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Review Article

The Influence of Foot Orthotic Interventions on Workplace Ergonomics

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ABSTRACT

Background: Work related musculoskeletal disorders and overuse injuries due to prolonged standing and walking activities are a common occurrence, leading to foot pain and disorders, owing to the repetitive stress on the bones, joints and soft tissues. Prevention of such injuries involves the strategic use of management strategies integrating physical and psychosocial requirements with human characteristics. Several footwear designs and foot orthotic interventions have shown to influence this relationship between musculoskeletal systems and work-place ergonomics.
Objective: The objective of this study is to summarize and highlight the use and impact of various foot orthotic interventions and shoe design features on the ergonomics of the lower limb and foot, specifically during long standing and work-place activities.
Method: A computerized search was conducted using Google Scholar, Science Direct, PubMed, Cochrane Library and reference lists from all retrieved articles, using various search strategies.
Result: The use of various orthotic modifications such as heel cups, arch supports, metatarsal pads and total contact inserts showed promising results, with respect to peak plantar pressure in the foot and lower limb dynamics. Shoe fit, design and its characteristics like heel height, toe box along with sole contouring and thickness are some of the important elements that influence foot comfort and activation of the lower limb muscles.
Conclusion: Ergonomically designed footwear and the appropriate orthotic interventions increase comfort and prevent injuries by optimally aligning the feet and improving the functional balance and muscular functions of the lower limb, for prevention and protection against workplace injuries.

Key Words: Overuse Injuries, Work Related Musculoskeletal Disorders, Foot Orthoses, Footwear, Ergonomics

INTRODUCTION

The human foot is the foundation of the whole body and is the primary link between the body and the ground when standing and walking, but very little consideration is given to proper ergonomics and their relationship with human feet, which carry much of the brunt of our everyday working lives.

Lower limb overuse injuries are common among those who are under physical stress. Foot problems occur when repetitive forces whose magnitude exceeds the tolerance threshold of the body act on the musculoskeletal system, both on and off the job. Additionally, there are certain work-related conditions that may contribute to or aggravate foot issues, particularly jobs requiring long standing or walking hours that place the feet at risk. Continuous standing misaligns the plantar joints and bones causing balance impairments which make the feet susceptible to rapid breakdown, leaving them prone to inflammation, joint or muscle overuse disorders, along with reduced bone density, thus facilitating degenerative changes. [1,2]

The dynamics of the lower limb kinetic chain depend on the sensory feedback of the plantar sole which in turn is affected by the distribution of plantar pressure. Studies have shown that the footwear construction and design directly influence plantar pressure, comfort, fatigue levels and muscle activation. [3]

Ergonomics claims that "neutral posture" of the foot is essential for minimizing overuse injuries. An incongruous shoe may alter the neutral alignment that the foot seeks, resulting in impairment of stability, strength and potential injury. For instance, wearing high heels for long hours, carrying heavy objects and working on wet, slippery surfaces are just a few of the hazards to which the feet are exposed at work. [4,5]

Orthotic interventions are widely used to treat existing pathological conditions and to prevent overuse injuries, and may also have indirect effects upon lower limb loading by affecting changes in gait kinematics and spatiotemporal parameters.[6]

There is limited literature summarizing and reviewing the influences and effects of the various orthotics interventions and the impact of shoe design considerations on the ergonomics of the lower limb and foot. Therefore, this study aims to highlight the effect of numerous foot orthotic interventions along with specific shoe features on occupational ergonomics, in order to improve efficiency and productivity at work, while at the same time ascertaining their role as a prophylactic measure against overuse disorders.

METHOD

A computerized search was conducted in Google Scholar, Science Direct, PubMed and Cochrane Database. The search queries used were - ‘foot orthoses and overuse injuries’, foot orthoses and overuse injuries and workplace ergonomics’. ‘footwear and ergonomics’, ‘shoe inserts’, ‘orthotic inserts’, ‘shoes designs’, ‘heel heights and workplace and plantar pressure’, ‘toe box and plantar pressure and comfort’, ‘work related musculoskeletal disorders and lower limb’, ‘arch supports and lower limb injuries’, ‘heel cup and lower limb injuries’, ‘metatarsal pad and lower limb injuries’.

RESULT

For this analysis 19 papers were chosen, 14 of which studied the influences and effects of the different orthotic interventions and 5 investigated the impact of the shoe design considerations on lower limb and foot ergonomics. The details of review articles are tabulated, where table 1 summarizes the orthotic interventions and table 2 summarizes the footwear designs respectively.

TABLE 1 - ORTHOTIC INTERVENTIONS

AUTHOR, YEAR	TITLE	INTERVENTION	IMPLICATIONS
Tarradea T et al (2019)	Are Custom-Made Foot Orthoses of Any Interest in Treatment of Foot Pain for Prolonged Standing Workers?	3-D printed custom-made foot orthoses (Immediate effects)	CFO was effective in alleviating foot pain in long-term standing workers. They fostered a balanced distribution of peak foot pressure by strengthening and relaxing foot arches, and by shifting the strain from heel to mid foot.[7]
Ostergaard J et al (2018)	Can an Off-the-Rack Orthotic Stiletto Alter Pressure and Comfort Scores in the Forefoot, Arch And Heel?	Orthotic stiletto consisting of a built-in insole including a heel cup, arch support and metatarsal pad. (Immediate effects)	Using orthotic stiletto decreased both peak and continuous pressure under the forefoot and heel, thus increasing stability and comfort in those areas compared to flat sole stiletto.[8]
Anita AR, Lee YY (2015)	Effects of Heel Heights and Shoe Inserts on Step Counts and Perceived Comfort Among Female University Students	3 heel heights -2 cm (flat), 4 cm (low), 6 cm (high). Shoe insert conditions - shoe only, heel cup, arch support, and TCI	Step counts and perceived discomfort rating during walking increased with increasing heel height and decreased with using inserts. TCI with heel cup and arch support for high heeled shoes improved comfort. [9]
Luximon Y, Yu J, Zhang M	A Comparison of Metatarsal Pads on	Comparison of 3 pairs of metatarsal pads (similar shape	Metatarsal pads significantly reduced peak pressure on the forefoot and also increased comfort when wearing

(2014)	Pressure Redistribution in High Heeled Shoes	and size but different materials) (Immediate effects)	high heeled shoes. PU pad was the most effective in relieving plantar strain and the bio-gel material was the most supportive substance.[10]
House C, Reece A, Roiz de Sa D (2013)	Shock-Absorbing Insoles Reduce the Incidence of Lower Limb Overuse Injuries Sustained During Royal Marine Training	Comparison between Saran insoles and Shock Absorbing Insoles (SAI)	Using SAI decreased lower limb stress fractures, tibial periostitis, foot tenosynovitis, Achilles tendinopathy and anterior knee pain. Rate of metatarsal and femoral stress fractures was the same for both groups. SAIs safeguarded against injuries by reducing the magnitude and intensity of initial contact while running and walking, and by redistributing GRF, thus, reducing the loads transferred to the skeletal system.[11]
Creaby M, May K, Bennell K (2011)	Insole Effects on Impact Loading During Walking	Off the shelf flat insole and insole with heel cup. Flat insole consisted of flat polyurethane (PU) foam base with inserts of sorbothane in heel and forefoot regions. Heel cup insole contoured the heel and supported medial longitudinal arch.	Flat material insole reduced peak impact forces between foot and ground and at knee; heel-cup insole was only effective in reducing peak forces at knee. Heel cupping and contouring facilitated natural shock absorption of heel pad, which reduced impact forces between foot and ground. Reduction of peak impact forces of asymptomatic cases helped to reduce risk of overuse injuries.[6]
Li J et al (2010)	Biomechanical Effects of Foam Inserts on Forefoot Load During the High-Heeled Gait: A Pilot Study.	Comparison of various heel heights (0 cm,4.5 cm,8.5 cm) and foam inserts (different shore hardness) in midfoot area. (Immediate effects)	Peak pressure, maximum force and integral force-time values under midfoot region increased with increase in heel height. Using soft foam inserts reduced the peak pressure of midfoot by 19%, 30%and 26% from barefoot to high heel shoes. The material property and thickness of insert were significant variables in footwear design to minimize plantar peak pressure.[12]
Ramanathan AK et al (2008)	The Effects of Off-the-Shelf In-Shoe Heel Inserts on Forefoot Plantar Pressure	Off-the-shelf heel inserts of six different brands (Immediate effects)	Heel inserts increased area of contact between heel and shoe, and reduced the pressure by distributing it over a larger area. Using heel inserts increased plantar pressure and pressure time integral under metatarsal heads, and also helped in shock absorption and altered foot biomechanics.[13]
Maclean C, Davis I, Hamill J (2008)	Short and Long Term Influences of a Custom Foot Orthotic Intervention on Lower Extremity Dynamics	Semi-rigid custom foot orthoses (6 weeks), consisting of a rearfoot post, heel cup and additional cushioning.	Decrease in vertical loading rate, maximum rearfoot eversion velocity, and ankle inversion angular impulse during loading phase with custom foot orthoses (CFO). CFO reduced loads associated with rearfoot eversion during loading phase and also reduced maximum impact peak and vertical loading rate.[14]
Hong WH et al (2005)	Influence of Heel Height and Shoe Insert on Comfort Perception and Biomechanical Performance of Young Female Adults During Walking	Comparison of shoes without inserts and with inserts. 3 heel heights- flat (1.0 cm), low heel (5.1 cm), and high heel (7.6 cm) and a custom molded Multiform TCI (7-10 days)	In high heels, heel and midfoot plantar pressure shifted to medial forefoot, vertical and antero posterior GRF increased. Using TCI reduced peak pressure in medial forefoot and altered foot biomechanics to add comfort. TCI effectiveness was greater in higher heels than in lower and flat heels.[15]
Yung-Hui L, Wei-Hsien H (2005)	Effects of Shoe Inserts and Heel Height on Foot Pressure, Impact Force, and Perceived Comfort During Walking	Five shoe-insert conditions (shoe only, heel cup, arch support, metatarsal pad, and total contact insert) along with various heel heights (Immediate effects)	Heel height is directly proportional to forefoot pressure, impact force and perceived discomfort during walking. Increasing heel height increases forefoot pressure, impact force and discomfort. TCI, consisting of a heel cup and an arch support, reduced heel, forefoot pressure and impact forces, and offered better comfort.[16]
Finestone A et al (2004)	A Prospective Study of the Effect of Foot Orthoses Composition and Fabrication on Comfort and the Incidence of overuse Injuries	Soft custom, soft pre-fabricated, semi rigid biomechanical, and semi rigid pre- fabricated orthoses (14 weeks)	Soft custom and soft pre- fabricated orthoses had higher comfort levels than semi-rigid biomechanical and pre-fabricated orthoses. In terms of occurrence of stress fractures, ankle sprains or foot problems among different orthoses, there was no statistically significant difference amongst all the orthoses categories.[17]
Mundermann A et al (2001)	Relationship Between Footwear Comfort of Shoe Inserts and Anthropometric and Sensory Factors	CFO consisted of an arch support and heel cup, varying in arch and heel cup shape, hardness, and elasticity in heel and forefoot regions. 7 insert conditions - no insert condition (control condition) and 6 conditions with inserts. (4 months)	For all shoe inserts, average comfort ratings were higher than the control condition. Incidence of stress fractures and pain at various sites was reduced for inserts. Foot arch height, foot-leg alignment, and foot sensitivity were correlated with variations in comfort perceptions and scores for combinations of hard/soft, viscous/elastic, and high arch/low insert.[18]
Kelaher D, Mirka G, Dudziak K (2000)	Effects of Semi-Rigid Arch-Support Orthotics: An Investigation With Potential Ergonomic Implications	Comparison between semi-rigid orthotic insert and a flexible PU/Sorbothane insert. (2 months)	Fatigue module pain surveys found that low back pain reduced when using semi-rigid orthotics compared to using flexible inserts. Effectiveness of arch support orthotics in improving the biomechanics of whole bodies in healthy adults was limited.[19]

TABLE 2 - FOOTWEAR DESIGNS

AUTHOR, YEAR	TITLE	DESIGN FEATURE	IMPLICATIONS
McRitchie M, Branthwaite H, Chockalingam N (2018)	Footwear Choices For Painful Feet – An Observational Study Exploring Footwear and Foot Problems in Women	6 styles of shoes – Slip ons (loafers,pumps), Formal (court,dress shoes), Open-toed (sandals, flip flops), Boots, Activity (trainers, walking shoes), T-bars	Consciousness towards body appearance and a tendency to conceal deformity prompts users to choose normal shoes over orthopedic ones. Orthopedic shoes are deemed hideous, and often have poor user compliance. [20]
Branthwaite H, Chockalingam N, Greenhalgh A (2013)	The Effect of Shoe Toe Box Shape and Volume on Forefoot Interdigital and Plantar Pressures in Healthy Females	3 types of foot-wear with difference in sole material, shape and dimensions of toe box: square, round and pointed toe	Toe box shape influenced foot pressures and comfort - round shoes produced less peak pressure around medial foot; pointed shoe distributed the least pressure in lateral toe area and intensified pressure over forefoot borders due to its angular shape, whereas square toed shoe exerted maximum peak pressure over fifth digit. Dorsal digital area showed higher peak pressure on medial foot with square and pointed shoe shapes. [21]
Mientjes M, Shorten M (2011)	Contoured Cushioning: Effects of Surface Compressibility And Curvature on Heel Pressure Distribution	PU foam blocks with heel cups molded into the top surface. Cups were 80 mm wide but differed in surface radius and depth. 4 different PU foam formulations were used to create samples of each heel cup condition.	Compressible and conformed footbeds under calcaneus reduced peak pressure and redistributed load to peripheral regions for better load distribution. When used with less compressible surface materials and vice versa, contoured footbeds exerted a greater influence on peak pressure.[22]
Ramanathan A et al (2010)	The Effect of Varying Footwear Configurations on the Peroneus Longus Muscle Function Following Inversion	Barefoot, standard training shoe, shoe with a sole flare, and an above ankle laced boot.	Standard shoe and flared sole design showed significant differences from unshod condition. Muscle responded earlier in shod conditions compared to barefoot conditions. Post-peak average amplitude with standard shoe and flared sole shoe were significantly different from barefoot conditions. Inherent construct of laced boot protected the ankle subtalar joint complex which was evidenced by a weak peroneus longus muscle protective response.[23]
Kai Way Li (2003)	An Ergonomic Assessment of Four Female Shoes: Friction Coefficients of the Soles on Floors and Electromyographic Activities in the Shank When Walking	4 off the shelf female shoes - Shoe A: raised heel with rubber soles. Shoe B: high heel with PU sole. Shoe C: flat thermal PU sole work shoe. Shoe D: flat polyvinyl chloride (PVC) sole casual shoe.	Coefficient of friction (COF) measurements showed shoe A to be least slip resistant and shoe B to be the most slip resistant. High heels increased electromyographic activity for tibialis anterior, peroneus longus and soleus muscles during walking, rendering them undesirable in terms of ergonomics. [5]

DISCUSSION

Excessive and/or repeated activities of lower limb lead to overuse injuries. The end result is a "micro-trauma" injury – the body cannot keep up with the needs for reconstruction and repair, so the tissue starts to fail and is symptomatic. Injuries consistent with overuse of the lower extremity often contribute to higher degrees of immobility, abnormal pressures on foot, and may significantly degrade the quality of life. When the forefoot load is increased, the body's natural shock absorbers cannot provide adequate protection, which can inevitably lead to excessive fatigue and degenerative joint disorders, and potentially low back pain.

The rationale connecting variations in the anatomy of the lower limbs to musculoskeletal damage remains unclear. Preventing such injuries at work requires the creative use of control strategies to balance the physical and psychosocial demands with the characteristics of the individual(s). Redesign / modification interventions in the workplace, implementation of protective equipment, and participatory programs may be best suited for prophylactic management of such injuries.[5] Nevertheless, some lower limb disorders are consistent with abnormal posture and are managed with foot orthoses or adjusted footwear, as seen in the literature.

ORTHOTIC INTERVENTIONS

Based on the observed literature, it can be concluded that orthotic treatments have indirect effects on lower limb loading by altering gait kinematics and spatiotemporal parameters (step length, stride length and cadence), along with the magnitude of ground reaction forces during walking and running. The use of various orthotic modifications such as heel cups, arch supports, metatarsal pads and total contact inserts showed promising results, regardless of the heel heights, further emphasizing that these may be used effectively with high heeled shoes which are a popular choice among working women.

Yung-Hui et al reported that inserts including the heel cup, arch support, and TCI altered pressure distribution across the different regions of the foot, and the heel cup and TCI attenuated the impact force magnitude. The pressure relief depended largely on the elastic properties of the insert, while the attenuation of impact force depended largely on its viscosity. The orthotic heel cup's viscoelastic properties significantly decreased heel pressure and also enhanced the shock absorption capacity in conjunction with the normal heel pad. Using a metatarsal pad increased mid-foot pressure, although it did not significantly reduce the medial forefoot and impact force pressure. Consequently, they concluded that its usage during high-heeled walking was not successful in enhancing footwear comfort.[16]

Luximon et al, on the other hand, concluded that using metatarsal pads had an impact on the plantar pressures of foot, especially when used with high heeled shoes. The reason was attributed to the transfer of the plantar pressure to the longitudinal side and other sections, such as the heel section. In the heel area, the value of pressure increased much less than in the forefoot area. Therefore they suggested the use of metatarsal pads when wearing high heeled shoes.[10]

Heel-cup insoles were more effective in persons with low intrinsic shock absorption capacity of the heel, as shown by Creaby et al., higher heel pressure reductions were apparent with complete contact insoles that changed the contact dynamics of the entire foot. The construction of insoles also influenced the relationship between the vertical reaction forces acting at the ground and the lower limb. [6]

Regarding the comfort, Finnestone A et al showed that soft orthoses were appropriate for the stable foot and semi-rigid orthoses for the foot which needs stabilization in the push-off phase. This study further hypothesized and proved that shoe inserts improve footwear comfort and decrease injury frequency.[17]

FOOTWEAR DESIGNS

Various shoe styles and designs are available commercially, therefore it is important to highlight that the design and fit of the footwear influences the foot function and lower extremity dynamics. A properly fitting shoe must maintain a balanced foot orientation, without which there is a risk of imbalance and possible injury. Inadequate fit of shoe and characteristics such as heel height, toe box width, sole hardness and thickness have all been identified as elements that contribute to foot pain, reduce stability, inhibit relevant rehabilitation and increase hyperkeratotic lesions, eventually leading to the development of progressive foot deformity and pathology.

Narrow toe boxes were found to restrict the movement of the forefoot resulting in a stiffer foot prone to increased stress from loading as well as significantly increasing dorsal and plantar forefoot pressures, and this type of habitual constriction caused by footwear was reported to result in osteological deterioration in feet over a long period of time. Fastening techniques used in shoe design have also been shown to influence the normal width expansion of the shoes upper around the metatarsal heads, which if compressed, increases internal stresses. [20]

Footwear is an important interface for the foot when walking. Proper slip resistance by the footwear sole is necessary to allow for an equitable foot-floor interaction, as reported by Li K. The absence of slip-resistance characteristics in the sole of the footwear puts the walker in danger of slipping and falling, because the slip-resistance of the sole counter balances the slip motion tendency of the foot on the ground, allowing for a smooth center of gravity transmission of the body along the trajectory of movement. The less resistant to slip the shoes are, the higher will be the required leg muscular activity for maintaining body stability during walking.[5]

Surfaces with concave curvatures have an influence on pressure distribution under the heel. Thus, contoured shoe sole surfaces can be used to manage plantar pressure distributions, either as an adjunct to, or as a substitute for compressible sole materials.[22]

CONCLUSION

Wearing the right footwear increases comfort and performance and, most importantly, prevents injuries. Physically draining activities and long standing hours can put enormous pressure on the lower extremity and create an impact force through the legs which is three to five times the body weight of a person. An ergonomically designed shoe, will keep the feet properly aligned and be fully functional and pain-free. It will help to minimize pressure on the heel and avoid shocks on the entire body, helping to alleviate long-term foot, back and knee pain. Orthotic interventions can trigger sensorimotor effects by increased proprioceptive sensation to feet, optimize skeletal alignment and improve the functional balance and muscular function of lower limb.

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