Everyday footwear: *An overview of what we know and what we should know on ill-fitting footwear and associated pain and pathology.*

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Abstract

Footwear has been used to protect feet for millennia with socially exclusive population adopting stylish and fashionable shoes with expensive materials. In terms of historic timeline, only more recently footwear has been worn by all classes in the western world as an integral part of their apparel. Traditionally, footwear has been constructed from natural materials, mainly leather, but has recently benefitted from the flexibility that technology has provided with a plethora materials and new design innovations. Although it has expanded the availability for a variety of consumers, the choice and fit continue to be problematic with many individuals wearing shoes that are ill-fitting. Provision of specific footwear advice for problem feet is poorly evidenced and is heavily practitioner dependant limiting its efficacy. There is limited understanding as to the changes that can occur from regularly wearing footwear that is unsuitable in shape, style and construction which is referred to as ill-fitting. Current research on the effect that everyday footwear has on foot function and pain focuses mainly on women's shoes, particularly high heels. Defining what is a good fitting shoe, that does not damage the foot or mechanics of walking, may need to be individualised, but best fit is based on loose historical parameters rather than research evidence. The aim of this overview is to highlight aspects of current research, establishing what we know about the effect's shoes have on the feet as well as exploring the mythology around footwear fit and advice that is often historical in nature.

Keywords

Footwear, Shoes, high heels, ill-fitting shoes

Highlights

- Research evidence on the effects of ill-fitting footwear is limited and often based on assumptions, indirect association and mythology.
- Footwear advice to direct people to healthy footwear needs to be individualised as there is no definition of an ill-fitting shoe.
- Footwear choice can alter gait and inappropriate fit can create pain and pathology
- The direct mechanism of ill-fitting footwear contributing to pathology needs to be explored further.

1.Introduction

In shod populations footwear is often worn daily as protection and warmth for the foot. However, over many centuries a shoe has become more than an item of clothing and provides a sense of identity and image leading to imaginative fashion designs [1]. Design led shoes can often be unsuitable in structure and function for the wearers foot [2]. Creative designers invent enormous heel heights, narrow toe boxes, attractive materials and strive for unique styling. However, footwear choices are not solely driven by design and women normally make a shoe choice governed by the activity for the day and comfort [3]. This leads to limited choice and frequent mismatch between shoe and foot.

Footwear shopping often causes stress in people's lives as there are a poor selection of suitable fitting shoes available and the prices of the products are high [4]. This is reflected in the lack of consideration to accurately measure the foot size prior to purchasing a shoe, leading to an estimated 50% of the population wearing shoes that are ill-fitting [5]. Particularly within older adults who often wear a shoe that is too narrow and long for the foot to improve comfort, which could have implications on associated pain [6]. This discrepancy between foot and shoe shape and sizing is often thought to lead to common foot pathologies [7,8]. Footwear advice in a clinical setting is often incorporated into effective treatment plans when ill-fitting shoes are linked to the presenting complaint, yet there is little understanding as to what specific advice should be given. Although, some footwear assessment tools are available to guide clinicians on evaluating shoes [9,10], there are factors that categorise "healthy" footwear that are ill founded and often based on myth. Additionally, it should be noted that when assessing footwear, the shoes worn to clinic appointments are often picked for convivence rather than a true representation of what is regularly worn [6]. This leads to an inhibited understanding with a lack of evidenced based knowledge about the effect everyday footwear has on the foot.

Many footwear researchers have previously investigated the effect of high heel shoes on gait as the glamour associated with this shoe steals the research limelight. Similarly, there is general acceptance from a smaller pool of work that wearing ill-fitting shoes will cause musculoskeletal based pathology. However, from both areas of research there is still limited consensus on the impact footwear has on human function. The purpose of this overview is to highlight some of the established outcomes of wearing ill-fitting footwear on function and pain during gait. This commentary will also explore the effect shoe styling has on the foot as well as examining the mythology around designs that may alter function.

2. Ill-Fitting Footwear

Defining ill-fitting footwear is, particularly the appropriateness of fit, subjective and difficult to quantify, although there have been some attempts [11,12]. Ill-fitting footwear can be viewed as a shoe that is too big in length and width with a sloppy fit but could also be too short and cramped giving a tight fit [7,13,14]. However, ill-fitting could be extended beyond length and width to including shoes that impede normal function of the foot causing an altered gait pattern because of the shoe. As there is not one clear category for ill-fitting footwear, the effects of wearing ill-fitting shoes can vary between individuals.

When considering the impact of wearing ill-fitting footwear on the parameters of gait there are several observed changes that have been reported. These include; balance and increase risk of falling [15], increased dorsal toe pressure [16], spatiotemporal factors including lowered gait velocity and stride length [17], and range of motion [18]. Using a shoe that does not conform to normal function of an individual and the environment will create alterations in movement patterns seen in gait as

highlighted. Additional to the gait changes that have been shown to occur, the clinical effects of ill-fitting footwear can lead to skin lesions (blisters, hyperkeratotic lesions, rubbing soreness and ulceration) [19,20] It is suggested that in turn these changes can lead on to pathology and pain [21,22]. This indirect association linking the development of a lower limb pathology to choosing to wear ill-fitting footwear is not based on strong evidence.

Determining whether a new pair of shoes will fit well and be classed as healthy footwear becomes difficult in the absence of reliable measures. The comfort of a shoe has been shown to be an overriding factor of good fit to avoid changes in gait [3]. Yet the complexity of what makes a shoe comfortable related to the fit of the shoe and the impact on gait and pathology is not understood. This void in clinical and scientific knowledge around ill-fitting footwear leads to a poor choice of appropriate footwear and low certainty of suitability whilst purchasing new shoes.

3. High Heels

High heeled shoe styles are an example of ill-fitting footwear, with the design compromising fit to enable the shoe to stay on the foot and style overriding any functionality. The height of the heel on a shoe often attracts research and media attention. Research on the effects of high heels shoes on gait parameters is the most frequently investigated footwear topic outside of athletic footwear. It is clear from this body of knowledge that there is not just one isolated parameter that is affected by using a high heel shoe to walk in, but a collection of changes that alter gait [23,24]. The most prevalent of these changes are around increases in forefoot pressure, compromised balance, changes to knee moments, altered muscle activity and forefoot pathology.

Altered forefoot pressure, towards the medial side of the foot, is observed as the heel height increases [25-27]. Loading of the forefoot is seen, as the centre of pressure is transferred anteriorly from the altered stack at the rearfoot. The pressure increases when this heel stack is more than 2cm [27] and continue to increase as the height gets larger [28]. This increased forefoot pressure continues to be a problem even when the heeled shoes are removed, with frequent users having elevated pressures when walking barefoot [29]. There is, however, limited evidence to support a negative outcome for the observed increases in forefoot pressure other than an association between high heel shoes and painful callus [30]. Therefore, it is difficult to make an unequivocal statement that increases in pressure are detrimental to normal function and responsible for established pathology.

However, the transfer of centre of pressure anteriorly could be linked to an offset of balance which is reported to be compromised in a heel height that is above 4.5cm [31]. Although, reducing the heel to lower than 0.5cm also incurs an alteration in the balance of the individual as the centre of pressure moves posteriorly [32]. It is therefore recommended that footwear should have a heel height of between 1cm and 4cm to limit falls and increase stability [33,34]. Reduced contact area has also been associated with instability [35]. High heel stiletto shoes often have a tapered shape with the contact area on the floor being $1cm^2$, increasing medial and lateral sway. The shape of the heel therefore must also be considered when assessing the effect of the heel on stability as well as the design of the upper of the shoe. (Figure 1&2)

Figure 1 Heel height of 9cm – stiletto and block heel will have differing effects for the wearer due to contact area, shape and styling

Figure 2 Heel height of 4cm, considered as stable, but shape and design of upper must also be considered.

Other ways to gain a stable gait pattern whilst wearing a high heeled shoe include changes in the moments and function of the knee joint, with an increase in knee flexion that alters the knee torque at early stance [36-38]. This altered flexion is thought to be because of reduced ankle dorsiflexion and the action of the triceps surae muscle group. At heel strike, the ankle is plantarflexed in a high heeled shoe compared to a low heel changing the range of motion which is compensated for by increased knee flexion [39]. By altering the range of motion and function at joints the mechanism for movement in muscle function is also affected.

Changes in muscle activity often accompany observed joint kinematic changes when wearing a high heel shoe [40]. Medial gastrocnemius has been shown to increase in activity as it concentrically contracts in a shortened position due to increased ankle plantarflexion. The muscle works with rectus femoris to stabilise and manage increased knee flexion [41]. This increase in muscle imbalance on the medial part of the limb could also be related to an observed lateral shift in the centre of pressure [42]. In addition to muscle changes from altered limb motion, there has also been a suggestion that altered architecture in the spine from adaptation causes an increase in the erector spinae muscle activity [43]. Increased muscle activation can lead to muscle fatigue and strain which could be associated with pain and discomfort experienced by high heel shoe wearers [39]

Injury to the foot and ankle increases, as the height of the heel increases with fractures, sprains and strains being the most prevalent pathology [44]. The main injury appears to be acute trauma and as a result from a fall in a high heel rather than a long-term deformity, however a heel higher than 2.5 cm in heel height leads to an increase in prevalence of corns and callus in older individuals [45]. Forefoot pathologies are reported to be associated with heel increases, particularly hallux abducto valgus [46,47] Although this is not clear if this is due to the height of the heel or the altered toe box depth and width that is often seen as a design feature of this style of shoe.

4. Mythology

It is clear from the research discussed so far that footwear shape plays a role in altered function and an ill-fitting shoe can lead to pain and pathology. However, there is no consensus on what an ill-fitting shoe is and more importantly how to assess best fit. Footwear tools have been developed to evaluate the characteristics of a shoe [9,48,49]. Yet the basis of these tools to evaluate a best fit shoe appear to be fragile with many parameters being historical in origin rather than based on research evidence. It is therefore not clear when and how the styling, design and definition of a best fit shoe occurred.

One design feature that is traditionally indicated as essential for good fit is that a shoe requires a stiff heel counter for stability of the rearfoot and reduced shoe slip whilst walking. Within different shoe styles the shaping and stiffness of the heel counter varies with a narrower shape being applied to slip on shoes and an array of different stiffnesses across all styles. Understanding the impact a stiff heel counter has on function and pain is limited. A stiffer counter does not alter pain in arthritic knees [50] and has no effect on athletic performance [51] but has been shown to reduce the risk of a person falling [45]. Application of when to use a stiff heel counter and how stiff the material should be is still not clear therefore making footwear advice tailored to specific patient complaints difficult.

A further stability feature is the use of a fastening, which is often advised to keep the shoe on the foot. This can be a lace, Velcro strap or buckle but there is no guidance as to which fastening should be used and how this helps with function. Mathematical modelling of lacing techniques suggests that a criss cross design of the lace are the most efficient lacing technique but not the strongest [52] and the tightness of the laces has no impact on plantar pressure but does alter heel slippage [53]. A dorsal fastening does improve walking confidence in older adults, reducing falls risk [54] but not all older adults could manage a lace shoe. A shoe without any fastening that stays on the foot during walking could be deemed as good fit if there are no alterations in gait and changes to function, yet a slip-on shoe like this is not classified as a healthy choice [55]. Effectively defining the multiple use of fastening shoes for different patient groups will improve clinical footwear advice as well as inform footwear designs expanding on commercial choice.

Purchasing shoes that fit well can be a troublesome task for many with mismatches occurring frequently between foot shape and shoe [5,6]. The same size foot length can be several different shapes from other key dimensions used in measurements, but consumers are often expected to fit to the same shoe last and shape. Many people do not consider footwear measurements as important when purchasing shoes [3] and rely more on comfort, which is the high risk diabetic foot is not suitable resulting in a high chance of incorrect fit [56]. The perfect length of a shoe is not known with a suggestion that this should be between 1-1.5cm beyond the longest point of the foot, however, there is no standard approach to the correct assessment of this [57] and often a depression of a thumb at the end of the shoe is used. Defining the optimum length and width of a shoe to achieve maximum comfort is required to be able to understand the correct fit regarding measurements.

5. Summary

Individualised shoes are not far off with 3d printing and scanning becoming a common place in many industries [58, 59]. Personalised footwear in the athletic sector is already observed and this trend is starting to influence production of everyday shoes with components being made as printed sections rather than cutting from sheet material. This reduces waste and can have the bonus of making the shoe sizing and shape custom made to the individual. In the future customisation of commercially available footwear fitting and choice could eradicate the associated footwear related pathologies that are observed in clinics. For this to be effective though, it is essential that there is an improved understanding regarding what individuals require to gain maximum function, comfort and fit. Thus, minimising the impact footwear has on the development of foot pathology. Therefore, a larger base

of knowledge is required to understand the direct impact of wearing ill-fitting shoes and how to effectively choose healthy shoes to minimise risk of associated pathology.

6.References

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