



Design of a female shoe sole under light parameters

Diseño de una suela para calzado femenino casual bajo parámetros de liviandad

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Abstract

Women nowadays work in different areas, in which professional excellence is combined with personal presentation. In this last aspect, the footwear is a fundamental and indispensable element. With the purpose to offer women not only an aesthetically acceptable footwear but also light and flexible, this work was developed in two stages: the first validated the need to design comfortable and esthetic shoes for the woman of today, through a survey of 50 women of different occupations, which travel long distances in their daily routine and to which were counted the number of steps that they regularly execute in the day, through an intelligent adjustment band. As a result, it was identified that the heel height and the number of steps in a day are the relevant factors that influence the pain level of these women's feet at the end of the working day. In this way, in a second stage, ergonomic women's casual shoes were designed to relieve pain and combine the development of a new sole and a characteristic shoe of a commercial company.

Keywords: woman; ergonomic; comfort; lightness; sole.

Introduction

Feet are some of the most complex organs the human body has, it is a fundamental part of the motor system and therefore it is a receiver, support and, propulsor during the march, cushioning and provides body balance (Carreña & Cabrera, 2014). In this sense, the choice of footwear is vital because it can alter the control of the motor system and body balance (Cronin, 2014). The main function of footwear is the protection of feet; however, aesthetics are prioritized over this aspect (American Academy of Orthopedic Surgeons, 2012). Therefore, to ensure the protection of the foot, the design of the shoes must contain ergonomic and

comfort criteria. To achieve this, the following aspects must be considered: cushioning, stability, durability, flexibility, and lightness (Jones, 2014).

The flexibility of a shoe is related to the effort required to bend it through the widest part of the forefoot. The lightness implies a decrease in the total weight of the shoe and depends largely on the material used to manufacture it. It has been demonstrated that the component that contributes the most weight to footwear is the sole (Vicén, Garrigós, González, & Salinero, 2012). With footwear that is not flexible and heavy, energy expenditure is greater to flex the foot and fatigue when walking, making walking difficult and increasing plantar pressures (Puigcerver *et al.*, 2012).

Given the above, the material has been reduced or eliminated in areas of the sole that are not in direct contact with the surface and that do not compromise the user's stability and support. Lower density materials such as rubber and / or foamed latex, foamed thermoplastic polyurethane, vinyl acetate (EVA), DNA foam, Spenco (neoprene foam), styrene, among others (Barnes, Connell, Elder, Fagergren, & Peters, 2017; Dhanapal & Raja, 2016; Doerer & Schauster, 2014; Nunes *et al.*, 2016; Prakash, Passi, Prakash, Bhatta, & Deane, 2014). In addition, expanded microspheres have been used for the manufacture of soles. These are small spherical plastic particles that can be added as a blowing agent and weight reducer in thermoplastic material (AkzoNobel, 2013).

At present, the regulations applied to footwear are defined by the Colombian Institute of Technical Certification Standards ICONTEC. The applicable standard is NTC 2396-1 (ICONTEC, 2002) and focuses primarily on safety footwear, which must affirm the protection of people with high-risk professions (Sáenz, 2008). As can be seen, there is a lack of regulations associated with ergonomics and comfort in footwear, which demonstrates once again that these concepts are undervalued in the sector.

Casual shoes are commonly called informal shoes. For the female audience, this footwear can have characteristics between sandals and shoes covered with flat sole or heel and can vary between 3 and 10 cm. (American Podiatric Medical Association APMA, 2014). Several studies on the use of high-heeled shoes have shown the problems or pathologies they cause (Barkema, Derrick, & Martin, 2012, Cronin, 2014, Wang *et al.*, 2016). The heel modifies the position of the foot and the rest of the body, which produces a postural alteration in a static position and a modification of the distribution of foot loads and pressures,

related to alterations in the pattern of the gait and in the form of contact with the soil (Collado, Pascual, Álvarez, & Rodríguez, 2003). These pathologies are caused because this type of shoe is not exactly the most comfortable or ergonomic. Some ergonomics specialists recommend that heels be worn for short periods (Blanchette, Brault, & Powers, 2011). Despite the effects on body health due to the use of high-heeled shoes, they are still fashion items (Lin & Chen, 2015). That is, the solution to prevent or reduce foot pathologies is ideally in the ergonomic design. At this point, it should be noted that although there are many parameters of ergonomic footwear design, especially for footwear that is used during long periods of walking, the sole is a key component, because it directly influences the characteristics of weight and flexibility, consequently, it intervenes in the appearance of discomfort in the feet during the march.

On the other hand, the professional women of today perform among their functions are customer service and participation in meetings and events. These activities are generally developed interacting with other people. Therefore, it is undoubted that in addition to performing as excellent professionals require a very good personal presentation and, according to social dress codes, the casual shoe is essential.

According to the DANE (2016), in Colombia, the labor participation of women is significantly concentrated, exceeding 30 %, in commerce, hotels, and restaurants, while in social, community and personal services they participate with 32 % (El Espectador, 2010).

The performance of these trades implies in most cases, overload in the lower limbs due to intrinsic or extrinsic factors. Among the first ones are gender, age, personality, emotions, physiological factors, anthropometric characteristics, traumatism, neurological pathology, physiology, etc. While in the latter are: the terrain, the type of footwear and the type of dress (Collado *et al.*, 2003).

With the above, a great scenario for the design of women's casual shoes that is comfortable, light and flexible, for the professional woman of today. In this way, the pain or damage caused to the foot and other parts of the body by the use of non-ergonomic shoes would decrease. To achieve this, it was used as the material to manufacture a rubber mixture with expanded microspheres. The innovative component of this project is that the microspheres are usually used in thermoplastic and not elastomeric materials for this purpose. 'This work is part of this line and was developed in two stages. In the first, a study was conducted

on female executives to identify the need they have to use ergonomic shoes in their workday. In the second stage, the requirements of a novel design that combines the geometry and the material of a sole were defined to obtain a prototype of casual, lightweight and flexible footwear that meets the comfort needs of the current executive woman.

Methodology

Based on a previous survey made to customers, where they were asked the type of footwear of preference, how they learned about the company and comments about the footwear offered by a commercial company, they obtained answers where according to requirements of the majority of clients of the company, the ideal in its design would be that the footwear was lighter, due to this, the commercial company began to look for alternatives in its design so that the footwear had criteria of lightness, due to this the research was carried out in two stages, the first consisted of selecting a group of 50 women belonging to 5 professions, which are considered to have long marching times and from this their pain level was evaluated. The second stage consisted of developing a prototype taking into account the type of sole that the shoes of the commercial company present and concepts of ergonomics, functionality, and aesthetics. The soles were evaluated for flexion, resistance to abrasive wear, hardness, and density.

Stage 1. Validation of the need

During the development of the research, a sample of 50 women was randomly selected, which presented certain characteristics, as indicated in Table 1.

Table 1. Characteristics of the 50 women participating in this study

Characteristics	AGE (YEARS)	Weight (kg)	Height (cm)	Shoe size (Fr)
RangE	25-46	49-68	151-173	35-40
Average	34	57	165	37
Standard deviation	± 5	±4	±4	±1

These women work 60 % of their time away from home experiencing a succession of steps or prolonged walking cycles. The step is understood as the set of phenomena that occur between the support of a heel and the successive support of the opposite heel, while the cycle of the march is the set of actions performed and phenomena

produced from the contact of the heel with the ground until the next contact of the same heel with said support plane (Collado, 2002). In Figure 1, the professions of the women who participated in this study are indicated.

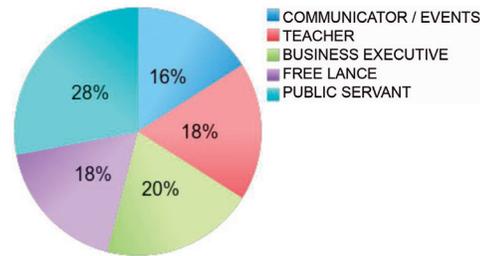


Figure 1. Professions of women in the sample study
Source: the authors

The teachers were selected from a university in the city of Medellin, which has an area of 127,792 square meters, which houses blocks of classrooms, offices, laboratories and other places to develop various academic and cultural activities.

The women who work as freelancers are independent designers, fashion designers, artisans and artists who do not have a defined schedule or a regular workspace, they can be 3 hours in the workshop, 2 hours in the store, 3 hours in the office and constantly be in motion, so in a workday they are subject to long cycles of walking or standing for long hours.

The communicators and organizers of events remain in the office 20% of their working day. The remaining 80% are serving customers, taking them to know the different locations for certain events and at the same time they are participating in them, they are in charge of logistics, food, decoration, the spatial location of people, between other activities. These professionals are in constant movement outside of their workplace, making long walking cycles.

The commercial executives are characterized by working in the office for long periods but also by fulfilling a number of visits per week from external clients. Although the vast majority said that the appointments are made in places close to their workplace, they also claimed to have to leave the office for meetings and events that require standing for long hours and walking cycles.

The public servants interviewed work in the city of Medellin and provide services to the municipality, visit other municipalities and different communes. They present long and constant march cycles.

To collect the information, a survey was initially carried out for each woman where questions such as working hours, standing time, time away from home, pain level, which was rated 1 to 5, were asked. In addition, each one was given an intelligent adjustment band, which is a system that records the steps taken, distances traveled and biological signals associated with the cardiovascular system. Thus, each one was counted the number of steps developed during two business days.

Stage 2. Design of a prototype

Once the need to develop casual and comfortable shoes for the current professional woman has been validated, proposed a solution to design a sole in a specialized software, Rhinoceros, version 5, under the concepts of ergonomics, functionality, and aesthetics to adapt it to a shoe with design characteristics of the commercial company, soles were obtained with rubber formulations used in the industry and soles that incorporate the concepts mentioned above, this process was carried out with equipment used in the rubber industry such as the open roller mill to obtain all the raw mixes, a vulcanization press to obtain the prototypes, finally all the prototypes were they performed abrasion, bending, hardness and density tests.

Results

Stage 1. Validation of the need

Based on the information collected in stage 1, in particular, the level of pain at the end of the day was analyzed as a response variable, to determine if there is an effect or not of a certain factor on this variable, an ANOVA variance analysis was performed. , one-way with a level of significance of 0.05.

At the end of the workday, the level of pain in the feet, indicated by the women surveyed in this study, depended on the number of steps, the type of shoe heel, while the weight, age, height and height of footwear were not influential factors in the level of pain.

The level of pain is higher for a number of steps between 11,000 to 13,000 (average: 3,1), compared to a range between 5,000 to 7,000 (average: 1,6), these data were corroborated with the ANOVA, which He indicated that both levels of the factor are different, (See Figure 2). While for the type of heel it was found that the high-heeled shoe

produces greater pain sensation than the low-heeled shoe, (See Figure 3).

This last result is consistent with numerous investigations that indicate that the high-heeled shoe, that is, more than 4 cm, can cause different pathologies, such as pain, particularly the ankle and forefoot (Borchgrevink, Viset, Wits, Schei, & Foss, 2015; Ho, Blanchette, & Powers, 2012; Yung-Hui & Wei-Hsien, 2005).

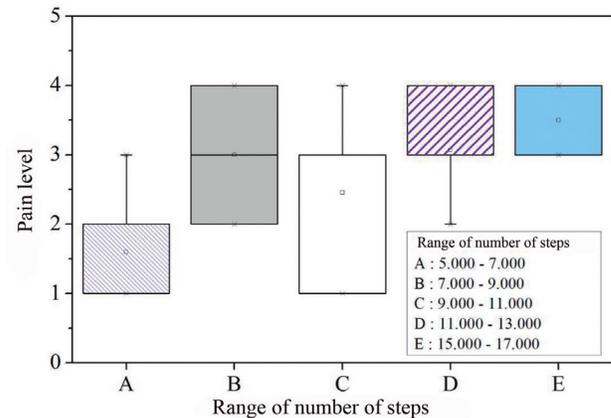


Figure 2. Effect of the number of steps executed in a working day on the level of pain of the women surveyed
Source: the authors

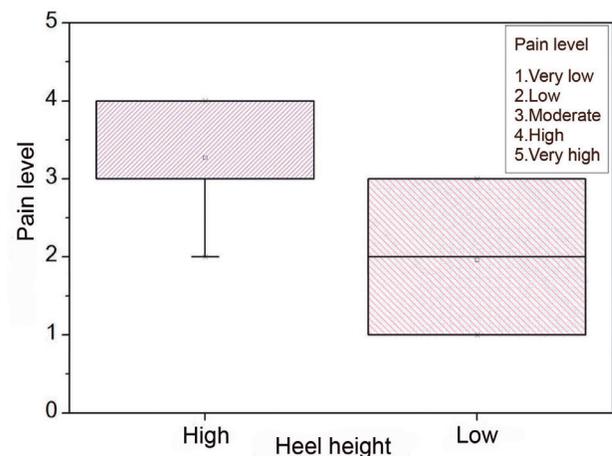


Figure 3. Effect of the type of heel on the level of pain of the women surveyed, after a working day
Source: the authors

Stage 2. Prototype design

A prototype of footwear was designed, with a novel sole whose characteristics are indicated in Table 2.

Table 2. Requirements and determinants for the design of the sole

Requirement	Determinant
Lightness	Circular sachets on the upper part of the sole, whose dimensions were determined according to obtaining the optimal weight of the sole. The economizers were separated from each other by a distance of 8 mm and with a depth of 1 cm to 3 cm, depending on the thickness of the sole.
Flexibility	A lightweight material that was an expanded natural rubber compound was also selected. Bending channels in the lower part of the sole and the metatarsal area, to facilitate the natural movements of the gait, optimize the energy consumption during this and reduce fatigue.
Evacuation of pollutants	Channels communicated with each other, distributed along the bottom of the sole, which are open to allow the evacuation of contaminants and enhance adherence and / or grip to the displacement surface.
Cushioning	This feature is intervened directly from the selection of the material, whose base is expanded natural rubber, which allows an efficient absorption of impacts during the march. In addition, a midsole is implemented, which is constituted by zones in silicone, strategically located, which will distribute loads in the foot in a more equitable and much healthier for the user.
Adherence and grip	In addition to the channels along the sole, the rough finish, especially in the forefoot area, allows a greater grip, specifically at the moment of takeoff, which is one of the phases of the gear mechanism. In this way, the risk of accidents associated with falls is minimized.
Durability	The resistance to abrasion in the sole is reflected in the selection of the material. The expanded natural rubber has been shown to have high characteristics with respect to the frictional wear resistance that is generated when walking. Thus the life of the sole is maximized, constituting a differentiating factor of design and design.
Distribution of plantar pressures	To achieve an equitable distribution of plantar pressures and avoid the appearance of pathologies associated with this parameter, a sole with a heel height of 3 cm was designed, with the addition of a 5 cm platform.

The sole design was graphed in specialized software, Rhinoceros, version 5 and shown in Figure 4.

Subsequently, 3 types of soles with a rubber formulation used in the industry were obtained, for the said formulation was had a reference mixture and two mixtures with the addition of the additive that would expand the rubber to achieve the criterion of lightness. After obtaining the sole prototypes, their performance in flexion and abrasion tests was evaluated and the change in their hardness and density was determined, the results obtained are presented in Table 3.

* In volumetric loss due to abrasion, it is considered that the material has a high resistance to abrasion when the losses are lower.

** The sole flexion was performed up to 30000 cycles, the reported value corresponds to the percentage increase in the incision that the specimen presents after reaching the maximum cycle.

As for the capellada, this has a design that is characteristic of the commercial company, with a space free of material in the instep, because in this area the greater flexion of the foot occurs during the march and thus this type of movement is facilitated. The buttress of the ankle is used double, to protect this area and the sole of the foot of external objects and also grant stability in irregular terrain. The cushioning of the ankle is also achieved with a neck formed by a foam of around 2 cm. (See Figure 5).

Conclusions

The height of the heel was a factor that directly influenced the level of pain in the feet of the professional women surveyed, at the end of their working day, with the high heel being more influential in the increase in the level of pain than the low heel.

The need to develop a type of casual shoe for the current woman was validated, due to the influence of the design characteristics of the shoe, as well as the relationship between the long journeys that the women surveyed must make during their working day and the pain or fatigue that this causes them.

A sole in expanded rubber was developed, complying with criteria of lightness and comfort, in addition to the characteristics required by a commercial company. Its mechanical performance was evaluated finding minimal differences, compared to a traditional rubber sole.

As future work, it is proposed to evaluate both new rubber formulations used for casual footwear and rubber processing methods with expandable microspheres. On the

other hand, the biomechanical responses associated with the use of the sole should be analyzed.

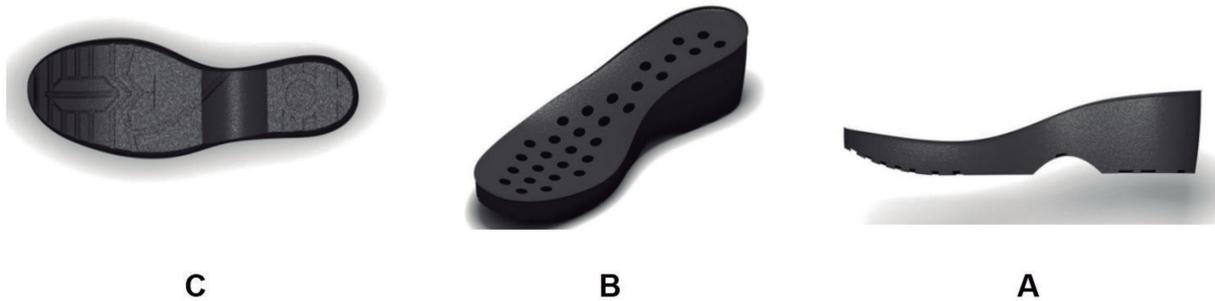


Figure 4. Sole design. A) Left side view. B) Rear side view. C) Bottom view
Source: commercial company.

Table 3. Results of prototype testing of the sole.

MATERIAL / TEST	Density (g/cm ³)	Hardness (Shore A)	Volumetric loss due to abrasion (mm ³) *	Flexing at 30000 cycles (%) **
Reference mix	1.14 ± 0.02	62 ± 1	140.81 ± 5.70	11.50 ± 3.04
mix with 3 phr of additive	0.86 ± 0.01	57 ± 1	320.67 ± 16.91	6.87 ± 6.93
mix with 10 phr of additive	0.67 ± 0.02	42 ± 0	242.57 ± 27.55	12.90 ± 4.85



Figure 5. Design of the female casual shoe
 Aesthetic and ergonomic
Source: Commercial enterprise

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