

Sánchez-Ramírez, C.; Alegre, L.M. (2020) Acute Changes in Foot Morphology and Plantar Pressures during Barefoot Running. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 20 (78) pp. 211-226
[Http://cdeporte.rediris.es/revista/revista78/artcambios1152.htm](http://cdeporte.rediris.es/revista/revista78/artcambios1152.htm)

DOI: <http://doi.org/10.15366/rimcafd2020.78.002>

ORIGINAL

ACUTE CHANGES IN FOOT MORPHOLOGY AND PLANTAR PRESSURES DURING BAREFOOT RUNNING

CAMBIOS AGUDOS EN MORFOLOGÍA DEL PIE Y PRESIONES PLANTARES AL CORRER DESCALZO

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Investigación financiada por proyecto Dicyt Usach n° 021887SR.

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Código UNESCO / UNESCO code: 240602. Biomecánica / Biomechanics; 3299 Medicina del Deporte / Sport's Science.

Clasificación Consejo de Europa / Council of Europe classification: 3. Biomecánica del deporte / Sport's Biomechanics

Recibido 29 de junio de 2018 **Received** June 29, 2018

Aceptado 11 de noviembre de 2018 **Accepted** November 11, 2018

ABSTRACT

The acute changes that occur in foot morphology and the distribution of plantar pressures during barefoot running after applying a barefoot running protocol was analyzed. A total of 42 subjects of both sexes participated in the study, divided into shod (SH) (n=20) and barefoot (BF) (n=22). The foot's anthropometry, arch index (AI) and plantar pressures were evaluated before and after the intervention, which consisted in running at $3.05 \text{ m} \cdot \text{s}^{-1}$ during 20 min. The nondominant foot of the BF group decreased the height of its plantar arch (AI pre=0.20, AI post=0.22, $p=0.01$, ES=0.4). Furthermore, the barefoot race caused in the nondominant feet smaller

decreases of plantar pressure and smaller decreases of the plantar support surface than running with shoes.

KEYWORDS: Plantar arch, plantar footprint, plantar pressure, dominant foot, running, barefoot, biomechanics.

RESUMEN

El objetivo de esta investigación fue analizar modificaciones agudas que se producen en la morfología del pie y distribución de presiones plantares luego de la aplicación de un protocolo de carrera a pie descalzo. 42 subjects de ambos sexos participaron de este estudio. quienes fueron divididos en Grupo Calzado (GC) (n=20) y Grupo Descalzo (GD) (n=22). Se evaluó antropometría del pie. índice del arco (AI) y presiones plantares antes y después de la intervención. que consistió en correr a $3.05 \text{ m}\cdot\text{s}^{-1}$ durante 20 min. El pie no dominante del GD disminuyó la altura de su arco plantar (AI pre=0.20. AI post=0.22; $p=0.01$; ES=0.4). asimismo. la carrera descalza produjo en el pie no dominante menores aumentos en los valores de presión plantar y menores disminuciones en la superficie de apoyo plantar que el correr con calzado.

PALABRAS CLAVE: Arco plantar, huella plantar, presión plantar, pie dominante, carrera, descalzo, biomecánica.

INTRODUCTION

The foot turns into an interesting study focus when movements like running are analyzed. It can even be considered as a starting point from an anatomic functional and biomechanical approach, because this segment is in contact with the supporting surface applying the forces generated by the locomotive apparatus and receiving the reaction forces of the ground (Salazar Gómez. 2007).

The role of the foot while practicing sports running has been widely studied, and in recent years there has been increasing interest in studying *barefoot running* (BFR) or the use of minimalist shoeing that provides minimal protection and minimal functional modification of the foot. Bramble and Lieberman (2004) (Lieberman, 2006) theorize from an evolutionary approach, specifying that the human foot evolved after acquiring the bipedal position reached by *Australopithecus afarensis* about 2.2 million years ago (Susman, 1983). Bramble and Lieberman (2004) also open an interesting debate by stating that resistance running, was a key factor in the evolution of modern human beings, and that during its practice as a means of locomotion and hunting there was no mediation of shoes to achieve the current foot of *homo sapiens*.

The above shows that the evolution of the human foot caused by the practice of long distances at relatively low speeds took place without using o specialized shoes, whose use is a rather recent phenomenon. In spite of the present massiveness of the use of sports shoes, characterized by their increasingly complex design and manufacture, which offer improved performance and decreased occurrence of injuries, there is an increased incidence of injuries that occur in the foot, the ankle, and the knee which vary between 30% and 75% of the runners every year (Daoud et al., 2012). This reality led the scientific community to question itself and motivate the realization of various studies oriented at inquiring on the differences existing between running barefoot, with minimalist shoes, or with sports shoes.

From 1999 to 2013 the study focus was centered on the analysis of kinematic, kinetic, and electric muscle activity variables -through the use of electromiography (EMG)- that were produced acutely after a barefoot training session. Since various hypotheses related to the chronic changes in those who begin practicing BFR, other variables like control of stability in the frontal plane (Ekizos, Santuz & Arampatzis, 2017), loads on the Achilles tendon (Rice & Patel, 2017), static equilibrium in posturography (Smith et al., 2015), tibial rotation and its influence on the abduction of the calcaneus (Fischer, Willwacher, Hamill & Bruggemann, 2017), use of minimalist shoes for the recovery and then run a marathon, a role of fatigue in the absorption of ankle forces (Hashish, Samarawickrame, Baker & Salem, 2016), improvement of cognitive capacities that occur by running barefoot (Alloway, Alloway, Magyari & Floyd, 2016), muscular rigidity (Tam, Astephen Wilson, Coetzee, van Pletzen & Tucker, 2016), running economy in women (Berrones et al., 2016), change in the typology of the medial longitudinal plantar arch (MLPA) (Dolenec, Radi & Strojnik, 2015), and the slope of the ground on which one runs (An, Rainbow, Cheung, 2015), among others.

In spite of the increasing number of studies that have been developed in this field, there are some aspects that have hardly been explored, such as the morphological adaptations that take place in the foot and allow a subject to adopt a BFR training. In this respect, a single study inquired on bone adaptations after ten weeks of using FiveFingers© minimalist sports shoes (Ridge et al., 2013), finding that in ten out of 19 subjects there was an increase in the degree of edema in the spinal bone marrow, pointing to the risks of the adoption of this training style. Another one of the few studies along this line is that of Johnson et al. (Johnson, Myrer, Mitchell, Hunter & Ridge, 2015), who described changes in the size of the intrinsic muscles of the foot after ten weeks of BFR training.

Beside the two papers mentioned in the previous paragraph, to date no papers have been published inquiring on the morphological changes that take place in the foot after practicing barefoot running or on the behavior of the plantar pressures, focused on postural balance in a static situation. That is why it is understandable that there still are knowledge voids which, if clarified, would contribute to understand the foot's behavior in a subject that is starting BFR.

Because of the above, the objective of this study was to analyze acute changes that take place in the foot's morphology and the distribution of plantar pressures after the application of a barefoot running protocol, establishing as a hypothesis that acute modifications are produced in both the morphological variables as well as in the plantar pressure of the subjects who run barefoot.

MATERIALS AND METHODS

Subjects

Forty-two subjects (36 men and 6 women) studying physical activity science (20.74 ± 2.73 years old; 71.47 ± 8.78 kg weight, 1.72 ± 0.07 m height and 24.23 ± 2.42 kg·m⁻² BMI) participated voluntarily in this study after signing an informed consent written under the guidelines and the approval of the Ethics Committee of the Universidad de Santiago de Chile (Ethical report No. 184-2018). At the time of signing the consent, the subjects answered a questionnaire in which they were asked about their sport practice habits and the existence of ankle and/or foot injuries.

Participants aged between 18 and 35 years who ran between 5 and 10 km per week in at least two weekly sessions and did not run barefoot during their practice. No subjects who had suffered a foot and/or ankle injury in the last six months were included.

The total sample was divided into a barefoot group (BF) with n=22 and a shod group (SG) with n=20. The subjects were characterized according to age, body mass and height, body mass index (BMI), and foot length normalized to the height (FLn). Both groups showed that they had no statistically significant differences in the characterization variables (Table 1).

	BAREFOOT GROUP N = 22	SHOD GROUP N = 20	p
Age (years)	20.18 ±1.84	21.35 ±3.41	0.25
Weight (kg)	69.23 ±9.70	73.93 ±7.09	0.08
Height (m)	1.71 ±0.08	1.73 ±0.06	0.33
BMI (kg·m⁻²)	23.72 ±2.59	24.79 ±2.13	0.06
FLn Left	0.15 ±0.01	0.15 ±0.00	0.74
FLn Right	0.15 ±0.01	0.15 ±0.00	0.79

Table 1. Characterization of the groups. FLn = Normalized foot length.

The participants were measured and weighed with a Seca© anthropometer model 220 (Germany) with an incorporated digital balance. The BMI was calculated with these data.

To verify that the subjects complied with the sample's selection criteria, a questionnaire of our own design on podalic and postural health and sport history (Sánchez et al., 2017) was applied. In addition, they were asked which was their dominant foot, defined as the one that they use to kick a ball and the one that they use in the first step of a staircase (Lake, Laude & Smith, 2011).

Procedure

To not alter the results from activities that the subjects performed before going into the laboratory, each subject remained at rest for 10 minutes in a supine position (Jimenez-Ormeño, Aguado, Delgado-Abellan, Mecerreyes & Alegre, 2011). Then the anthropometric measurements of the foot and the plantar pressures were made. Then each participant ran on a treadmill (Technogym model Excite Run 500, Italy) during 20 min at $3.05 \text{ m}\cdot\text{s}^{-1}$ ($11 \text{ k}\cdot\text{h}^{-1}$), with a slope of 5%. This speed was chosen because it has been the most frequently used one in running kinematics and plantar pressure evaluation related to BFR (Warne et al., 2017). The SH subjects ran with their conventional sports shoes and the BF subjects ran barefoot. Once this event was finished, their anthropometric measurements and plantar pressures were evaluated again.

To obtain data that indicate the size and shape of the subjects' feet, the anthropometric measurement was made, consisting in measuring the foot length (FL), forefoot width (FW), hindfoot width (HW), and navicular height (NH).

The participants were made to stand on a level table in an upright relaxed two-footed standing position with both feet 10 cm apart. The location of the feet was controlled with lines drawn on the evaluation table. The evaluator marked the anatomic point determined by the underface of the tuberosity of the navicular bone (Fig. 1).



Figure 1. Anthropometric evaluation.

An anthropometer with a precision of 0.1 mm was used for the measurements. FL, FW, HW, and NH were obtained according to the protocol presented by Sánchez (2017). To compare the dimensions between subjects, the variables were normalized by dividing them by the subjects' height, obtaining the normalized foot

length (FLn), the normalized forefoot width (FWn), the normalized hindfoot width (HWn) and the normalized navicular height (NHn).

To evaluate the distribution of plantar pressures the subjects were made to stand with the body weight distributed evenly over both bare feet on a pressure posturology Presscam V4 platform (baropodoscope) (Sidas®, Francia) with 1600 reading sensors. Once the position was stabilized, the print of the plantar pressures obtained from the average of 10 s at a frequency of 100 Hz was obtained. The application of the equipment provides the maximum pressure, understood as the value obtained by the sensor that registered the highest pressure expressed in $\text{kg}\cdot\text{cm}^{-2}$ and the plantar support surface of each foot, expressed in cm^2 . The maximum pressure was normalized to the subject's body weight ($\text{MP}^{\circ}\text{n}$). and the plantar support surface was normalized to the subject's height (MSn). Furthermore, the location of the maximum pressure point of plantar support standing on both feet ($\text{MP}^{\circ}\text{P}$) was defined, and it can be located on the dominant or not dominant foot, on an anterior or posterior quadrant, depending on the variation of the projection of the center of gravity.

From the print obtained with the pressure posturology platform (baropodoscope), and the analysis with the AreaCalc software (Elvira. Vera-García & Meana, 2008), the Arch Index of Cavanagh and Rodgers (1987) (AI) (Cavanagh, Rodgers & Virginia, 1986) was calculated, determining the type of foot (cavus, flat or normal).

Statistical analysis

Descriptive statistics was used for the continuous variables. The Shapiro Wilk test was used to determine the normality of the variables.

For the initial comparison of both groups in the characterization variables use was made of the t test for independent samples when the variables presented a normal distribution, and the Mann Whitney test when this condition was not present.

Results between the pre- and post-test of each group were compared applying t tests for the related samples. When the variables were not distributed normally, the statistical test was used.

Additionally, the size effect was calculated for each of the comparative analyses from the calculation of Cohen's d.

The statistical significance was determined as $p < 0.05$. All the analyses were made using the statistical GraphPad Prism program (version 7.0).

RESULTS

Table 2 shows a comparison between SH and BF in the two evaluation instances of all the studied evaluations. In the dominant foot both groups showed equal conditions for all the variables except in NHn, whose value was 0.021 for BF and 0.019 for SH; with statistically significant differences. With respect to the not-dominant foot, significant differences were found between both groups in MP⁰ⁿ and MSn. The BF had higher pressures than SH, with values of 12.18 against 10.53, and lower MSn with values of 52.52 against 57.68, both statistically significant.

The results obtained in the post-test are shown on the right side of Table 2, where it is seen that in the dominant foot the difference between the groups seen in variable NHn disappeared, but two new significant differences appear in MP⁰ⁿ and MSn. In MP⁰ⁿ BF is 12.36 and SH is 10.53. On the contrary, SH had a value of 58.38 for MSn which is 12.8% greater than that registered for BF. This condition also appeared in the pre-test, but in contrast with the post-test no significant differences were found.

With respect to the not-dominant foot, it is seen that the statistically significant differences were maintained between the groups in the MP⁰ⁿ and MSn variables, with the same pattern seen in the pre-test.

	PRE-TEST			POST-TEST		
	Shod Group	Barefoot Group	p	Shod Group	Barefoot Group	p
DOMINANT FOOT						
FLn	0.15 ±0.00	0.15 ±0.01	0.93	0.15 ±0.00	0.15 ±0.01	0.70
FWn	0.06 ±0.00	0.06 ±0.00	0.49	0.06 ±0.00	0.06 ±0.00	0.51
HWn	0.04 ±0.00	0.04 ±0.00	0.36	0.04 ±0.00	0.04 ±0.00	0.49
NHn	0.019 ±0.00	0.021 ±0.00	<0.0001***	0.02 ±0.00	0.02 ±0.00	0.19
MP°n	10.90 ±2.25	12.22 ±2.67	0.92	10.53 ±1.74	12.36 ±3.17	0.03*
MSn	55.95 ±9.25	48.46 ±11.57	0.05	58.38 ±8.94	51.75 ±7.92	0.01*
AI	0.21 ±0.09	0.20 ±0.09	0.91	0.22 ±0.08	0.22 ±0.08	0.98
NOT DOMINANT FOOT						
FLn	0.15 ±0.00	0.15 ±0.01	0.94	0.15 ± 0.00	0.15 ±0.01	0.96
FWn	0.06 ± 0.00	0.06 ±0.00	0.75	0.06 ±0.00	0.06 ±0.00	0.47
HWn	0.04 ±0.00	0.04 ±0.00	0.69	0.04 ±0.00	0.04 ±0.00	0.78
NHn	0.02 ± 0.00	0.02 ±0.00	0.35	0.02 ±0.00	0.02 ±0.00	0.72
MP°n	10.53 ±2.09	12.18 ±3.11	0.04*	9.74 ±1.97	11.65 ±2.74	0.01*
MSn	57.68 ±8.93	52.52 ±8.74	0.03*	60.40 ±6.22	54.33 ±8.17	0.03*
AI	0.23 ±0.08	0.20 ±0.09	0.17	0.24 ±0.07	0.22 ±0.07	0.35

Table 2. Comparison between the pre-test and post-test groups. FLn: Normalized foot length; FWn: Normalized forefoot width; HWn: Normalized hindfoot width; NHn: Normalized navicular height; MP°n: Normalized maximum pressure; MSn: Normalized maximum surface; AI: Arch index.

With respect to the comparisons between the pre- and post-test in a same group, the left side of Table 3 shows the comparison in the SH, showing that in the dominant foot a statistically significant difference was registered only in the FLn variable oriented to an increase of this variable 0.1506 in the pre-test to 0.1512 in the post-test, which represents a 0.01% increase. Although this change is statistically significant ($p=0.02$), it had a small size effect ($ES=0.13$). With respect to the not-dominant foot, statistically significant differences were registered between the pre- and post-test in the MP°n and MSn variables. MP°n decreased 7.5%, from 10.53 to 9.74 in the post-test, with a medium size effect ($ES=0.4$). On the contrary, MSn increased 4.71% from the pre- to the post-test, from 57.68 to 60.40, also with a medium size effect ($ES=0.4$).

The right side of the table shows the comparison of the results obtained between the pre- and the post-test in the BF. In the dominant foot, modifications took place between the pre- and post-test in the HWn and NHn variables, with statistically significant differences. In the case of the former, a change took place from 0.0366 to 0.0371, with a small size effect ($ES=0.17$). NHn, on the other hand, underwent a decrease, registering a value of 0.0213 in the pre-test and 0.0204 in the post-test, with a small size effect ($ES=0.18$). In the not-dominant foot, on the other hand, a

statistically significant difference was registered only in AI, with a 10% increase, with a small size effect (ES=0.3).

	SHOD GROUP				BAREFOOT GROUP			
	Pre-Test	Post-Test	p	ES	Pre-Test	Post-Test	p	ES
DOMINANT FOOT								
FLn	0.15 ±0.00	0.15 ±0.00	0.02*	0.13	0.15 ±0.01	0.15 ±0.01	0.61	0.02
FWn	0.06 ±0.00	0.06 ±0.00	0.88	0.05	0.06 ±0.00	0.06 ±0.00	0.79	0.04
HWn	0.04 ±0.00	0.04 ±0.00	0.25	0.14	0.04 ±0.00	0.04 ±0.00	0.02*	0.17
NHn	0.02 ±0.00	0.02 ±0.00	0.88	0.03	0.02 ±0.00	0.02 ±0.00	0.04*	0.18
MP°n	10.90 ±2.25	10.53 ±1.74	0.26	0.18	12.22 ±2.67	12.36 ±3.17	0.84	0.05
MSn	55.95 ±9.25	58.38 ±8.94	0.07	0.27	48.46 ±11.57	51.75 ±7.92	0.11	0.33
AI	0.21 ±0.09	0.22 ±0.08	0.39	0.10	0.20 ±0.09	0.22 ±0.08	0.23	0.22
NOT DOMINANT FOOT								
FLn	0.15 ±0.00	0.15 ±0.00	>0.999	0	0.15 ±0.01	0.15 ±0.01	0.68	0.06
FWn	0.06 ±0.00	0.06 ±0.00	0.73	0.09	0.06 ±0.00	0.06 ±0.00	0.78	0.04
HWn	0.04 ±0.00	0.04 ±0.00	0.12	0.16	0.04 ±0.00	0.04 ±0.00	0.30	0.13
NHn	0.02 ±0.00	0.02 ±0.00	0.86	0.03	0.02 ±0.00	0.02 ±0.00	0.11	0.17
MP°n	10.53 ±2.09	9.74 ±1.97	0.03*	0.39	12.18 ±3.11	11.65 ±2.74	0.36	0.18
MSn	57.68 ±8.93	60.40 ±6.22	0.01*	0.35	52.52 ±8.74	54.33 ±8.17	0.16	0.21
AI	0.23 ±0.08	0.24 ±0.07	0.47	0.17	0.20 ±0.09	0.22 ±0.07	0.01*	0.26

Table 3. Intra-group comparison in the pre-test and post-test FLn: Normalized foot length; FWn: Normalized forefoot width; HWn: Normalized hindfoot width; NHn: Normalized navicular height; MP°n: Normalized maximum pressure; MSn: Normalized maximum surface; AI: Arch index.

Table 4 specifies the behavior of the MP°P with respect to its location before and after the intervention. It is seen that 35% of the subjects of the SH changed the location of their MP°P after running 20 min at 3.05 m·s⁻¹ wearing conventional sports shoes, in contrast with 63.64% of the BF group. The table also shows the percentage of subjects who not only changed the position of their MP°P, but they also changed feet, with 25% of the SH group presenting this condition, compared to 50% of the BF subjects. The table's results are illustrated in Fig. 2.

	SHOD GROUP		BAREFOOT GROUP	
	n	%	n	%
Subjects that changed the location of the MP°P	7	35.00	14	63.64
Subjects in which the MP°P changed foot	5	25.00	11	50.00

Table 4. Descriptive summary of the modifications seen in the location of the Maximum Pressure Point of the plantar support in standing position (MP°P).

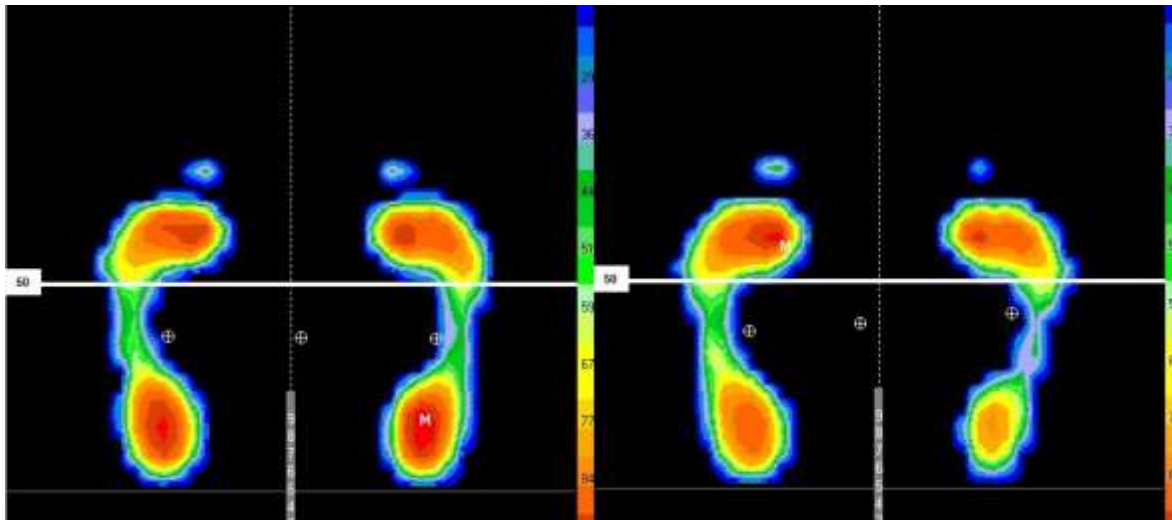


Figure 2. Example of plantar pressures obtained before (left) and after (right) the intervention. A modification of the location of the Point of Maximum Pressure of plantar support in the standing position (letter M), from the right hindfoot to the left forefoot after the intervention.

DISCUSSION

The hypothesis presented in this paper stated that there would be acute modifications in the morphological variables as well as in the plantar pressures in the subjects who ran barefoot, and this hypothesis was confirmed partially because anatomically significant modifications occurred only in the height of the MLPA, and in the plantar pressures only a decrease of MP^on and MSn was seen.

As other authors have shown (Jimenez-Ormeño et al., 2011), in this study morphological changes were found in some of these variables after applying the intervention protocol. They can be summarized in changes between groups and within groups. In the present study the only morphological variable changes recorded between groups was NHn of the dominant foot, which in the pre-test showed a significant difference in favor of the BF, but after the intervention this difference disappeared. This result can shed some light on the behavior of the height of MLPA which, according to Tsung et al., after an exercise which assumes a load -such as running- the MLPA can decrease its height by up to 15% (Tsung, Zhan, Fan & Boone, 2003). In this particular case, the conditions of both groups were equalized after the intervention, with the decrease of NHn in the BF the factor that caused the disappearance of the difference found in the pre-test.

With respect to the differences within the same group, it was shown that between the pre- and the post-tests the SH increased the dominant foot length, and the BF increased the heel width, results that agree with what was reported by Coughley and Mawsdey with respect to the increase of the total volume of the foot and ankle after running for 20 min (Cloughley & Mawsdey, 1995). On the contrary, after the intervention the BF decreased the height of the MLPA, a result that confirms what was stated in the previous paragraph, where the change registered in the BF was

responsible for the disappearance of the differences between groups noted in the post-test.

Although the changes found in the morphological variables of FLn, NHn, and HWn due to the intervention allow us to say that barefoot running for 20 min at $3.05 \text{ m}\cdot\text{s}^{-1}$ led to an increased heel width and a decrease of the height of the MLPA, it must be noted that when analyzing the not normalized values the differences are caused by real changes of the foot's size in the order of 1 mm. We believe that if we consider how this modification can influence the postural stability or the comfort of using shoes -which considers at least differences of 5 to 8 mm in the size of the shoe's dimensions compared to those of the foot- the change can be negligible (Miller, Nigg, Liu, Stefanyshyn & Nurse, 2000). This reflection is also supported by the small effect size registered in each of the variables in question, which did not exceed 0.2. Therefore, the stated findings must be taken in moderation.

With respect to the comparison between groups of the variables related to plantar pressure and the plantar print, it must be stated that various studies have described that after running there is an increase of the plantar pressure running on a treadmill or on the ground (Kyung, Ali & Fernandez, 2017). The differences seen between the groups on the not-dominant foot in MP^on and MSn before and after the intervention tells us that it did not produce changes between the groups. However, the intervention protocol used produced a decrease of the plantar pressures and an increase of the plantar support surface in the not-dominant group in the SH, a result that can be related to some extent to the work of Hohmann et al. on marathon runners, where they found that the changes in the plantar pressure occurred mostly in the dominant foot (Hohmann, Reaburn, Tetsworth & Imhoff, 2016). The same changes were found in BF, but without statistical significance, providing clues on the fact that barefoot running modifies these variables to a lower extent when conventional sports shoes are used. This result can be contrasted with what has been found by other authors in the sense that barefoot running tends to increase the pressure and decrease the surface (Bergstra et al., 2015) (Fernández-Torres et al., 2018). In the dominant foot, on the other hand, a difference was recorded in the post-test, given by an increase of the MP^on in the BF and a decrease in the SH. Also, a difference was registered in the MSn variable, where both groups increased, with this increase greater in the BF compared to the SH, taking into account the size of the effect ($d=0.27$ for SH and $d=0.33$ for BF). Because this difference appeared after the application of the running protocol, it can be considered as a consequence of it. Again, these values agree with those of previous studies. But since they show no consistency, these changes must be taken cautiously.

One of the limitations of this study is the fact that the baropodoscope used did not distinguish among the plantar pressures registered for the different zones of the foot, so this does not allow the results cannot be compared with those of other authors who found increased plantar pressures in specific zones like that of the forefoot (Szulc et al., 2017). Also, a number of studies have used instrumental

insoles, whose results can differ from those obtained on a platform (Chevalier, Hodgins & Chockalingam, 2010).

The AI variable, which through the analysis of the plantar support areas allows determining the constitution of the MLPA and in turn classify flat, normal and cavus feet, only showed significant differences between the pre- and post-test in the not dominant foot in BF, with a tendency to flattening the plantar arch, as stated by Tsung et al. (Tsung et al., 2003) and Jiménez et al. (Jimenez-Ormeño et al., 2011). A similar study made on running is that of Maslon et al. (Maslon, Golec, Szczygiel, Czechowska & Golec, 2016), who found that runners flatten the arch of the foot as an active force-absorbing mechanism.

The changes seen in the location of MP°P shed light on the behavior that postural control has after barefoot practice. The BF was the one that presented the highest frequency of changes in the location of the MP°P, something that other authors have studied (Hohmann et al., 2016), which has not been studied in static situations like the present study. What is known is that the runners, after finishing the protocol, tend to charge their body weight more on the dominant foot, a fact that was shown here in the group of subjects who ran barefoot.

CONCLUSION

In conclusion, it can be stated that running barefoot for 20 min at 3.05 m·s⁻¹ did not produce important modifications in the dimensions of the foot, except for those registered on the not-dominant foot, leading to the flattening of the MLPA. Also, barefoot running produced smaller increases in the not dominant foot in the values of plantar pressure, and smaller decreases on the plantar support surface than running with shoes.

The present study provides information that allows understanding in greater depth the behavior shown by the foot morphology and the distribution of plantar pressures by depriving of sport shoes, posing new questions on the postural balance of sports people, which is aimed to be further studied.

REFERENCES

- Alloway, R. G., Alloway, T. P., Magyari, P. M. & Floyd, S. (2016). An Exploratory Study Investigating the Effects of Barefoot Running on Working Memory. *Perceptual and Motor Skills*, 122(2), 432–443. <https://doi.org/10.1177/0031512516640391>
- An, W., Rainbow, M.J. & Cheung, R. (2015). Effects of Surface Inclination on the Vertical Loading Rates and Landing Pattern during the First Attempt of Barefoot Running in Habitual Shod Runners. *Biomed Res Int.*, Article ID. 240153. <http://dx.doi.org/10.1155/2015/240153>
- Bergstra, S. A., Kluitenberg, B., Dekker, R., Bredeweg, S. W., Postema, K., Van den Heuvel, E. R., ... Sobhani, S. (2015). Running with a minimalist shoe increases plantar pressure in the forefoot region of healthy female runners. *Journal of Science and Medicine in Sport*, 18(4), 463–468. <https://doi.org/10.1016/j.jsams.2014.06.007>
- Berrones, A. J., Kurti, S. P., Kilsdonk, K. M., Cortez, D. J., Melo, F. F. & Whitehurst, M. (2016). Barefoot Running Reduces the Submaximal Oxygen Cost in Female Distance Runners. *Journal of Strength and Conditioning Research*, 30(8), 2348–2353. <https://doi.org/10.1519/JSC.0000000000001330>
- Bramble, D. M. & Lieberman, D. E. (2004). Endurance running and the evolution of Homo. *Nature*, 432(7015), 345–352. <https://doi.org/10.1038/nature03052>
- Cavanagh, P. R., Rodgers, M. & Virginia, W. (1986). Technical Note the Arch Index : a Useful Measure. *J Biomech*, 20, 547–551. [https://doi.org/10.1016/0021-9290\(87\)90255-7](https://doi.org/10.1016/0021-9290(87)90255-7)
- Chevalier, T. L., Hodgins, H. & Chockalingam, N. (2010). Plantar pressure measurements using an in-shoe system and a pressure platform: A comparison. *Gait and Posture*, 31(3), 397–399. <https://doi.org/10.1016/j.gaitpost.2009.11.016>
- Cloughley, W. B. & Mawdsley, R. H. (1995). Effect of running on volume of the foot and ankle. *The Journal of orthopaedic and sports physical therapy*, 22(4), 151–4. <https://doi.org/10.2519/jospt.1995.22.4.151>
- Daoud, A. I., Geissler, G. J., Wang, F., Saretsky, J., Daoud, Y. A. & Lieberman, D. E. (2012). Foot strike and injury rates in endurance runners. *Medicine & Science in Sports & Exercise*, 44(7), 1325–1334. <https://doi.org/10.1249/MSS.0b013e3182465115>
- Dolenec, A., Radi, P. & Strojnik, V. (2015). An Explanation of the Influence on Deciding which Type of Foot Strike to Use when Running Barefoot or in Minimalistic Shoes. *Collegium antropologicum*, 39 Suppl 1(suppl 1), 147–51. <https://doi.org/10.2307/1268751>
- Ekizos, A., Santuz, A. & Arampatzis, A. (2017). Transition from shod to barefoot alters dynamic stability during running. *Gait & Posture*, 56(April), 31–36. <https://doi.org/https://doi.org/10.1016/j.gaitpost.2017.04.035>
- Elvira, J. L. L., Vera-García, F. J. & Meana, M. (2008). Subtalar joint kinematic correlations with footprint arch index in race walkers. *The Journal of sports medicine and physical fitness*, 48(2), 225–34. Recuperado a partir de <http://www.ncbi.nlm.nih.gov/pubmed/18427419>

- Fernández-Torres, V., Robles-Rodríguez, C., De Castro-Maqueda, G., Candelario-Poteleschenko, V., Gutiérrez-Manzanedo, V. & Ponce-González, J. (2018). Diferencias de la pisada en estático después de una maratón. *Retos. Nuevas tendencias en Educación Física. Deporte y Recreación*, (33), 134–137. Recuperado a partir de <http://0-eds.b.ebscohost.com.fama.us.es/eds/detail/detail?vid=0&sid=579183cf-65aa-493a-bcde-38f5efab3d89%40sessionmgr103&bdata=Jmxhbm9ZXMmc2l0ZT1lZHMtbGl2ZSZyZ29wZT1zaXRI#AN=126604332&db=edb>
- Fischer, K. M., Willwacher, S., Hamill, J. & Bruggemann, G. P. (2017). Tibial rotation in running: Does rearfoot adduction matter? *Gait and Posture*, 51, 188–193. <https://doi.org/10.1016/j.gaitpost.2016.10.015>
- Hashish, R., Samarawickrame, S. D., Baker, L. & Salem, G. J. (2016). The influence of a bout of exertion on novice barefoot running dynamics. *Journal of Sports Science and Medicine*, 15(2), 327–334.
- Hohmann, E., Reaburn, P., Tetsworth, K. & Imhoff, A. (2016). Plantar Pressures during Long Distance Running : An Investigation of 10 Marathon Runners. *Journal of sports science & medicine*, 15(November 2015) 254–262. Recuperado a partir de <http://www.ncbi.nlm.nih.gov/pubmed/27274662%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4879438>
- Jimenez-Ormeño, E., Aguado, X., Delgado-Abellan, L., Mecerreyes, L. & Alegre, L. M. (2011). Changes in footprint with resistance exercise. *International Journal of Sports Medicine*, 32(8), 623–628. <https://doi.org/10.1055/s-0031-1275354>
- Johnson, A., Myrer, J., Mitchell, U., Hunter, I. & Ridge, S. (2015). The effects of a transition to minimalist shoe running on intrinsic foot muscle size. *International Journal of Sports Medicine*, 37(2), 154–158. <https://doi.org/10.1177/0363546514553779>
- Kyung, H., Ali, S. & Fernandez, J. (2017). Human Movement Science Gait kinetics, kinematics, spatiotemporal and foot plantar pressure alteration in response to long-distance running : Systematic review. *Human Movement Science*, (February), 0–1. <https://doi.org/10.1016/j.humov.2017.09.012>
- Lake, J., Lauder, M. & Smith, N. (2011). Does side dominance affect the symmetry of barbell end kinematics during lower body resistance exercise? *Journal of Strength and Conditioning Research*, 25(3), 872–878. <https://doi.org/10.1519/JSC.0b013e3181cc2397>
- Lieberman, D. E. (2006). The human gluteus maximus and its role in running. *Journal of Experimental Biology*, 209(11), 2143–2155. <https://doi.org/10.1242/jeb.02255>
- Maslon, A., Golec, J., Szczygiel, E., Czechowska, D. & Golec, B. (2016). Assessment of the influence of jogging on the shape of female foot arches. *Annals of agricultural and environmental medicine*. <https://doi.org/10.5604/12321966.1230672>
- Miller, J. E., Nigg, B. M., Liu, W., Stefanyshyn, D. J. & Nurse, M. A. (2000). Influence of foot, leg and shoe characteristics on subjective comfort. *Foot and Ankle International*, 21(9), 759–767.

- <https://doi.org/10.1177/107110070002100908>
- Nakagawa, K., Inami, T., Yonezu, T., Kenmotsu, Y., Narita, T., Kawakami, Y. & Kanosue, K. (2017). Unstable rocker shoes promote recovery from marathon-induced muscle damage in novice runners. *Scandinavian Journal of Medicine & Science in Sports*, (May), 1–9. <https://doi.org/10.1111/sms.12911>
- Rice, H. & Patel, M. (2017). Manipulation of Foot Strike and Footwear Increases Achilles Tendon Loading During Running. *The American Journal of Sports Medicine*. 36354651770442. <https://doi.org/10.1177/0363546517704429>
- Ridge, S. T., Johnson, A. W., Mitchell, U. H., Hunter, I., Robinson, E., Rich, B. S. E. & Brown, S. D. (2013). Foot bone marrow edema after a 10-wk transition to minimalist running shoes. *Medicine and Science in Sports and Exercise*, 45(7), 1363–1368. <https://doi.org/10.1249/MSS.0b013e3182874769>
- Salazar Gómez, C. (2007). Pie plano. como origen de alteraciones biomecánicas en cadena ascendente. *Fisioterapia*, 29(2), 80–89. [https://doi.org/10.1016/S0211-5638\(07\)74418-8](https://doi.org/10.1016/S0211-5638(07)74418-8)
- Sánchez, C. (2017). Caracterización Morfológica del Arco Plantar Longitudinal Medial del Pie en una Población Chilena. *International Journal of Morphology*, 35(1), 85–91. <https://doi.org/10.4067/S0717-95022017000100015>
- Sánchez, C., Alarcón, E. & Morales, H. (2017). Características Morfofuncionales del Pie de Deportistas Universitarios Chilenos en Diez Disciplinas Deportivas Morphofunctional Foot Characteristics of Chilean University Athletes in Ten Sports Disciplines. *Int. J. Morphol*, 35(4), 1403–1408. <https://doi.org/10.4067/S0717-95022017000401403>
- Smith, B. S., Burton, B., Johnson, D., Kendrick, S., Meyer, E. & Yuan, W. (2015). Effects of wearing athletic shoes. five-toed shoes and standing barefoot on balance performance in young adults. *International Journal of Sports Physical Therapy*, 10(1), 69–74. Recuperado a partir de <http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4325290&tool=pmc-entrez&rendertype=abstract%5Cnhttp://www.ncbi.nlm.nih.gov/pubmed/25709865%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4325290>
- Susman, R. L. (1983). Evolution of the Human Foot: Evidence from Plio-Pleistocene Hominids. *Foot & Ankle*, 3(6), 365–376. <https://doi.org/10.1177/107110078300300605>
- Szulc, P., Waszak, M., Bartkowiak, M., Bartkowiak, P., Tomczak, M., Boch-Kmieciak, J. & Cieslik, K. (2017). Distribution of plantar pressure during jogging barefoot or in minimalistic shoes in people who used to run in cushioned shoes. *The Journal of Sports Medicine and Physical Fitness*, 57(5), 565–571.
- Tam, N., Astephen Wilson, J. L., Coetzee, D. R., van Pletzen, L. & Tucker, R. (2016). Loading rate increases during barefoot running in habitually shod runners: Individual responses to an unfamiliar condition. *Gait and Posture*, 46, 47–52, <https://doi.org/10.1016/j.gaitpost.2016.02.013>
- Tsung, B. Y. S., Zhang, M., Fan, Y. B. & Boone, D. A. (2003). Quantitative comparison of plantar foot shapes under different weight-bearing conditions. *Journal of rehabilitation research and development*. 40(6), 517–526.

<https://doi.org/10.1682/JRRD.2003.11.0517>

Warne, J. P., Smyth, B. P., Fagan, J. O. C., Hone, M. E., Richter, C., Nevill, A. M., ... Warrington, G. D. (2017). Kinetic changes during a six-week minimal footwear and gait-retraining intervention in runners. *Journal of Sports Sciences*. 35(15), 1538–1546.

<https://doi.org/10.1080/02640414.2016.1224916>

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