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ORIGINAL

FOOT INJURIES IN SPORT CLIMBERS: FOOTWEAR AND OTHER ASSOCIATED FACTORS

ALTERACIONES PODOLÓGICAS EN LA ESCALADA: PIES DE GATO Y OTROS FACTORES ASOCIADOS

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ABSTRACT

Introduction: Foot injuries are frequent among climbers. This may be due to several factors, such as the use of climbing shoes. **Objectives:** To perform a descriptive analysis of foot injuries in sport climbers and to examine their possible relationship with various factors, including the use of climbing shoes. **Methods:** 26 climbers participated in the study. General characteristics, foot pain during climbing, observed podiatric conditions and the reductions in the size (cm) of climbing shoes compared to daily footwear were noted. **Results:** All climbers presented foot injuries and most had foot pain. In addition, hallux valgus, grazes, and hyperkeratosis were related to the small size of climbing

shoes. **Conclusions:** Foot disorders and foot pain are very frequent in sport climbing. Furthermore, along with other associated factors, the size of the reduction of climbing shoes increases the probability of developing various podiatric conditions.

KEY WORDS: climbing, foot injuries, foot deformities, foot pain, prevention, footwear

RESUMEN

Introducción: Los escaladores presentan alteraciones podológicas frecuentemente. Esto puede deberse a distintos factores, incluido el uso de los pies de gato. **Objetivos:** Realizar un análisis descriptivo de las afecciones podológicas en la escalada y analizar su posible relación con varios factores, incluidos los pies de gato. **Métodos:** 26 escaladores participaron en el estudio. Se anotaron sus características generales, el dolor de pies sufrido al escalar, las alteraciones podológicas presentes y la reducción del tamaño de los pies de gato respecto al calzado habitual. **Resultados**: Todos los escaladores padecían alteraciones podológicas y la gran mayoría escalaba con dolor. Asimismo, el hallux valgus, las rozaduras y la hiperqueratosis se relacionaron con el tamaño reducido de los pies de gato. **Conclusiones:** Las alteraciones y el dolor de pies son muy habituales en escaladores, siendo varias las alteraciones propiciadas por la magnitud de la reducción de los pies de gato, entre otros factores asociados.

PALABRAS CLAVE: escalada, pie, lesión, alteración, dolor, prevención, calzado

1 INTRODUCTION

Climbing is an athletic activity where the climber goes up steep walls or crosses them, either outdoors (in rock) or indoors (in a climbing wall). Sport climbing firstly originated from mountain climbing, and it was not until the late ‘80s and early ‘90s that it was established as a sport itself (Buzzacott, Schöffl, Chimiak and Schöffl, 2019). Ever since, its popularity has increased in such a way that the International Federation of Sport Climbing (IFSC) estimates that, in 2019, there were 44.5 million climbers worldwide (International Federation of Sport Climbing, 2019). Moreover, after the inclusion of this modality in the Tokyo 2020 Olympic Games, it is expected that this increase will continue.

Due to this rise in popularity, the number of untrained beginners who start to climb without the supervision of a professional and lacking the basic physical abilities has increased in recent years (Morenas, Luis and Ramos, 2021; Núñez, Ramírez, Lancho, Poblador and Lancho, 2018; Schöffl and Lutter, 2017). In addition, trend in climbing route setting is changing and more and more difficult routes are being designed, making the climber perform more complex and demanding movements (Lutter, El-Sheikh, Schöffl and Schöffl, 2016). In this way, it is probable that, in coming years, the number of injuries will

increase (Schöffl and Lutter, 2017) and a change in injury pattern will occur (Lutter, et al., 2020) in sport climbing.

The vast majority of epidemiological studies published lately state that the most frequent climbing injuries are those affecting the upper extremities (Asakawa and Sakamoto, 2019; Cole, Uhl and Rosenbaum, 2020; Grønhaug, 2018; Lum and Park, 2019; Lutter, Hotfiel, Tischer, Lenz and Schöffl, 2019; Lutter, et al., 2020; McDonald, Henrie, Teramoto, Medina and Willick, 2017; Schöffl, Lutter, Woollings and Schöffl, 2018; Woollings, McKay, Kang, Meeuwisse and Emery, 2014). In addition, it is also noted that lower extremity injuries are mainly acute injuries caused by a trauma or a fall (Buzzacott, et al., 2019; Grønhaug, 2018; Lum and Park, 2019; McDonald, et al., 2017; Rauch, Wallner, Ströhle, Dal Cappello and Brodmann-Maeder, 2019; Rugg, et al., 2020; Schöffl, et al., 2018; Woolings, et al., 2014).

In this context, foot injuries have been barely studied in the field of sport climbing. Nevertheless, those researches that have exclusively examined the injury epidemiology of the climbers' foot indicate that injuries in this region are much more common than stated in generic studies (Killian, Nishimoto and Page, 1998; Schöffl and Winkelmann, 1999; Buda, Di Caprio, Bedetti, Mosca and Gianinni, 2013). Moreover, it has been seen that climbing footwear increases the risk of suffering foot pain, injuries and deformities (Killian, et al., 1998; McHenry, Arnold, Wang and Abboud, 2015; Peters, 2001; Schöffl and Küpper, 2013; van der Putten and Snijders, 2001), making clear the need of conducting more research work on this topic.

Climbing shoes are designed in such a way that they enable climbers to lean on tiny grips. For this matter, these shoes are usually smaller than daily footwear, forcing the foot into a supinated position along with a flexion of the toes (Killian, et al., 1998; Peters 2001; van der Putten and Sneijders, 2001). Another unique characteristic of this footwear is asymmetry: the lateral length is greater than the medial length, generating more pressure on the hallux (Buda, et al., 2013; van der Putten and Sneijders, 2001; Schöffl and Küpper, 2013). Likewise, in order to improve proprioception, climbing shoes are very light and have an exceptionally thin sole (Killian, et al., 1998; van der Putten and Sneijders, 2001). Furthermore, these shoes are rigid, being the foot the one that conforms to the footwear and not the other way around (Killian, et al., 1998). All the mentioned factors influence foot biomechanics and increase injury risk.

It is worth mentioning that most foot injuries are usually mild, and normally enable the athletes to continue with their training. In an investigation conducted among elite athletes, only 21% of all ankle and foot injuries were time-loss injuries (Hunt, et al., 2016). In spite of it, the issue of foot injuries should not be underestimated, because these lesions may have detrimental effects in the long term, such as a diminished functionality (González-Martín, et al., 2017) and a worse quality of life (López-López, et al., 2018).

Given all the above, the objectives of these study are (1) to conduct a descriptive analysis of foot injuries in sport climbers and (2) to analyse their

eventual relationship with several factors, among others, the use of climbing shoes.

2 MATERIALS AND METHODS

2.1 SAMPLE

After sending informative leaflets, participants were recruited from climbing teams and bouldering gyms nearby the Faculty of Medicine and Nursing of University of the Basque Country (UPV/EHU) in Leioa (Biscay, Basque Country). The inclusion criteria were as follows: a) to be over 18 years old, b) to practice sport climbing actively at the time of the beginning of the study. All climbers interested in participating were included in the research. After being informed about the methods and objectives of the study, they all signed an informed consent. The project was approved by the University Ethics Committee of the University of the Basque Country (UPV/EHU) (M10_2016_210).

26 climbers, 7 women and 19 men, took part in the study. Their general characteristics are shown in Table 1. All of them came willingly to the Faculty of Medicine and Nursing of University of the Basque Country (UPV/EHU).

Table 1. General characteristics of the study participants

Characteristic	Value [mean (sd)]
Age (years)	30.58 (9.42)
Height (m)	1.71 (0.07)
Weight (kg)	65.85 (8.49)
BMI ($kg \cdot m^{-2}$)	22.37 (1.89)
Age at which they started climbing (years)	19.92 (6.01)
Years climbing	10.65 (8.35)
Hours/week climbing	11.60 (7.20)
Hours/week rock climbing	6.48 (6.38)
Hours/ week indoor climbing	5.12 (4.32)
Level of experience according to IRCRA	16.54 (2.37)

BMI = Body Mass Index; IRCRA = International Rock Climbing Research Association; sd = standard deviation

2.2 STUDY PROTOCOL

2.2.1 QUESTIONNAIRE

Participants answered a questionnaire about their age, age at which they had started climbing, number of years they had been climbing, weekly training hours indoors and outdoors, level of difficulty surpassed according to the French sport climbing grading system (at first glance and tried out), frequency of foot pain

while climbing (never, sometimes, always) and if they considered normal to feel foot pain while climbing.

The level of experience of the participants was determined using the IRCRA scale, as recommended by the International Rock Climbing Research Association (IRCRA) (Draper, et al. 2016). This scale was designed based on the French sport climbing grading system. Thus, the IRCRA scale assigns a number from 1 to 32 to each grade on the French grading system, where 1 is the easiest level and equivalent to grade 1 on the French system, 2 is equivalent to grade 2, 3 to 2+, 4 to 3-, and so on, until reaching level 32, equivalent to grade 9b+. The level surpassed at first glance was taken into account when determining the level of experience of the climber.

2.2.2 ANTHROPOMETRY

After filling out the form, height (m) and weight (kg) of the participants were measured according to the protocol set by the ISAK (International Society for the Advancement of Kinanthropometry) (Stewart, Marfell-Jones, Olds and de Ridder, 2011). Weighing was done using the Omron portable weighing machine (Spain) and height was measured by the portable height meter Añó Sayol (Barcelona, Spain).

2.2.3 VISUAL ANALOGUE SCALE (VAS)

Foot pain intensity while climbing was determined using the VAS scale. For this purpose, participants had to mark a point equivalent to the intensity of their pain on a 10 cm long line, where 0 corresponded to “no pain”, and 10 to “unbearable pain” (Gould, 2001).

2.2.4 DIGITAL FORMULA AND FOOT INJURY REGISTRATION

After the anthropometric measurements, a photo of the superior view of the feet of each participant was taken (Figure 1). On the one hand, the digital formula of each climber was identified and grouped into one of the following categories: Egyptian, Greek or Square foot (Buda, et al., 2013). On the other hand, two experienced podiatrists analysed the photographs and reached a consensus on the existing foot injuries.

Figure 1. Superior view of the feet and the comparison between daily footwear and climbing shoes

2.2.5 FOOTWEAR MEASUREMENTS

At the request of the research group, participants came to the laboratory wearing a pair of regularly used trainers. Thus, that was considered the daily footwear of the climber. The European size provided by the manufacturer of both, daily footwear and climbing shoes, was noted. Additionally, the outer and inner length and the distal width of both footwears were measured. The outer length and the distal width were measured using a Lufkin measuring tape (Germany) and the inner length was measured with a rigid measuring tape Flexómetro Medid Promo (Spain). Data was recorded in centimetres (cm).

2.3 VARIABLES

2.3.1 CLIMBING SHOES SIZE REDUCTIONS

The reduction is the difference between the size (cm) of climber's daily footwear and that of climbing shoes. The climbing shoe size reduction was calculated using the following formula

$$\text{Reduction (cm)} = \text{size of daily footwear (cm)} - \text{size of climbing shoes (cm)}$$

The percentage (%) of the above-mentioned reduction was estimated using the following formula:

$$\text{Reduction percentage (\%)} = 100 \cdot \left(1 - \frac{\text{size of climbing shoes (cm)}}{\text{size of daily footwear (cm)}}\right)$$

The reductions of the inner and outer lengths and the distal width of the climbing shoes compared to the daily footwear were calculated.

2.3.2 FOOT INJURIES

Musculoskeletal or dermal alterations observed in the photograph taken on the day of the measurements were registered.

2.4 STATYSTICAL ANALYSIS

Data was analysed using Microsoft Excel 2016 (Microsoft, Redmond, WA, USA) and the 4.0.1 version of R (R Core Team 2020, R Foundation for Statistical Computing, Viena, Austria). The distribution and the equality of variances of the quantitative variables were examined using the Shapiro-Wilk test and the Levene test, respectively. In order to examine the eventual effect of age on various variables, participants were grouped into three categories according to their age (<30 years old, 30-40 years old, <50 years old). Fischer test was used to compare qualitative variables, and Pearson's and Spearman's correlations were used to examine the correlation between parametric and non-parametric quantitative variables, respectively. Non-parametric quantitative variables were

analysed by the U Mann Whitney test. Lastly, the relation between the reduction of climbing shoes size and foot injuries was analysed by logistic regression. The significance level was set at $p<0.05$.

3 RESULTS

3.1. FOOT INJURIES

Thirteen different foot injuries were observed among participants (Table 2). The most frequent injuries were varus fifth toe (81% climbers), onychopathies (69%), grazes (65%), hallux valgus (54%), infraductus of the fifth toe (54%), pronated foot (54%) and hyperkeratosis (50%).

Table 2. Observed foot injuries

Foot injury	Number of climbers (%)
Varus fifth toe	21 (81)
Onychopathy	18 (69)
Grazes	17 (65)
Hallux Valgus	14 (54)
Infraductus of the fifth toe	14 (54)
Pronated foot	14 (54)
Hyperkeratosis	13 (50)
Blisters	6 (23)
Infraductus of the fourth toe	3 (12)
Varus fourth toe	3 (12)
Tailor's bunion	2 (8)
Varus second toe	1 (4)
Syndactyly	1 (4)

Every single climber suffered at least three different foot injuries (4.88 ± 1.48 injuries per climber) (Figure 2). However, only three of them had to stop climbing due to these injuries. Those climbers who had greater experience according to the IRCRA scale suffered more foot injuries ($p = 0.06$, $r_s = 0.38$).

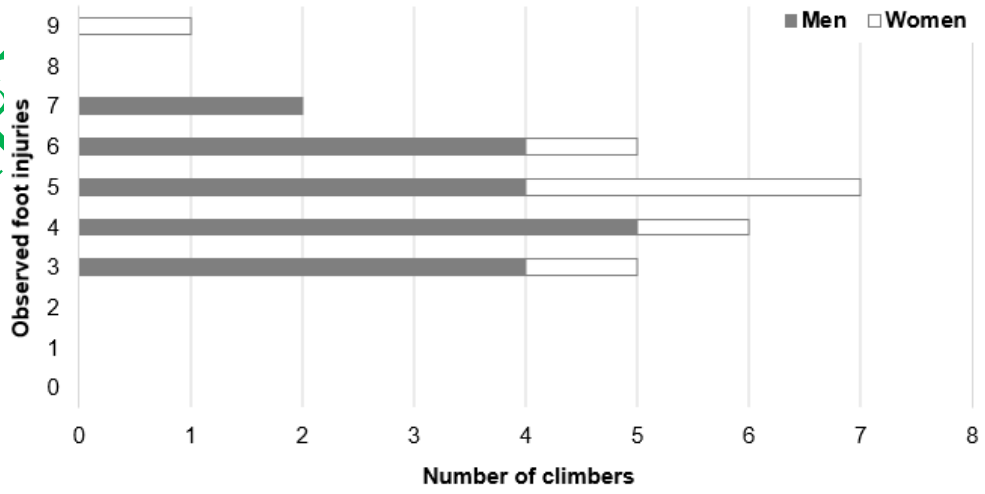

Figure 2. Number of foot injuries suffered per climber

3.2 CLIMBING SHOES SIZE REDUCTIONS

The values of climbing shoe size reductions are shown in Table 3. Climbing shoes were nearly two sizes smaller (1.84 ± 0.94) than daily footwear. Moreover, this difference was greater in men than in women (p= 0.02).

Table 3. Reductions of climbing shoes

Characteristic	Value [mean (sd)]
European size	1.84 (0.94)
Women	1.29 (0.76)*
Men	2.05 (0.95)
Inner length	
Mean reduction (cm)	3.75 (0.97)
Reduction percentage (%)	14.77 (3.41)
Outer length	
Mean reduction (cm)	5.68 (1.27)
Reduction percentage (%)	19.40 (3.58)
Distal width	
Mean reduction (cm)	1.53 (0.83)
Reduction percentage (%)	14.56 (7.65)

* Significant difference (p = 0.02) between men and women

sd = standard deviation

3.3 FOOT PAIN

Five climbers stated that their foot ached whenever they climbed, nineteen of them felt pain occasionally, and only two of them reported never experiencing foot pain while climbing. According to the VAS scale, the intensity of the pain suffered was of 6.72 ± 1.19, and it increased significantly the higher the level of experience according to the IRCRA scale (p = 0.04, r_s = 0.41).

3.4 AGE, LEVEL OF EXPERIENCE AND FOOT INJURIES

Infraductus of the fourth toe was more frequent in the youngest climbers (p = 0.04, r = -0.40). Those who had started climbing at an earlier age were more prone to have a varus fifth toe (p = 0.05, r = -0.38). Finally, tailor's bunion (p = 0.07, r = -0.36) and varus fourth toe were more frequent in those who had been climbing for less years (p = 0.09, r = -0.33).

3.5 DIGITAL FORMULA

Grazes were more frequent in climbers who had either a Greek or Square foot compared to those with an Egyptian foot (p = 0.02).

3.6 REDUCTIONS AND FOOT INJURIES

The relationship between climbing shoes size reduction (cm) and foot injuries is shown in Table 4. Although not all the results reached statistical significance, it was observed a trend toward suffering more hyperkeratosis in those climbers who used climbing shoes with greater external length reduction (p = 0.07). In addition, the greater the reduction of the inner length and its percentage, more grazes were observed (p = 0.03 and p = 0.08, respectively). Furthermore, it was also observed a positive correlation between grazes and the reduction of the outer length and its percentage (p = 0.06 and p = 0.04, respectively). Hallux valgus was related to a greater reduction of the distal width and its percentage (p = 0.08 and p = 0.06, respectively).

Table 4. Relationship between foot injuries and climbing shoes size reduction

	Odds Ratio (CI 95 %)	p
Hyperkeratosis		
Reduction percentage of the outer length (%)	1.28 (1.00-1.78)	0.07
Grazes		
Mean reduction of the inner length (cm)	4.32 (1.37-21.80)	0.03
Reduction percentage of the inner length (%)	1.28 (0.99-1.78)	0.08
Mean reduction of the outer length (cm)	2.18 (1.05-5.51)	0.06
Reduction percentage of the outer length (%)	1.36 (1.04-1.96)	0.04
Hallux Valgus		
Mean reduction of the distal width (cm)	2.82 (0.96-10.21)	0.08
Reduction percentage of the distal width (%)	1.13 (1.00-1.30)	0.06

CI = Confidence Interval

4 DISCUSSION

The aim of this study was to carry out a descriptive analysis of foot injuries suffered by sport climbers and to examine the relationship between these injuries and various associated factors, including the reductions in the size (cm) of climbing shoes compared to daily footwear. All climbers suffered at least three different foot injuries, and more than 90% of participants felt foot pain while climbing. Specifically, the most experienced climbers were more prone to suffer both, foot injuries and pain. Moreover, a relation between various reductions and grazes, hyperkeratosis and the hallux valgus was observed.

Every single climber suffered at least three different foot injuries. In another investigation that was conducted among climbers and specifically analysed the epidemiology of foot injuries, Buda et al. (2013) stated that 86% of the population studied suffered at least one lesion in this region. In contrast, generic epidemiological researches performed in this field, which examine various body regions, establish a much lower proportion of foot injuries, ranging between 3.8% (McDonald, et al., 2017) and 9.1% (Buzzacott, et al., 2019). Probably, in those studies aiming to conduct a specific analysis of the foot, a more precise podiatric examination is carried out, thus obtaining a higher number of injuries in this region.

The most frequent injuries in the studied population were structural lesions of the fifth toe and hallux valgus, pronated foot, onychopathies, grazes and hyperkeratosis. These results reinforce what stated in previous studies, since hallux valgus (Killian, et al., 1998; Schöffl and Winkelmann, 1999; McHenry, et al., 2015), onychopathies (Killian, et al., 1998; Buda, et al., 2013; McHenry, et al., 2015) and pressure related dermal alterations (Schöffl and Winkelmann, 1999; McHenry, et al., 2015) are highlighted as some of the most common foot injuries in the field of sport climbing.

Besides, our results demonstrate that structural lesions are very prevalent among sport climbers. Precisely, hallux valgus was present in 54% of the participants, a figure well above from the 35.7% estimated for the general population aged 18-65 years (Nix, Smith and Vicenzino, 2010). Furthermore, Golightly, Hannan, Dugour, Hillstrom and Jordan (2014) found that 14% of adults aged over 45 years had a pronated foot. Although methodological differences between both studies makes difficult the direct comparison of them, that number is far away from the 50% observed in our study. The infraductus and varus fifth toe were also very common, their prevalence being 81% and 54%, respectively. In this case, as far as we know, there is no data published for the general population, but the fact that these injuries are present in more than half of the climbers demonstrates their relevance in sport climbing.

Bearing in mind that the studied population is relatively young (30.58 ± 9.42 years), and that the prevalence of some of the observed lesions increases with age (Nix, et al., 2010; Menz, 2014), data presented above is alarming. Actually, although foot injuries normally do not limit sport activity (Hunt, et al., 2016), in the long term they may have detrimental effects in many aspects. For example, hallux valgus disturbs normal gait pattern (Shih, Chien, Lu, Chang, and Kuo, 2014; Buddhadev and Barbee, 2020), increases fall risk (Menz et al., 2018) and diminishes both functionality and quality of life (López-López et al., 2018). Finally, pronated foot has been associated with low back pain (O'Leary, Cahill, Robinson, Barnes, and Hong, 2013) and knee osteoarthitis (Almeheyawi, Bricca, Riskowski, Barn, and Steultjens, 2021), two chronic conditions that limit both functionality and quality of life.

Another factor to highlight is that our results suggest that those who start climbing at a younger age have a higher risk of suffering structural injuries. Thus, climbers who had started climbing at younger ages suffered varus fifth foot more frequently. Infraductus of the fourth toe was more commonly diagnosed among the youngest climbers, who were, in fact, those who had started climbing at an earlier age ($p = 0.04$, $r_s = 0.40$). In addition, tailor's bunion and varus fourth toe were more frequent among climbers who had been climbing for fewer years, precisely, those in the youngest age group ($p= 9.141e-07$, $r_s = 0.80$). Taking into account that joint laxity decreases with age (Singh, et al. 2017), this places those who start to use climbing shoes at an early age at a higher risk of developing foot deformities.

All the above mentioned demonstrates the importance of educating climbers who start climbing at an early age to prevent the use of small climbing shoes for a long time. Furthermore, the correct assessment and treatment of foot injuries

that a climber may suffer is of utmost importance, not only to prevent possible injuries during the sports career, but also to maintain a good foot health and avoid eventual detrimental effect in the long term.

Focusing on foot pain, 92.3% of the participants climbed, at least occasionally, with pain. This data is in line with previously published studies, where the percentage of climbers who felt pain while climbing ranged between 81% and 91.07% (Killian, et al., 1998; Schöffl y Winkelmann, 1999; McHenry, et al., 2015). Moreover, climbing with foot pain was considered normal by all participants. This data shows that foot pain is completely normalized among sport climbers.

The intensity of perceived pain was directly proportional to training hours performed each week ($p = 0.06$, $r_s = 0.38$), which may be a consequence of the prolonged use of climbing shoes. This trend was evident in the most experienced climbers, who trained more outdoors (where holds are not only of lower quality, but also smaller) ($p = 0.008$, $r_s = 0.51$) and climbed more hours per week ($p = 0.016$, $r_s = 0.47$). In agreement with the previously published studies these climbers suffered more foot injuries and pain (Killian, et al., 1998; van der Putten and Sneijders, 2001; Buda, et al., 2013; Woolings, McKay and Emery, 2015).

In a similar way, it is still widely believed that the smaller the climber shoes, the better the performance. Consequently, climbers assume that foot pain is an inevitable part of sport climbing. However, as far as we are concerned, there are no investigations that examine the influence of the magnitude of the reduction of climbing shoes on climbers' performance, so it would be of great interest to conduct research on this topic.

On the other hand, our data indicate that both, digital formula and the reduced size (cm) of climbing shoes, are related to the development of certain foot injuries. Foot shape itself makes the contact area between the foot and the shoes to be greater in those with a Square or Greek foot. In the same way, the larger the reduction of the footwear the more pressure the skin receives, thus facilitating the development of grazes and hyperkeratosis. Accordingly, the fact that hallux valgus was more frequent on those using climbing shoes with a narrower distal width supports the hypothesis that wearing footwear with a narrow toe cap is a risk factor for developing this deformity (Menz, et al., 2016).

This study is not without limitations. On the one hand, podiatrists could not examine participants *in situ,* and feet were only examined through an upper view photograph. Taking into account that certain foot characteristics and injuries are better observed through the lateral, medial or posterior view, it is possible that some existing injuries could not be identified. However, in the vast majority of epidemiological analyses conducted in this field auto referred questionnaires have been used to fulfill injury registration. Therefore, the fact that two podiatrists examined our participants can also be considered a positive point. Anyway, it is advised that in future work a photo of the lateral, medial and posterior view is also taken, or, if possible, an *in situ* examination conducted.

Another weakness of the study is the small sample size, making it difficult to draw conclusions for the general climbing population. Lastly, injuries have a multifactorial aetiology, thus, many factors that have not been controlled in this study may also influence the development of foot injuries. Furthermore, due to the cross-sectional nature of the research a cause-effect relationship cannot be established between the studied factors. For all the above mentioned, obtained results must be interpreted with caution.

5 CONCLUSIONS

Altogether, foot injuries and pain are very prevalent among sport climbers, being the prolonged use of climbing shoes one of the factors that eases the development of foot injuries. Some of these, such as dermal lesions, are temporary, but structural injuries that might affect quality of life may also result. Therefore, educating climbers and promoting preventive measures from an early age is of utmost importance.

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