NORTHERN OHIO FOOT & ANKLE FOUNDATION

The Northern Ohio Foot and Ankle Journal *Official Publication of the NOFA Foundation*

The Effects of High-Heeled Shoes: A Practical Review

by Scott D. Walker, DPM[1]

The Northern Ohio Foot and Ankle Journal 4(28): 1

Abstract: High-heeled shoes are a prevalent form of fashionable footwear. Historically, physicians have decried these shoes' use due to the unnatural effects on posture they produce. While most historical views regarding these shoes were based upon clinical observation, significant progress has been made in accurately characterizing many of the biomechanical and postural effects of this style of shoe. The purpose of this article is to present a practical review of the postural and dynamic gait changes patients experience when wearing high-heeled shoes.

Key words: Shoes, high-heeled, high heel, stiletto, platform, wedge, pump

Accepted: April 2018 **Published:** May 2018

High-heeled shoes have been worn as fashionable footwear in Western society since the 17th century.[1] Since that time, the prevalence of this shoe type has waxed and waned on account of various influences. Although previously worn by both men and women, high heels are contemporarily worn almost exclusively by women. Physicians have advised of the ill-effects this type of footwear has on comfort and function for over two hundred years, yet a high proportion of women (37-69%) continue to wear high-heeled shoes daily.[1,2]

A number of reasons are suspected to account for women's persistent use of high-heeled shoes. One motivation is occupational. Women increasingly entered the sales workforce toward the end of the 19th century and were encouraged by their employers to wear high-heeled footwear.[1] Even now, high heels remain an official dress code requirement for some workers, such as flight attendants.[1,3] In the United States, the early 20th century saw a new focus on the legs and feet of women.[1] High heels continued to become more prevalent socially due to French influence.[1] Once established as a social norm for females, implicit social compliance became and remains an additional motivation for the shoe style's use.[4] Frequent media portrayal and celebrity influences are thought to have contributed to this expectation.[4]

Address correspondence to: SDWalker@mercy.com. [1]Resident, Foot and Ankle Surgery, Mercy Health Regional Medical Center, Lorain, OH.

There are a number of psychosexual benefits that high heels afford women, and these are also suspected to further perpetuate the fashion.[4,5] Wearing high heels, for example, has been demonstrated to improve women's self-evaluation of their own attractiveness, increase women's perceived attractiveness to both men and women, increase the likelihood of helping behavior from males, and decrease the likelihood of being mistaken for a man in silhouette.[4,6]

Regardless of the reason for wearing them, high heels are associated with a number of effects on human static and dynamic biomechanics. The purpose of this article is to present a practical review of the postural and dynamic gait effects patients experience when wearing high-heeled shoes.

Foot

Pressure under the metatarsal heads during walking increases with increasing heel height.[2,7-9] The distribution of this pressure has been found to shift medially in high heels, with more weight borne at the hallux, first metatarsal, and central metatarsals.[2,7-9] Interestingly, Snow et al. found that increasing heel height diminished, but did not eliminate, the medial shift of the forefoot pressures up to a heel height of 8.26cm.[7] The rate at which pressure is loaded at the metatarsals in stance is also increased under high-heeled conditions.[7,8,10] Force at the heel during stance is decreased with high heels.[9]

Arch height is increased, and length of the foot decreased in the high-heeled shoe condition.[8] Also, hindfoot pronation is limited upon ground contact due to fixed ankle plantarflexion. It is suspected that the normal subtalar joint range of motion, and thus ability to absorb shock upon impact, is impaired in this footwear.[2,8] Some painful foot conditions associated with high-heeled shoe use include hallux abductovalgus deformity, metatarsalgia, painful hyperkeratoses, plantar fasciitis, and Haglund's deformity, but the association of some of these with heel height has not been isolated from other characteristics commonly found in this shoe type, such as narrow toe boxes, little padding, and lack of arch support.[8]

Ankle and Lower Leg

In high-heeled gait, the ankle exhibits increased plantarflexion and decreased range of motion.[8,11-14] Peak plantarflexion torque at the ankle joint is decreased in high heels.[12,14] The reduced torque results from the fixed plantarflexed orientation of the foot which, although reducing the plantarflexory moment arm of the Achilles tendon, most importantly decreases the moment arm of the dorsiflexory vertical ground reactive force about the ankle joint axis.[8,12,14,15] The plantarflexed position of the foot throughout stance also limits the available range of internal rotation for the tibia.[8]

Under normal conditions, the center of the ankle axis of rotation in the coronal plane has been demonstrated to lie medial to the heel's point of contact with the ground for most of stance phase.[16] In the study by Barkema et al., this axis is elegantly demonstrated to shift from a predominately medial position at a 1cm heel height to a predominately lateral position at 5cm and 9cm heel heights, causing the external forces acting upon the ankle to transition from predominately everting to predominately inverting in nature.[16] The intrinsic moment required to counteract these external forces concomitantly transitions from an intrinsic inversion moment under normal conditions to an intrinsic eversion moment with high heels (which increases with increasing heel height).[8,14,16] Consistent with requisite intrinsic eversion with high-heeled gait, studies have demonstrated increased peroneus longus activity with high heels via electromyography (EMG).[17,18] There is agreement among many authors that coronal plane changes at the ankle with increasing heel height biomechanically predispose patients to lateral ankle sprains.[8,17,18]

Additional changes also occur in the musculature of the lower leg during high-heeled ambulation and after chronic use of the shoes. During high-heeled gait, studies demonstrate increased activation of the tibialis anterior, medial gastrocnemius, and soleus muscles, although there is some difference between the studies as to when the increased activation is.[8,12,15,20] The lower study populations among the relevant EMG studies may contribute to the variation among findings.

When comparing cohorts of chronic ambulators in high heels and a control group not accustomed to routine use of these shoes, increased medial gastrocnemius activity is observed during barefoot gait among those who frequently walk with high heels.[15] Ultrasound examination has shown decreased medial gastrocnemius fascicle length in stance and with isometric contraction against a dynamometer in chronic users.[15,21] No changes to Young's modulus of the Achilles tendon has been demonstrated compared with the control population, but dynamometry did show increased Achilles tendon stiffness in habitual users of high heels.[21] Magnetic resonance imaging (MRI) has further confirmed that increased cross-sectional Achilles tendon thickness occurs with chronic high heel use compared to controls.[15,21] It is posited that the increased tendon stiffness and decreased medial gastrocnemius fascicle lengths account for increased gastrocnemius muscle strains observed, via ultrasound, in high-heeled (compared to barefoot) gait among habitual wearers of high heels, which is not reproduced in the control group.[15] Present evidence, however, ultimately associates the chronic use of high heels with some structural and neuromuscular changes in the posterior crural musculature.[15,21]

A further biomechanical influence which has provided some controversy is the relationship between high heels and the venous pump of the calf. Using air plethysmography (APG), Potério-Filho et al. compared the variation in calf cuff pressure with standing, static ankle flexion and extension, barefoot ambulation, and high-heeled (7cm) ambulation among 10 females.[22] They concluded that ambulation in high-heels optimized the calf muscle venous pump since this scenario produced the greatest variation in cuff pressure, and attributed the improvement to the increased anterior and posterior crural muscle group activation as discussed above.[22] Tedeschi Filho et al. contended that this conclusion is contrary to the "prerequisites" of an ideal calf pump set forth by Recek, since one of the essential components for the pump's function is unrestricted ankle motion.[23,24] To investigate this, 30 females were evaluated using calf APG for venous filling index (VFI), ejection fraction (EF), and residual volume fraction (RVF) comparing toe raises barefoot and while wearing 3.5cm stiletto, 7cm stiletto, and 7cm platform high-heeled shoes using a carefully standardized procedural protocol.[23] EF was significantly higher in the barefoot and 3.5cm stiletto groups compared to the 7cm shoes and RVF was significantly lower in the barefoot group compared to all others, both findings consistent with improved calf venous pump function with less heel height (VFI exhibited no difference between the groups).[23] Of the two studies, the latter may be the more reliable given its design.

Knee and Thigh

The knee must compensate for the plantarflexed position and decreased range of motion of the ankle in high-heeled gait. Total range of motion of the knee during stance phase increases to compensate for reduced ankle joint compliance.[8,11] Maximum knee flexion increases with increasing heel height to compensate for the decreased available ankle dorsiflexion during stance phase, allowing forward motion over the foot.[8,14,25] During swing phase, flexion at the knee is reduced.[8,11,14,25] Given the increased flexion of the knee in stance, an increased net knee extensor moment is present to maintain upright posture.[8] While the duration of knee extensor moment is consistently found to be increased during midstance, the peak stance extensor moment is not always elevated and appears to be related both to walking speed and height of the heel.[8,26,27] Activation of the quadriceps functions to effect the increased intrinsic extensor moment upon the knee, which has been verified experimentally by increased rectus femoris peak and mean amplitudes via EMG in the speed-controlled study by Simonsen et al.[12] The increased tension at the patellar tendon and increased patellofemoral compression is thought to contribute to the development of patellofemoral osteoarthritis.[14,27,28]

In the coronal plane, an increased varus moment on the knee is consistently present due to high-heeled shoes' resultant medial shift of the body weight relative to the foot.[8,12,14,16,29] This results in increased pressure at the medial compartment of the knee, even with more mild high heels of 3.8cm, and is suspected to contribute to tibiofemoral osteoarthritis.[14,16,26,27,30]

Hip

In the sagittal plane, there is little if any impact on stance phase hip motion due to high-heeled footwear, although some studies have found minor variations not corroborated by others.[8] In swing phase, there is a small decrease in hip flexion with high heels. Barkema et al. found a 10% increase in the hip abduction moment with 9cm high heels compared with heel heights of 5cm and 1cm.[16] Simonsen et al. similarly found an increased hip abduction moment in midstance without any associated position change, whereas studies by Esenyel et al. and Kerrigan et al. did not find any statistically significant changes to the hip in the frontal plane.[12,14,29]

Spine and Pelvis

In younger women, Mika et al. found the pelvic range of motion in the sagittal plane to be increased when wearing high heels without this effect in middle-aged women.[11] Another study found posterior pelvic tilt with high-heeled gait in 13-20 year old girls compared with anterior pelvic tilt in girls who were experienced wearers.[8] A recent dynamic study comparing high-heeled with barefoot gait by Baaklini et al. showed no significant differences between inexperienced and experienced wearers and demonstrated increased pelvic range of motion in the high-heeled state.[31] Another static study examining full body standing comparison lateral radiographs of women standing with and without high-heeled shoes found no changes in pelvic tilt, spino-sacral angle, or sacral slope.[32]

Increased lumbar lordosis was historically believed to result from high-heeled posture.[1] According to a thorough contemporary review, however, the majority of studies have demonstrated that lumbar lordosis is either decreased or unchanged in patients' shod with high-heeled shoes.[8] After its publication, a static radiographic study from China found that lumbar lordosis increased with heel height, followed by Baaklini et al. again finding decreased lumbar lordosis with dynamic high-heeled gait.[31,33] In the same study of girls aged 13-20 years mentioned prior, experienced wearers of high heels did exhibit increased lumbar lordosis, in contrast to inexperienced wearers whose lumbar lordosis decreased, but this finding is the exception rather than the rule.[8] To summarize, there is significant variability between studies regarding lumbar lordosis in high heels, but most would probably agree that increased lumbar lordosis is not a common effect.

While increased lumbar lordosis is unlikely to account for the lumbago that was previously attributed to it, changes in the paraspinal musculature due to high heels are more probable to blame for some of the discomfort these shoe wearers experience. Multiple studies have demonstrated increased EMG activity in the erector spinae muscles in patients wearing high heels.[8,34] Furthermore, cervical paraspinal muscle activation is increased at heel-strike and toe-off in high-heeled gait and may present another potential source of discomfort.[35]

General Properties of Gait

Walking in high heels is associated with decreased stride length.[8,11,36] Patient-selected walking velocity decreases in high-heeled gait.[8,11,16] Cadence remains unchanged with increasing heel height in most studies.[8,25,36,37]

The body's center of mass is shifted anteriorly and superiorly when shod with high-heeled footwear.[1,8,28,32,38] As discussed in the lower leg, thigh, and paraspinal musculature, high-heeled gait is associated with increased muscle activation. Additionally, more energy is expended due to braking forces in high-heeled gait since ground reactive forces are increased in all three planes with increasing heel height.[8] As a result, the energy cost of locomotion is increased with increasing heel height as demonstrated experimentally.[8,25,39]

Conclusion

High-heeled shoes are an established form of fashionable footwear in Western countries. Although popular, they produce significant alterations to normal biomechanics and some potential adverse effects may result. While avoiding this shoe type entirely may be ideal, 42% of women continue to wear them despite pain due to their aesthetic properties.[8] Patients should be advised of the changes imposed by this type of footwear and encouraged to at least limit the frequency, duration of wear, and heel height as much as possible.

References

1. Linder M, Saltzman CL. *A history of medical scientists on high heels.* Int J Health Serv. 1998;28(2):201-25.
2. Yung-Hui L, Wei-Hsien H. *Effects of shoe inserts and heel height on foot pressure impact force and perceived comfort during walking.* Appl Ergon. 2005 May;36(3):355-62.
3. United Inflight Services. *Flight Attendant Uniform Appearance Standards.* United Airlines, Inc. https://unitedafa.org/docs/uniforms/appearance_standards.pdf. Accessed 24 Apr. 2018.
4. Barnish M, Morgan HM, Barnish J. *The 2016 HIGh Heels Health effects And psychosexual BenefITS (HIGH HABITS) study: systematic review of reviews and additional primary studies.* BMC Public Health. 2017 Aug 1;18(1):37.
5. Smith EO, Helms WS. *Natural selection and high heels.* Foot Ankle Int. 1999 Jan;20(1):55-7.
6. Guéguen N. *High Heels Increase Women's Attractiveness.* Arch Sex Behav. 2015 Nov;44(8):2227-35.
7. Snow RE, Williams KR, Holmes GB Jr. *The Effects of Wearing High Heeled Shoes on Pedal Pressure in Women.* Foot Ankle. 1992 Feb;13(2):85-92.
8. Cronin NJ. *The effects of high heeled shoes on female gait: A review.* J Electromyogr Kinesiol. 2014 Apr;24(2):258-63.
9. Nyska M, McCabe C, Linge K, Klenerman L. *Plantar foot pressures during treadmill walking with high-heel and low-heel shoes.* Foot Ankle Int. 1996 Nov;17(11):662-6.
10. McBride ID, Wyss UP, Cooke TDV, Murphy L, Phillips J, Olney SJ. *First metatarsophalangeal joint reaction forces during high-heel gait.* Foot Ankle. 1991 Apr;11(5):282-8.
11. Wiedemeijer MM, Otten E. *Effects of high heeled shoes on gait. A review.* Gait Posture. 2018 Mar;61:423-430.
12. Simonsen EB, Svendsen MB, Nørreslet A, Baldvinsson HK, Heilskov-Hansen T, Larsen PK, Alkjær T, Henriksen M. *Walking on high heels changes muscle activity and the dynamics of human walking significantly.* J Appl Biomech. 2012 Feb; 28(1):20-8.

13. Alkjær T, Raffalt P, Petersen NC, Simonsen EB. *Movement Behavior of High-Heeled Walking: How Does the Nervous System Control the Ankle Joint during an Unstable Walking Condition?* PLoS One. 2012;7(5):e37390.

14. Kerrigan DC, Todd MK, Riley PO. *Knee osteoarthrits and high-heeled shoes.* Lancet. 1998 May 9;351(9113):1399-401.

15. Cronin NJ, Barrett RS, Carty CP. *Long-term use of high-heeled shoes alters the neuromechanics of human walking.* J Appl Physiol (1985). 2012 Mar;112(6):1054-8.

16. Barkema DD, Derrick TR, Martin PE. *Heel height affects lower extremity frontal plane joint moments during walking.* Gait Posture. 2012 Mar;35(3):483-8.

17. Kermani M, Ghasemi M, Rahimi A, Khademi-Kalantari K, Akbarzadeh-Bghban A. *Electromyographic changes in muscles around the ankle and the knee joints in women accustomed to wearing high-heeled or low-heeled shoes.* J Bodyw Mov Ther. 2018 Jan;22(1):129-133.

18. Foster A, Blanchette MG, Chou YC, Powers CM. *The influence of heel height on frontal plane ankle biomechanics: Implications for lateral ankle sprains.* Foot Ankle Int. 2012 Jan; 33(1):64-9.

19. Luximon Y, Cong Y, Luximon A, Zhang M. *Effects of heel base size walking speed and slope angle on center of pressure trajectory and plantar pressure when wearing high-heeled shoes.* Hum Mov Sci. 2015 Jun;41:307-19.

20. Joseph J. *The Pattern of Activity of Some Muscles in Women Walking on High Heels.* Ann Phys Med. 1968 Aug;9(7):295-9.

21. Csapo R, Maganaris CN, Seynnes OR, Narici MV. *On muscle tendon and high heels.* J Exp Biol. 2010 Aug 1;213(Pt 15):2582-8.

22. Potério-Filho J, Silveira SA, Potério GM, Fecuri RJ, de Almeida FH, Menezes FH. *The effect of walking with high-heeled shoes on the leg venous pressure.* Angiology. 2006 Aug-Sep;57(4):424-30.

23. Tedeschi Filho W, Dezzotti NRA, Joviliano EE, Moriya T, Piccinato CE. *Influence of high-heeled shoes on venous function in young women.* J Vasc Surg. 2012 Oct;56(4):1039-44.

24. Recek C. *Conception of the venous hemodynamics in the lower extremity.* Angiology. 2006 Oct-Nov;57(5):556-63.

25. Ebbeling CJ, Hamill J, Crussemeyer JA. *Lower extremity mechanics and energy cost of walking in high-heeled shoes.* J Orthop Sports Phys Ther. 1994 Apr;19(4):190-6.

26. Ho KY, Blanchette MG, Powers CM. *The influence of heel height on patellofemoral joint kinetics during walking.* Gait Posture. 2012 Jun;36(2):271-5.

27. Kerrigan DC, Johansson JL, Bryant MG, Boxer JA, Della Croce U, Riley PO. *Moderate-Heeled Shoes and Knee Joint Torques Relevant to the Development and Progression of Knee Osteoarthritis.* Arch Phys Med Rehabil. 2005 May;86(5): 871-5.

28. Fulkerson JP, Arendt EA. *Anterior knee pain in females.* Clin Orthop Relat Res. 2000 Mar;(372):69-73.

29. Esenyel M Walsh K Walden JG Gitter A. *Kinetics of High-Heeled Gait.* J Am Podiatr Med Assoc. 2003 Jan-Feb; 93(1):27-32.

30. Chue CR, Andriacchi TP. *Dance between biology mechanics and structure: A systems-based approach to developing osteoarthritis prevention strategies.* J Orthop Res. 2015 Jul;33(7):939-47.

31. Baaklini E, Angst M, Schellenberg F, Hitz M, Schmid S, Tal A, Taylor WR, Lorenzetti S. *High-heeled walking decreases lumbar lordosis.* Gait Posture. 2017 Jun;55:12-14.

32. Weitkunat T, Buck FM, Jentzsch T, Simmen HP, Werner CML, Osterhoff G. *Influence of high-heeled shoes on the sagittal balance of the spine and the whole body.* Eur Spine J. 2016 Nov;25(11):3658-3665.

33. Dai M, Li X, Zhou X, Hu Y, Luo Q, Zhou S. *High-heeled-related alterations in the static sagittal profile of the spino-pelvic structure in young women.* Eur Spine J. 2015 Jun;24(6): 1274-81.

34. Mika A, Clark BC, Oleksy L. *The influence of high and low heeled shoes on EMG timing characteristics of the lumbar and hip extensor complex during trunk forward flexion and return task.* Man Ther. 2013 Dec;18(6):506-11.

35. Mika A, Oleksy L, Mikolajczyk E, Marchewka A, Mika P. *Changes of bioelectrical activity in cervical paraspinal muscle during gait in low and high heel shoes.* Acta Bioeng Biomech. 2011;13(1):27-33.

36. Merrifield HH. *Female Gait Patterns in Shoes with Different Heel Heights.* Ergonomics. 1971 May;14(3):411-7.

37. Schaefer S, Lindenberger U. *Thinking while walking experienced high-heel walkers flexibly adjust their gait.* Front Psychol. 2013 Jun 3;4:316.

38. Roman de Mettelinge T, Calders P, Danneels E, Geeroms S, Du Four C, Cambier D. *Does Footwear Matter When Performing Spatiotemporal Gait Analysis Among Older Women?* J Geriatr Phys Ther. 2015 Oct-Dec;38(4):155-61.

39. Mathews DK, Wooten EP. *Analysis of Oxygen Consumption of Women While Walking in Different Styles of Shoes.* Arch Phys Med Rehabil. 1963 Oct;44:569-71.