics of human walking significantly. *Journal of Applied Biomechanics*, *28*(1), 20-28.

Soames, R. W. (1985). Foot pressure patterns during gait. *Journal*

of Biomedical Engineering, *7*(2), 120-126.
Stefanyshyn, D. J., Nigg, B. M., Fisher, V., O'Flynn, B. & Liu, W. (2000). The influence of high heeled shoes on kinematics, kinetics, and muscle EMG of normal female gait. *Journal of Applied Biomechanics*, *16*(3), 309-319.
Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture*, *3*(4), 193-214.
Wu, D. & Louie, L. (2010). Does wearing high-heeled shoe cause hallux valgus? A survey of 1,056 Chinese Females. *The Foot and Ankle Online Journal*, *3*(5), 3.