Original paper

# The influence of climbing shoes on the morphological structure of the foot and the occurrence of ailments and deformities

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Medical Studies
DOI: https://doi.org/10.5114/ms/209769

**Key words:** feet, morphological structure, pain, sport climbing.

**Abstract**

**Introduction:** Climbing shoes are characterised by a specific structure. Their use can lead to dysfunction within the foot.
**Aim of the research:** The aim of the study was to assess the frequency of pain and the effect of climbing shoes on the morphological structure of the foot.
**Material and methods:** The study included 98 subjects in the age range 20 to 50 years. The study group consisted of 17 women and 26 men climbing for a minimum of one year with climbing shoes, and the control group consisted of 17 women and 38 men. Podoscan 2D FootCAD was used to assess the shape of the soles of the feet. Information was collected on climbing training, pain complaints, and injuries in the foot. The length of footwear worn every day was compared with that of climbing shoes. Data analysis was performed with Statistica 13.0 PL.
**Results:** In 86% of climbers, the use of climbing shoes was associated with experiencing pain. The studied groups of men and women did not differ significantly in the values of $\alpha$, $\beta$, and $\gamma$ angles and Wejsflog index. Clarke's angle values in both men and women were significantly higher in the climbing groups. The difference between the length of climbing shoes and athletic shoes worn daily averaged 3.5 cm.
**Conclusions:** Pain complaints were common in the climbing training group. The effect of climbing shoes on the alignment of the toe, little toe, and transverse articulation was not demonstrated. Sport climbers are characterised by increased longitudinal arches of the foot.

## Introduction

Climbing is a sport discipline that enjoys great popularity. The literature on injuries, contusions, and overload syndromes occurring in people practicing climbing focuses primarily on the upper limbs; there are far fewer reports on changes and threats within the lower limbs. However, injuries in the lower limbs are not rare, and most often they affect the foot and ankle and are caused by a blow or fall [1–3]. A separate problem in this area are deformations and overload syndromes. Available studies confirm that foot pain is common among climbers – the vast majority of athletes complain about it [4, 5]. During the climbing itself, pain occurs in up to 90% of people [6]. Most people unequivocally associate them with the use of specialised climbing shoes. Climbing shoes usually have a downward-curved toe that allows for better contact with any bends, small steps, and holes. They are also equipped with a specially profiled heel, thanks to which the climber gains the ability to hook on rock elements or protruding structures, for example on an artificial climbing wall. The asymmetrical structure of the shoe forces the foot to take a specific shape, with a high arch, with forefoot adduction and weight concentrated on the toes and forefoot [7, 8]. In addition, to achieve even better foot profiling and the possibility of using small steps, there is a common tendency among climbers, especially those with long experience, to choose footwear with significantly lower numbering [6, 9]. This significantly limits the extension of the toes. Studies confirm the limitation of the range of motion in the first metatarsophalangeal joint in people training climbing [10]. In the literature, you can find several studies indicating the influence of a specific type of footwear and the selection of the correct size on the occurrence of foot deformities [11]. It has been shown, among other things, that wearing shoes with a tapered toe has an impact on the incidence of both pain and hallux valgus [12, 13]. The above ailments and deformities are also associated with wearing undersized shoes [14].

People who train climbing usually choose the tightest footwear possible, but on the other hand, the time of using the shoes is often short and limited only to the duration of climbing itself. Available publications indicate a relationship between climbing shoes and the occurrence of corns and skin problems

in the feet, and they suggest an effect on hallux valgus [5]. However, the number of available studies assessing the incidence of foot deformities and pathologies in climbers is relatively small, and there is a need for a thorough analysis of the problem.

## Aim of the research

The aim of the study was to assess the incidence of pain and foot deformities in people practicing the sport of climbing and the effect of footwear on the morphological structure of the foot.

## Material and methods

The research was conducted among adult members of local climbing groups. The criterion for inclusion in the study group was considered to be a minimum of one year of regular climbing with the use of climbing shoes. The control group consisted of people who did not and currently do not climb. Gout, uncontrolled diabetes mellitus, and rheumatoid arthritis were considered disqualifying criteria. All people agreed to participate in the study, and the research was carried out in accordance with the assumptions of the Declaration of Helsinki. A total of 107 people aged 20–50 years were examined. After taking into account the exclusion criteria, the results of 98 people were finally analysed. The study group consisted of 43 people (17 women, 26 men), while the control group consisted of 55 people (17 women, 38 men).

All patients gave information on gender, age, height and weight, and the size of footwear used on a daily basis, and the shape of the plantar part of the feet was assessed using a Podoscan 2D FootCAD device. The photos were taken in a secluded room, for rested people; in the group of climbers this took place before the start of training. Using the FreeStep program, the angles of $\alpha$, $\beta$, and $\gamma$ and Clarke were determined, and the Wejsflog index was calculated based on the data obtained during the study. The norm for the $\alpha$ angle is in the range of 0–9°, for the $\beta$ angle – 0–5°, and for the $\gamma$ angle in the range between 15° and 18°. In the case of the Clarke angle, the results between 42° and 54° indicated the correct shape of the longitudinal arch, and the value of the Wejsfog index above 2.55 indicated the correct transverse arch [15, 16]. Photos taken on the Podoscan platform allowed for accurate measurement of the length of the participants' feet and determination of the actual size of shoes according to European numbering.

The length of footwear used on a daily basis and the length of climbing shoes were also subjected to a comparative analysis. The measurements were made with a tape measure on the soles of both types of footwear. An original survey was also carried out in the study group, concerning the length of climbing experience of the respondents, the time they devoted to climbing training, the use of climbing shoes, and pain.

### Statistical analysis

All the collected information was analysed using the Statistica 13.0 PL tool. Basic descriptive statistics were calculated. The distribution of variables was assessed using the Shapiro-Wolf test. Intergroup differences, depending on the normality of the distribution, were determined using Student's *t*-test and the Mann-Whitney *U* test. Percentages were used to analyse the data from the responses to the questionnaire questions, and the Spearman rank correlation coefficient was also determined.

## Results

The men's group consisted of 26 climbers and 38 non-climbers. The study groups differed significantly in terms of age. Men in the control group were on average 0.6 cm taller than men in the study group, and they were also characterised by higher body weight, by an average of 3.6 kg. However, these differences, as well as the differences between the BMI calculated on the basis of the above parameters, were not significant. The average size of shoes worn on a daily basis was similar in both groups and differed by 0.43. The difference between a sports shoe worn by a group of climbers on a daily basis and a climbing shoe was on average 3.6 cm (Table 1).

The women's group consisted of 34 people, 17 non-training and training people each. The study groups were homogeneous in terms of age, size of shoes worn on a daily basis, as well as body weight and height. Women who trained in climbing were on average 2.64 cm taller and had a lower body weight by 1.41 kg, but the BMI calculated on the basis of these data also did not significantly differentiate the two groups. The difference between the length of climbing shoes and sports shoes worn on a daily basis ranged from 1.5 to 5 cm and averaged 3.5 cm (Table 2).

The mean values of the $\alpha$ angle showed a difference between the two groups of men of 0.21° in the right foot and 0.88° in the left foot. In women, the difference in the right foot was 2.65° and in the left foot was 1.7°. The values for all angles were higher in the training groups, but the differences were not significant. The $\beta$ angle, in the observed climbing men was 17.9° in the right limb and 18.4° in the left. In non-training men, it was 0.76° and 0.36° greater, respectively. In the women's groups, the same parameter differed in the right feet by an average of 0.71° and by 1.83° in the left feet. For both women and men, the differences turned out to be statistically insignificant. Also, no significant changes were observed in the mean values of the $\gamma$ angle, otherwise known as the calcaneus angle. The differences in the mean of this angle

**Table 1.** Basic demographic and anthropometric data of the surveyed men

| Variable | Group | *N* | $\bar{x}$ | Med | Min | Max | SD | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Age [years] | Climbing group | 26 | 35.00 | 32.50 | 20.00 | 50.00 | 10.50 | 0.00* |
| | Control group | 38 | 25.74 | 22.00 | 20.00 | 50.00 | 8.56 | |
| Body height [cm] | Climbing group | 26 | 178.54 | 178.00 | 166.00 | 89.00 | 6.29 | 0.73 |
| | Control group | 38 | 179.13 | 179.00 | 163.00 | 197.00 | 6.78 | |
| Weight [kg] | Climbing group | 26 | 73.08 | 70.50 | 57.00 | 92.00 | 8.49 | 0.18 |
| | Control group | 38 | 76.68 | 76.50 | 53.00 | 100.00 | 11.48 | |
| BMI [kg/m$^2$] | Climbing group | 26 | 22.89 | 22.62 | 19.66 | 28.41 | 2.02 | 0.15 |
| | Control group | 38 | 23.84 | 23.61 | 16.18 | 30.96 | 2.85 | |
| Shoe size | Climbing group | 26 | 42.23 | 42.00 | 39.00 | 45.00 | 1.50 | 0.41 |
| | Control group | 38 | 42.63 | 42.75 | 37.50 | 48.50 | 2.00 | |
| Length of sports shoes [cm] | Climbing group | 26 | 29.15 | 29.00 | 27.00 | 33.00 | 1.50 | |
| Length of climbing shoes [cm] | Climbing group | 26 | 25.54 | 26.00 | 21.00 | 28.00 | 1.65 | |
| Sport and climbing shoes: difference in length [cm] | Climbing group | 26 | 3.62 | 3.50 | 2.00 | 6.00 | 1.13 | |

**Statistically significant differences.*

**Table 2.** Basic demographic and anthropometric data of the surveyed women

| Variable | Group | *N* | $\bar{x}$ | Med | Min | Max | SD | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Age [years] | Climbing group | 17 | 27.18 | 25.00 | 20.00 | 48.00 | 7.82 | 0.68 |
| | Control group | 17 | 28.06 | 24.00 | 20.00 | 49.00 | 9.80 | |
| Body height [cm] | Climbing group | 17 | 168.76 | 169.00 | 163.00 | 176.00 | 3.82 | 0.06 |
| | Control group | 17 | 166.12 | 165.00 | 158.00 | 174.00 | 4.08 | |
| Weight [kg] | Climbing group | 17 | 57.53 | 58.00 | 47.00 | 71.00 | 6.12 | 0.60 |
| | Control group | 17 | 58.94 | 57.00 | 46.00 | 80.00 | 9.03 | |
| BMI [kg/m$^2$] | Climbing group | 17 | 20.21 | 20.20 | 16.04 | 24.57 | 2.11 | 0.23 |
| | Control group | 17 | 21.38 | 21.14 | 16,90 | 29.24 | 3.35 | |
| Shoe size | Climbing group | 17 | 38.82 | 39.00 | 36.00 | 41.00 | 1.38 | 0.40 |
| | Control group | 17 | 38.29 | 38.00 | 37.00 | 41.00 | 1.10 | |
| Length of sports shoes [cm] | Climbing group | 17 | 26.79 | 27.00 | 25.00 | 28.00 | 0.79 | |
| Length of climbing shoes [cm] | Climbing group | 17 | 23.53 | 23.00 | 22.00 | 25.50 | 0.94 | |
| Sport and climbing shoes: difference in length [cm] | Climbing group | 17 | 3.26 | 3.50 | 1.50 | 5.00 | 1.00 | |

**Statistically significant differences.*

in individual groups ranged between 0.06° and 0.24°. In the group of male climbers, the Wejsflog index in both feet was on average 2.61, and in women it was 2.64. The results obtained in the control group differed slightly, but none of the differences were statistically significant. Clarke angle values in both men and women in both feet were significantly higher in the climbing groups. The differences in the male group were 5.7° in the right foot and 8.9° in the left foot. In women, the difference between the climbing group and the control group was 6.8° in the right and 8.0° in the left foot (Table 3).

Almost 2/3 of the training women were characterised by correct positioning of the big toe in both feet, while in the group of non-training women, the correct position of the big toe was noted in 15 patients (88.23%) in the right foot and in 12 in the left foot (70.5%). In both groups of men, the correct positioning of the big toe was recorded with almost the same frequency in both feet (training/non-training men,

**Table 3.** Shape of the plantar part of the feet of the examined women and men [°]

| Sex | Indicator | Group | $\bar{x}$ | Me | Min. | Max. | SD | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Men | Right α angle | Climbing group | 5.00 | 4.50 | 0.00 | 17.00 | 4.60 | 0.94 |
| | | Control group | 4.79 | 4.00 | 0.00 | 16.00 | 4.28 | |
| | Left α angle | Climbing group | 5.27 | 4.00 | 0.00 | 26.00 | 5.66 | 0.93 |
| | | Control group | 4.39 | 4.00 | 0.00 | 12.00 | 3.41 | |
| Women | Right α angle | Climbing group | 7.59 | 7.00 | 1.00 | 17.00 | 5.03 | 0.10 |
| | | Control group | 4.94 | 4.00 | 0.00 | 16.00 | 4.37 | |
| | Left α angle | Climbing group | 7.88 | 8.00 | 0.00 | 20.00 | 5.54 | 0.35 |
| | | Control group | 6.18 | 6.00 | 0.00 | 14.00 | 4.86 | |
| Men | Right β angle | Climbing group | 17.92 | 18.00 | 3.00 | 28.00 | 6.11 | 0.59 |
| | | Control group | 18.68 | 18.50 | 8.00 | 28.00 | 5.06 | |
| | Left β angle | Climbing group | 18.38 | 19.00 | 9.00 | 28.00 | 5.15 | 0.77 |
| | | Control group | 18.74 | 19.00 | 10.00 | 29.00 | 4.35 | |
| Women | Right β angle | Climbing group | 14.00 | 15.00 | 0.00 | 22.00 | 5.69 | 0.71 |
| | | Control group | 13.29 | 14.00 | 0.00 | 22.00 | 5.45 | |
| | Left β angle | Climbing group | 16.18 | 16.00 | 4.00 | 21.00 | 4.20 | 0.77 |
| | | Control group | 14.35 | 15.00 | 0.00 | 25.00 | 5.97 | |
| Men | Right γ angle | Climbing group | 13.88 | 14.00 | 12.00 | 17.00 | 1.40 | 0.86 |
| | | Control group | 13.82 | 14.00 | 10.00 | 17.00 | 1.57 | |
| | Left γ angle | Climbing group | 14.00 | 14.00 | 10.00 | 18.00 | 1.79 | 0.57 |
| | | Control group | 14.24 | 14.00 | 11.00 | 18.00 | 1.50 | |
| Women | Right γ angle | Climbing group | 13.88 | 14.00 | 12.00 | 16.00 | 1.17 | 0.88 |
| | | Control group | 13.94 | 14.00 | 12.00 | 16.00 | 1.03 | |
| | Left γ angle | Climbing group | 13.76 | 14.00 | 12.00 | 16.00 | 1.15 | 0.68 |
| | | Control group | 13.94 | 14.00 | 12.00 | 16.00 | 1.30 | |
| Men | Wejsflog index right | Climbing group | 2.61 | 2.63 | 2.43 | 2.79 | 0.10 | 0.85 |
| | | Control group | 2.62 | 2.63 | 2.40 | 2.76 | 0.10 | |
| | Wejsflog index left | Climbing group | 2.61 | 2.61 | 2.42 | 2.83 | 0.10 | 0.81 |
| | | Control group | 2.60 | 2.61 | 2.38 | 2.75 | 0.09 | |
| Women | Wejsflog index right | Climbing group | 2.64 | 2.65 | 2.48 | 2.81 | 0.09 | 0.36 |
| | | Control group | 2.61 | 2.62 | 2.41 | 2.75 | 0.08 | |
| | Wejsflog index left | Climbing group | 2.64 | 2.64 | 2.52 | 2.78 | 0.07 | 0.50 |
| | | Control group | 2.62 | 2.64 | 2.42 | 2.79 | 0.11 | |
| Men | Right Clarke angle | Climbing group | 58.62 | 59.00 | 40.00 | 73.00 | 10.46 | 0.03* |
| | | Control group | 52,87 | 54,00 | 32,00 | 71,00 | 9,45 | |
| | Left Clarke angle | Climbing group | 63,27 | 62,50 | 44,00 | 83,00 | 10,69 | 0.00* |
| | | Control group | 54,39 | 54,00 | 35,00 | 79,00 | 10,19 | |
| Women | Right Clarke angle | Climbing group | 60,41 | 60,00 | 44,00 | 85,00 | 11,34 | 0.02* |
| | | Control group | 53,59 | 53,00 | 22,00 | 73,00 | 13,70 | |
| | Left Clarke angle | Climbing group | 62.76 | 63.00 | 46.00 | 85.00 | 10.52 | 0.00* |
| | | Control group | 54.82 | 52.00 | 26.00 | 74.00 | 12.79 | |

**Statistically significant differences.*

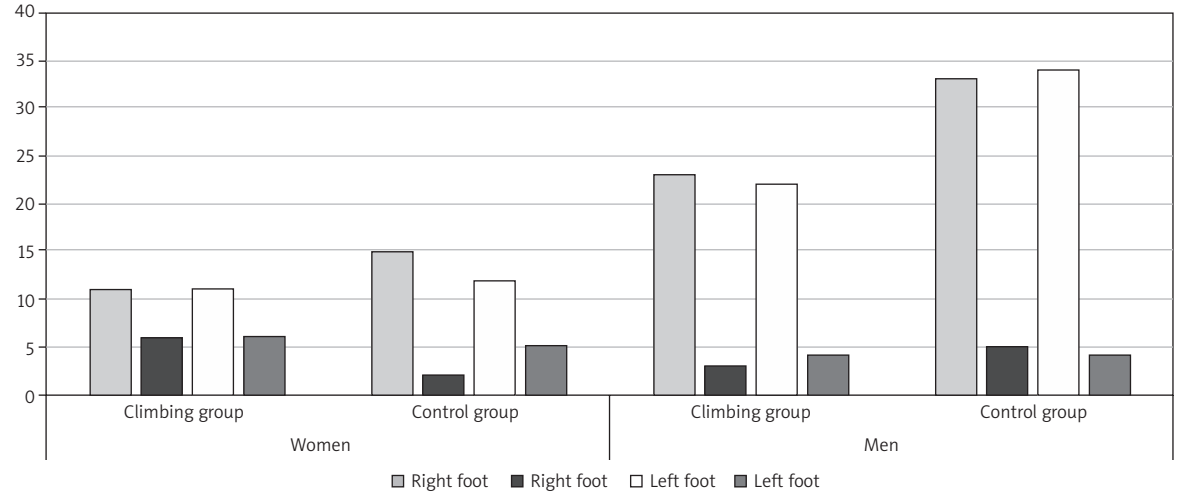


**Figure 1.** Position of the first toe in a group of men and women training and not training climbing – qualitative data (*n*)

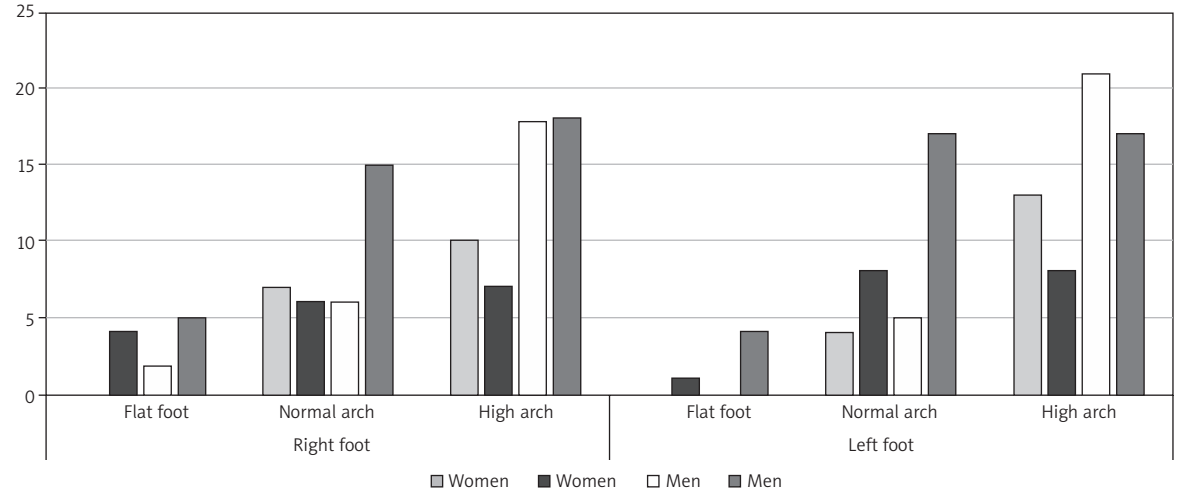


**Figure 2.** Longitudinal arches in a group of men and women with and without climbing training – qualitative data (*n*)

respectively: right foot 88.46%/86.84%; left foot 84.61%/89.47%) (Figure 1).

Correct shape of the transverse arch was noted in 15 examined women in both groups in the right foot and in 13 women who did not train in the left foot (Figure 2).

In just over 3/4 of the surveyed women from the group who trained in climbing, a high arch was observed in the left foot, and in the group of non-training women in 47%. In the right foot, 58.82% of the training women and 41.17% of the non-training women had a high arch. In almost half of the men in both groups, a high arch was recorded in the right foot (47.36%), while in the left foot a high arch was recorded in 80.76% of the subjects and in 44.73% of the subjects from the control group (Figure 3).

In total, 88% of the survey participants declared that they wear shoes only when climbing. The rest admitted that they sometimes forget to take off their shoes after climbing and spend most of their time in them during training. The majority of respondents (67%) declared that when buying shoes they try to choose shoes that fit the foot as tightly as possible. Only 19% of participants indicated the purchase of comfortable shoes, and the answer indicating the purchase of the tightest possible shoes was indicated by 14% of respondents. Almost half of the climbers surveyed (42%) also agreed that shoes should not be comfortable for the wearer. The vast majority of people (86%) also admitted that they feel pain in their feet when using climbing shoes. The dominant place of the ailment was the fingers (61% of respondents). Pain in the heel, metatarsal, or the entire foot was occasionally reported. Only 6 people did not suffer from wearing climbing shoes. Pain most often occurred only during the use of climbing shoes (64%), much less often during the entire training and immediately after it (13% of responses). No one reported constant

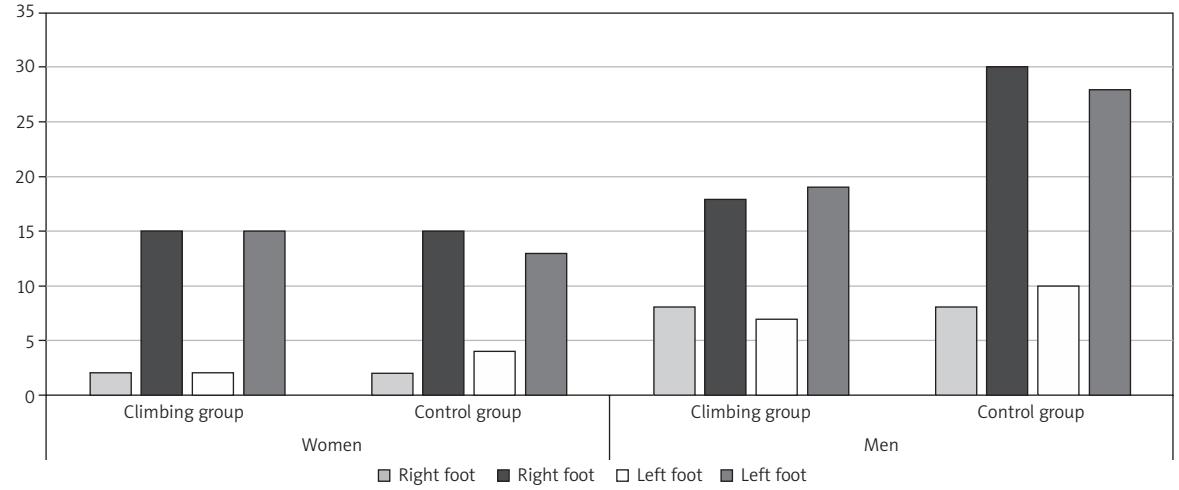


**Figure 3.** Wejsflog index in a group of men and women training and not training climbing – qualitative data (*n*)

pain. 84% of the people reporting pain definitely associated it with the use of specific climbing shoes; only 16% did not notice this relationship.

The responses from the surveys were analysed using the Spearman correlation coefficient, but most of the results were statistically insignificant. No significant effect of climbing experience or shoe size on the analysed parameters was observed.

## Discussion

Climbing shoes are an element of the climber's equipment, largely determining the sports result. However, the choice of shoes should also be considered in terms of comfort and proper functioning of the foot, which most climbers seem to forget. Research shows that climbers generally decide to buy shoes with smaller size compared to their standard footwear. Usually, these differences range from 2–4 numbers [5, 6, 9]. Even if the size of climbing shoes corresponds to the size of everyday shoes, their length differs on average by 2.5 cm [17–19]. This is a commonly observed phenomenon; among the evaluated group of 56 people in the Avertical World Climbing Centre, only one climber did not have too tight and ill-fitting shoes [6]. This is also confirmed by the results of our own research – the climbing shoes of the members of the study were shorter than sports shoes by an average of 3.5 cm, and the largest difference was as much as 6 cm.

Unnatural positioning of the foot in overly tight footwear is associated with discomfort and pain. Up to 91% of climbers report this [6]. Only 8% of the group of Spanish climbers surveyed had never experienced pain in the foot area during climbing; on average the pain was rated 6.7 on the VAS scale [9]. In our own research, 86% of people complained of pain, the vast majority of whom associated it directly with climbing shoes. Only one in five respondents declared the purchase of comfortable shoes. This phenomenon confirms that the discomfort associated with wearing tight shoes is widely accepted in the climbing community and treated as an essential element when achieving better results [20].

The impact of unusual footwear on the morphological structure of the foot and the risk of changes and dysfunctions is the subject of research by specialists in various sports disciplines. Metatarsal pain and big toe deformity resulting from the characteristic position of the foot and overloading of joints and muscles are often observed in groups of dancers. Studies conducted among young ballet dancers indicate an increased risk of hallux valgus, with a tendency to worsen as training experience increases [21–23].

Biomechanical studies show that heel lift increases pressure under the metatarsal heads and limits mobility of the first metatarsophalangeal joint, while shoes with a tapered front increase pressure on the medial side of the foot and between the toes [13]. Over time, these changes can contribute to foot deformities, although these relationships are not well documented. We deal with both of these situations during climbing.

According to Killian *et al.* [19], the prevalence of hallux valgus in groups of climbers at different levels of advancement was estimated at 34% overall. Higher values were observed by Lejonagoitia-Garmendia *et al.*; in the group studied by them, hallux valgus was present in 54% of climbers [9]. Increased incidence of hallux valgus was also indicated by van der Putten and Snijders [18]. However, their work focuses on the analysis of the construction of the climbing shoe, and they do not provide specific results regarding the frequency of injuries and deformities. In our own studies, the mean values of the hallux valgus angle in the analysed groups of women and men did not differ significantly, but in the groups of climbers they were higher compared to the control groups.

Also, the incidence of hallux valgus in at least one foot in the group of climbers was higher. In the group of women training climbing, hallux valgus deformity was noted in 35% of the subjects, both in the right and left foot, while in the group of non-training women, this abnormality occurred slightly less frequently (right foot – 11%, left foot – 29%). In the group of men, hallux valgus deformity was noted with comparable frequency in both feet, and it was, respectively, for men training/non-training: right foot – 11%/13%; left foot – 15%/10%).

From the diagnostic point of view, it should be noted that in the group of women, the mean values of the α angle were close to the upper limit of normal [24], which may indicate an increased probability of hallux valgus in the future. In addition, women are more likely to suffer from this deformity due to the more flaccid ligamentous-articular system.

The mean values of the angle of β determined in climbers and in non-trainers did not differ significantly, but in both groups they exceeded the accepted norms. Overstated values of this parameter were also observed in other groups of athletes [25, 26]. Therefore, it can be assumed that varus of the fifth toe is a common problem, perhaps due to the incorrect selection of shoes used on a daily basis.

Individual studies indicate a positive effect of climbing shoes on the structure of the arches of the foot. The results of our own research indicate that there are no differences in the quality of the transverse arch in both study groups, both in women and men. Significant differences were noted in the quality of the longitudinal arch. The group of climbing practitioners (both women and men) had higher average Clarke angle values compared to the non-training group. Qualitative results indicate a higher incidence of high arch in the group of trainees, especially observed in the left foot. Therefore, it can be assumed that practicing sport climbing could be an element of flat foot prevention. The beneficial effect on the structure of the longitudinal arch is also confirmed by previous studies [4].

Undoubtedly, the specific structure of a climbing shoe forces a specific position of the foot associated with discomfort and pain, but the long-term impact on the morphological structure and possible deformations is not clear. Perhaps the time associated with the use of shoes is too short for permanent changes to develop. The climbing time itself during training is usually short, and most people declared changing their shoes during breaks in climbing. Nevertheless, it is necessary to increase the level of awareness among climbers about the possible dangers of wearing incorrectly selected footwear. It is also worth noting that the studies presented in the submitted paper were conducted only on adults in whom the growth process has been completed. To assess in more detail the impact of climbing shoes on the structure and functioning of the foot, it would be necessary to deepen the research with a training group of children and adolescents in the phase of progressive development.

## Funding

No external funding.

## Ethical approval

Not applicable.

## Conflict of interest

The authors declare no conflict of interest.

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**Received:** 24.01.2025
**Accepted:** 21.08.2025
**Online publication:** 13.08.2026