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ORIGINAL

INFLUENCE OF SPORTS PRACTICE ON THE FOOTPRINT OF SPANISH ATHLETES

INFLUENCIA DE LA PRÁCTICA DEPORTIVA SOBRE LA HUELLA PLANTAR EN ATLETAS ESPAÑOLES

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ABSTRACT

The aim of the present study was to determine the association between athletic training and characteristics of each foot. Plantar foot print of three groups of athletes (28 sprinters, 29 distance runners, 47 swimmers) and 67 sedentary subjects (CG) were measured and compared. A scanning platform breech Podoscanalyzer was employed to obtain plantar pressure measurements. The breech, metatarsal, middle breech, and calcaneus index, were lower in CG compared to sprinters, long-distance runners, and swimmers ($p<0.001$). The relative risk of having a cavus foot or any specific type of foot as a result of practicing a particular athletic discipline was not significant (all $p>0.05$). We conclude that the years of training and the age are not significantly associated neither with the curvature and the type of the foot nor with any specific plantar arch index in Spanish athletes. Nevertheless, sex and BMI are significantly associated with the plantar arch indexes according to the athletic discipline.

KEYWORDS: Plantar footprint, athletes, swimmers, foot type, cavus foot.

RESUMEN

El objetivo de este estudio fue conocer la asociación entre el entrenamiento de atletas con las características de cada pie. Se midieron y compararon las huellas plantares de tres grupos de deportistas (28 velocistas, 29 fondistas, 47 nadadores) y de 67 sujetos no entrenados (GC). Para la captura de parámetros plantares se empleó una plataforma de escaneado podálico Podoscanalycer®. El índice podálico, metatarsal, medio podálico, y calcáneo fue inferior en GC respecto a corredores de velocidad, fondo, y nadadores ($p<0.001$). El riesgo relativo de tener un pie cavo o un tipo de pié específico por pertenecer a una determinada modalidad atlética no resulto significativo (todos $p>0.05$). Se concluye que los años de entrenamiento y la edad en atletas españoles no se asocian significativamente con la curvatura y tipología del pie ni sobre ningún índice plantar específico. Sin embargo, sexo e IMC se asocia significativamente con los índices plantares según la modalidad atlética.

PALABRAS CLAVE: Huella plantar, atletas, nadadores, tipo de pie, pie cavo.

INTRODUCTION

Feet are the supporting base of the human body, and are used in most of the common forms of locomotion. According to Viladot (2000), the foot is a variable three-dimensional structural, and the basis of the anti-gravitational servomechanisms of the human body. It is therefore instrumental in keeping a bipodal position and in walking and running. In addition to its static and dynamic functions (Torrijos, Abián-Vicen, Abián and Abián, 2009) the foot has a dome-like structure which, supported by the heel and the metatarsals, can bear the weight of the whole body (Hernández Corvo, 1989; Viladot, 2000). The morphological features of the human foot vary with age as well as between individuals (Scott, Menz, and Newcombe, 2007, Mayorga-Vega, Brenes, Rodríguez, and Merino, 2012): These variations, however, are not easily observable, and the analysis of specific features requires specialized instruments. A simple and widely validated way of analyzing the foot is by obtaining a plantar footprint (Shiang, Lee, Lee, and Chu, 1998). This technique enables the assessment of growth-related structural variations, as well as others caused, for example, by the age at which sports practice starts receiving a medium or high degree of dedication (Zahínos, González, and Salinero, 2010), by the condition of being overweight (Sachithanandam y Joseph, 1995), by fatigue (Abián, Alegre, Lara, Jiménez, and Aguado, 2005), or by the common execution of a specific sports technique.

It has been proven that every movement process is affected by several factors, be they extrinsic (terrain, type of shoes, warming-up, movement technique, etc.), intrinsic (physical condition, type of feet, evertors/inverters torque, ligamentous laxity, etc.), or even pathological (decompensations, physical ailments, previous injuries, etc.; Olivera, Holgado, and Cabello, 2001). Such factors and the changes they may produce in the movement patterns can be either temporary or permanent, and their study has revealed, for example, that athletes are able to modify and correct, on the fly, problems with their walking, running, or swimming patterns in order to improve performance, avoid injuries, or recover from said injuries once they have happened (Viel, 2002). It would appear that in each sports modality the foot adapts towards more stressful work (sprint running), more strenuous work (long-distance running), or work requiring greater joint flexibility (swimming). Berdejo-del-Fresno, Lara, Martínez-López, Cachón, and Lara (2013), showed, using Hernández Corvo's method (HC) the trend for the feet of female hockey players to flatten, as well as adaptations in the dominant foot of female futsal players. On the other hand, the feet of sedentary women did not undergo any change in their plantar footprint.

In addition, several studies have dealt with the association between types of physical activity and the most common injuries (Sánchez, 1993; Comín, Villarroya, Pérez García, Nerín, and Marco Sanz, 1999; Fourchet, Horobeanu, Loepelt, Taiar, and Millet, 2011; Nagel, Fernholz, Kibele, and Rosenbaum, 2008; Nigg, Nurse, and Stefanyshyn, 1993; Lee and Piazza, 2009). Out of these potential injuries, those related with plantar support (involving a reduction in the support area) or with the speed or length of movement are of the greatest importance, as they may cause the athlete to either develop a harmful gait which may overload other structures of the musculoskeletal system, or to adopt unhealthy postures (Merriman and Tollafield, 1995).

Recent research has highlighted the association between high performance in sports and some frequent injuries. In sprint runners, tendinopathies are common due to the big strength-training workloads applied to their rapid movements and sprint racing (Lee y Piazza, 2009). On the other hand, metatarsal stress fractures are common among long-distance runners due to the overload of constant and lengthy training sessions. In both modalities, the number of support points in the foot is considerably larger than in any other sport (Lieberman, Venkadesan, Werbel, Daoud, D’Andrea, Davis, et al., 2010). In addition, this overload of the metatarsal may be due as much to muscle fatigue and bone health as to the type of foot (Nagel et al., 2008). Zurita, Martínez, and Zurita (2007) observed that subjects with cavus feet are more prone to injuries than those with flat feet. Also, stress fractures in runners with a high arch have an incidence of 40% (Korpelainen, Orava, Karpakka, Siira, and Hulkko, 2001), and they are therefore more prone to injuries such as plantar fasciitis, sprains, tendinopathies, or chronic lateral knee instability (Nigg et al., 1993).

Furthermore, Hintermann and Nigg (1998) showed that excessive overpronation is potentially detrimental to racing athletes, as the pronation-related eversion of the foot causes a tibial rotation which may in turn overload the knee, causing injuries at the knees and ankles. Contrary to their findings, in a recent study conducted on 927 runners, it was concluded that the risk of injury is the same for all runners after the first 250 km, regardless of their foot strike type. In addition, it concluded that the number of injuries per 1.000 km was significantly lower for runners with some type of pronation than for those with a neutral strike (Oestergaard, Buist, Thorlund, Aagaard, Sørensen, Lind, et al., 2013).

Franco, Nathy, Valencia, and Vargas (2009) compared plantar footprints of practitioners of several sports like swimming, weightlifting, and athletics with those of sedentary students. Their results showed that both athletes and sedentary subjects tend to have normal-cavus feet with Egyptian forefeet, and that sport is not a factor in the adaptations concerning the symmetry or asymmetry of an individual's plantar footprint. Previous studies have assessed foot type in a population of children aged 9-12, and found a higher prevalence of high arches and normal feet since the infantile stage (Hernández Guerra, 2006). Therefore, sport might not be as influential a factor in the morphological changes of the footprint as commonly believed. This controversy is still the subject of current debate, and further research will be required in order to ascertain the real influence of sports modalities on the morphology of the foot.

Based on the preceding arguments, the aim of this study was to determine the association of years of training with plantar index measures in Spanish sprinters, long-distance runners, and swimmers, as well as the relationship of each sport with the subject's type of foot. It also sought to describe the nature and characteristics of the feet of athletes in each modality.

METHODS

The present study is a cross-sectional comparison between groups. A comparison of results was carried out between athletes in three different sports modalities and sedentary people.

Participants

A total of 171 subjects took part in this study (96 men aged 16 to 46, and 75 women aged 16 to 39) from Jaén, Málaga, Granada and Murcia. Out of these, 29 athletes were long-distance runners (age 30.1±11.7 years, body mass index (BMI) 21.25 ±2.65 kg/m^2), 28 were sprinters (age 23.4 + 8.4 years, BMI 25.54 ± 2.55 kg/m^2), and 47 were swimmers (age 19.4 + 5.5 years, BMI 22.38 ± 2.43 kg / m^2). In addition, a control group of 67 sedentary individuals (age 20.6 +3.1 years, BMI 22.83 ± 3.38 kg / m) was used for comparison. For the control group, data were collected on students currently at their second or third year of the Physical Therapy degree at the University of Jaén (Spain) who reported not to practice any sports performance training. As an inclusion criterion, athletes had to have competed in at least two seasons at the regional category to ensure a sufficient level of training. Subjects with chronic or temporary injuries or deformities that could influence the outcome of the measurements were excluded. Anthropometric features and training time of the subjects are shown in Table 1.

Table 1. Anthropometric features and training time. Data split by sports modality (sprint, long-distance, and swimming) and control group.

		Sprinters (n = 28)	**Long-distance runners (n = 29)**	**Swimmers (n = 47)**	**Control Group (n = 67)**	**P**
Age (years)		23,4 ±8,4	30,1 ±11,7	19,4 ±5,5	20,6 +3,1	<0,001
Sex (%)	**Male** (56.14)	22 (78,57)	27 (93,10)	30 (63,82)	17 (25,37)	<0,001
	Female (43.85)	6 (21,42)	2 (6,89)	17 (36,17)	50 (74,62)	
Weight (kg)		66,74 ±12,68	65,65 ±8,79	68,4 ±11,11	62,41 +11,46	0,039
Height (cm)		175,07 ±8,37	175,68 ±5,46	174,38 ±8,10	165,16 +8,10	<0,001
BMI (kg/m^2)		25.54 ±2.55	21.25 ±2.65	22.38 ±2.43	22.83 ±3.38	NS
Years of training		9,6 ±5,70	8,2 ±6,44	9,08 ±4,95	0	<0,001
Days/week of training		5,53 ±0,74	5,62 ±0,82	5,27 ±0,97	0	<0,001
Minutes/day of training		113,21 ±20,55	94,13 ±31,45	96,27 ±25,82	0	<0,001

Measurements expressed as mean ± SD and percentages.

Materials

For the measurement of weight and BMI a KERN MFB 150® digital precision scale by Kern & Sohn (Germany) was used. Height was measured with a telescopic height rod (Holtex©, France). In order to measure plantar parameters, a Podoscanalyzer® computerized podoscope was used, along with the Milletrix® (Italy) baropodometric recognition and comparison software (Bellomo, Barassi, Lodice, Di Pancrazio, Megna, & Saggini, 2012).

Procedure

Data were recorded during the competition season as well as the off-season in each of the categories and according to the availability of athletes (sprinters, long-distance runners, and swimmers). Participants were briefed in advance of the measurement process. All provided written informed consent, and in the case of underage athletes, their parents and legal tutors provided consent. The design of the study complies with the standing regulations of clinical research in humans *(Real Decreto 561/1993)* and personal data protection *(Ley Orgánica 15/1999)*. Research also complied with the Ethical Principles for Medical Research in Humans of the Declaration of Helsinki (2008 version).

Measurement sessions took place in the sports facilities where participant athletes carry out their usual trainings. Data were recorded immediately after the specific training of each of the groups. Participants were encouraged to proceed normally with their training routine, with no regard for this research. Prior to data recording, a form was completed with the sociodemographical information for each of the participants, and a height and weight measurement was performed. Lastly, a measurement of the plantar footprint was recorded with a Podoscanalyzer® platform. The software used generates a plantar footprint image which includes toes and discriminates their position and distribution. From that image, data regarding foot index, isthmus index, midfoot index, calcaneus index, and metatarsal index were recorded, and, from these, variables were extracted regarding foot and footprint type through the calculation of the HC index (Hernández Corvo, 1989; Figure 1).

$\%X = \frac{X - Y}{X} . 100$	0-34% Flat foot 35-39% Flat-normal foot 40-54% Normal foot 55-59% Normal-cavus foot 60-74% Cavus foot 75-84% Strong cavus foot 85-100% Extreme cavus foot

Figure 1. Calculation of the Hernández Corvo (HC) Index. X = width of the metatarsal, Y = external arch (midfoot support area).

Statistical analysis

A one-factor ANOVA and chi-squared test were performed to compare anthropometric features, training time and plantar footprint of the different sports modalities and the control group, and the percentage of participants according to their gender and foot type, respectively. Homoscedasticity and normality of the variables were tested through the Levene and the Kolmogorov-Smirnov tests, respectively. The degree of association between years of training (predictor variable) and the plantar footprint measurements (criterion variable = foot index, metatarsal index, midfoot index, calcaneus index, isthmus index and HC index) was ascertained through linear regression analysis. In order to establish the association between trained subjects (sprinters, long-distance runners, and swimmers) and the control group logistic regression was performed regarding foot curvature: non-cavus (reference) vs cavus foot; and foot type: non-Egyptian foot (reference) vs Egyptian foot, non-squarefoot (reference) vs square foot, and non-Greek foot (reference) vs Greek foot. For this analysis data were recoded as follows regarding the morphology of feet: non-cavus foot = flat + flat-normal + normal + normal-cavus; and cavus foot = cavus + strong cavus + extreme cavus). All regression analyses were adjusted to gender (male = 0 and female = 1), age, and BMI. Significance level was established at p<0.05. Data were analyzed using the SPSS v.19 (Chicago) statistical analysis software package for Windows.

RESULTS

Tables 2 and 3 display, respectively, the average results (SD) of plantar footprint measurements and the percentages of foot types (type 1 or 2) split by sports modality (sprinters, long-distance runners, and swimmers) and control group. The post-hoc analysis of variables that showed significant differences after the one-factor ANOVA (p<0.05) revealed that long-distance runners were significantly older than the rest of the participants in the study (long-distance runners vs all = p<0.003). No differences were found in the years and days/week of training between sports modalities (p>0.05), although sprint runners declared training more minutes/day than long-distance runners and swimmers (p<0.005 for both). Foot index, metatarsal index, midfoot index, and calcaneus index were lower in the control group than in the case of athletes (sedentary vs all = p<0,001), and no significant differences were found between sports modalities (p>0.05). Isthmus index and HC index were similar for all groups (p>0.05). The Egyptian type foot was significantly more prevalent than other types in all groups (p<0.05). A certain trend toward cavus feet was detected but it did not reach significance (average = 51.89%).

Table 2. Plantar footprint measurements (foot index, metatarsal index, midfoot index, calcaneus index, isthmus index, and HC index). Data split by sports modality (sprint, long-distance, and swimming) and control group.

	Sprinters (n = 28)	Long-distance runners (n = 29)	Swimmers (n = 47)	Control Group (n = 67)	P
Foot index (cm)	25,6 ±1,38	25,72 ±0,97	25,43 ±1,41	23,95 ±1,49	<0,001
Metatarsal index (cm)	10,17 ±0,59	10,2 ±0,80	10,22 ±0,55	9,54 ±0,59	<0,001
Midfoot index (cm)	13,71 ±0,73	13,77 ±0,53	13,63 ±0,75	12,9 ±0,90	<0,001
Calcaneus index (cm)	6,15 ±0,38	6,35 ±0,54	6,24 ±0,36	5,85 ±0,36	<0.001
Isthmus index (cm)	3,95 ±1,04	4,04 ±1,10	3,99 ±1,24	4,09 ±1,18	NS
HC index (%)	60,96 ±10,68	60,01 ±11,56	61,12 ±11,24	57,14 ±12,06	NS

Measurements expressed as mean ± SD.

Table 3. Foot type 1 (flat, normal, and cavus) and 2 (Egyptian, square, and Greek). Data split by sports modality (sprint, long-distance, and swimming) and control group.

		Sprinters (n = 28)	**Long-distance runners (n = 29)**	**Swimmers (n = 47)**	**Control Group (n = 67)**	**P**
Foot type 1 (%)	**Flat**	0	0	0	1 (1,49)	NS
	Flat-normal	0	0	1 (2,12)	4 (5,97)	
	Normal	10 (35,71)	11 (37,93)	14 (29,78)	24 (35,82)	
	Normal-cavus	1 (3,57)	0	4 (8,51)	5 (7,46)	
	Cavus	15 (53,57)	16 (55,17)	24 (51,06)	32 (47,76)	
	Strong cavus	2 (7,14%)	2 (6,89%)	4 (8,51%)	1 (1,49%)	
	Extreme cavus	-	-	-	-	
Foot type 2 (%)	**Egyptian**	16 (57,1%)	17 (58,6%)	36 (76,6%)	56 (83,6%)	0,013
	Square	6 (21,4%)	7 (24,1%)	4 (8,5%)	10 (14,9%)	
	Greek	6 (21,4%)	5 (17,2%)	7 (14,9%)	1 (1,5%)	

Measurements expressed as percentages.

Linear regression analysis

The association between years of training and plantar footprint measurements for each sports modality is shown in table 4. All analysis were adjusted for gender, age, and BMI. Years of training did not show any significant association with any plantar index (all p>0,05). On the other hand, gender showed a negative association (female subjects scored lower values) with the metatarsal index in the sprinters (β=-0,664; p=0,006), long-distance runners (β=-1,430; p=0,015) and control group (β=-0,828; p<0,001) categories. Untrained female subjects also had lower values of foot index, midfoot index, and calcaneus index β=-2,080, β =-1,080, and β=-0,381, respectively (all p<0,001). In addition, as BMI increased, also increased foot index values for sprinters (β=0,302; p=0,028), although this association was negative for long-distance runners (β=-0,260; p=0,020). All other BMI-related associations were positive: β=0,106 (p=0,030) and β=0,047 (p=0,005) for the metatarsal index in sprinters and control group, respectively; β=0,057 (p=0,024) and β=0,158 (p=0,031) for the midfoot index in long-distance and sprint runners respectively; β=0,086 (p=0,017) for the calcaneus index in sprint runners; and β=0,047 (p<0,001) for the control group. Age did not have any significant association with plantar footprint measurements (all p>0,05). No Significant association was found between predictor variables and plantar footprint measurements in swimmer either (p>0,05).

Table 4. Regression analysis for the association between years of training and plantar footprint measurements (foot index, metatarsal index, midfoot index, calcaneus index, isthmus index, and HC index).

VD	VI	Sprinters (n = 27)			Long-distance runners (28)			Swimmers (46)			Control group (66)		
		β	**SE**	**P**	**β**	**SE**	**P**	**β**	**SE**	**P**	**β**	**SE**	**P**
Foot index	**Years of training**	-,031	,059	0,610	,019	,032	0,550	,047	,042	,272	–	–	–
	Gender	-,522	,608	0,399	,610	,692	0,387	,219	,482	,652	-2,08	,323	**<,001**
	Age	,028	,046	0,543	,031	,026	0,247	,058	,041	,164	,064	,047	,182
	BMI	,302	,129	**0,028**	-,260	,104	**0,020**	,143	,102	,170	,063	,042	,140
Metatarsal index	**Years of training**	-,010	,021	0,642	,046	,025	0,084	,020	,017	,178	–	–	–
	Gender	-,664	,217	**0,006**	-1,43	,548	**,015**	,141	,197	,478	-,828	,122	**<,001**
	Age	,007	,016	0,689	-,013	,021	,517	,027	,017	,112	,005	,018	,800
	BMI	,106	,046	**0,030**	-,024	,083	,771	,023	,042	,581	,047	,016	**,005**
Midfoot index	**Years of training**	-,017	,032	0,591	,009	,017	,618	,024	,022	,298	–	–	–
	Gender	-,295	,325	,373	,377	,378	,328	,153	,259	,557	-1,08	,216	**<,001**
	Age	,016	,024	,523	,017	,014	,251	,032	,022	,149	,048	,031	,136
	BMI	,158	,069	**,031**	-,138	,057	**,024**	,078	,055	,160	,024	,028	,407
Calcaneus index	**Years of training**	-,004	,015	,802	-,003	,022	,878	,013	,011	,248	–	–	–
	Gender	-,242	,156	,135	,004	,467	,993	,059	,127	,641	-,381	,079	**<,001**
	Age	,005	,012	,686	,006	,017	,726	,012	,011	,291	,005	,012	,690
	BMI	,086	,033	**,017**	-,038	,070	,591	,033	,027	,230	,047	,010	**<,001**
Isthmus index	**Years of training**	,082	,059	,175	,028	,041	,505	,011	,040	,795	–	–	–
	Gender	,178	,605	,771	,955	,896	,297	,145	,465	,756	-,159	,331	,633
	Age	-,056	,045	,227	-,028	,034	,409	,049	,040	,223	,006	,048	,909
	BMI	-,023	,128	,857	,010	,135	,942	-,001	,099	,988	,081	,043	,067
HC index	**Years of training**	-,840	,576	,158	-,097	,418	,819	-,02	,368	,954	–	–	–
	Gender	-4,47	5,932	,458	-16,5	9,033	,079	-,75	4,232	,860	-2,18	3,41	,526
	Age	,592	,446	,197	,211	,338	,539	-,37	,360	,303	-,080	,50	,863
	BMI	,587	1,258	,645	-,15	1,360	,913	,112	,897	,902	-,64	,44	,155

Data split for sports modality (sprinters, long-distance runners, swimmers) and control group. Non-standardized beta and standard error (EE). Analysis were adjusted for gender, age, and BMI.

Binary logistic regression analysis

A logistic regression analysis, using foot curvature as dependent variable (with non-cavus as reference vs cavus foot) and sports modality (trained) and sedentary (control group) as independent variables, showed that none of them were in relative risk (odss ratio, OR) of having cavus foot (all p>0.05; Table 5). The same analysis, only using foot type as a dependent variable, showed that neither sports modalities nor the control group were in a higher risk of having a specific foot type, be it Egyptian, square, or Greek (all p>0.05), as displayed in Table 6).

Table 5. Relative risk (OR) of cavus foot for each sports modality.

		Sprinters				Long-distance runners			
		N	p	OR	95%CI	N	p	OR	95%CI
Cavus foot	**No**	75		1	Reference	75		1	Reference
	Yes	96	0,688	0,831	0,338-2,047	96	0,937	0,960	0,346-0,661
		Swimmers				**Control group**			
	No	75		1	Reference	75		1	Reference
	Yes	96	0,907	1,051	0,454-2,432	96	0,981	1,1013	0,366-2,804

CI = Confidence interval. OR was adjusted for gender, age, and BMI.

Table 6. Relative risk of Egyptian, square, or Greek foot for each sports modality.

		Sprinters				Long-distance runners			
		N	p	OR	95% CI	N	p	OR	95% CI
Egyptian	**NO**	47		1	Reference	47		1	Reference
	YES	124	0.172	0.531	0.214-1.318	124	<0.999	1.000	0.340-2.943
Square	**NO**	144		1	Reference	144		1	Reference
	YES	27	0.285	1.839	0.602-5.621	27	0.511	0.642	0.171-2.409
Greek	**NO**	152		1	Reference	152		1	Reference
	YES	19	0.279	1.867	0.603-5.781	19	0.293	2.229	0.501-9.924
		Swimmers				**Control group**			
Egyptian	**NO**	47		1	Reference	47		1	Reference
	YES	124	0.214	1.842	0.703-4.829	124	0.850	1.110	0.354-3.475
Square	**NO**	144		1	Reference	144		1	Reference
	YES	27	0.394	0.578	0.164-2.040	27	0.461	1.649	0.437-6.226
Greek	**NO**	152		1	Reference	152		1	Reference
	YES	19	0.388	0.545	0.137-2.163	19	0.204	0.208	0.018-2.345

CI = Confidence interval. OR was adjusted for gender, age, and BMI.

DISCUSSION

The present study aimed at analyzing the influence of training on the foot type of athletes with a specialization in sprint running, long-distance running, and swimming, as well as finding similar patterns between groups. Results reveal that years of training and age do not associate significantly with any specific footprint index. Female subjects in the sprinter, long-distance runner, and untrained categories scored lower on their metatarsal index, and only the untrained ones had lower values of foot index, midfoot index, and calcaneus index than male subjects. A positive association was also apparent between BMI and foot index, metatarsal index, midfoot index, and calcaneus index in sprint runners. For long-distance runners, however, BMI is positively associated with midfoot index but negatively associated with foot index. Results have also shown that regular training in sprint and long-distance runs, as well as in swimming, does not have a significant influence on foot curvature, nor does it modify foot type. Although not significant, the predominant foot type according to toe distribution was the Egyptian type, and according to curvature it was the cavus foot.

In the results of this research, the years of training have not caused adaptations in foot curvature or foot type in the case of sprinters, long-distance runners, or swimmers. These results differ from the findings of Sirgo, Méndez, Egocheaga, Maestro, and Del Valle (1997) who found differences in the foot print and support of practitioners of several disciplines (soccer and swimming). In the framework of a single sport, however, López, Alburquerque, Santos, Sánchez, and Domínguez (2005) concluded that there were no differences between the foot types of soccer players belonging to different categories.

In our findings, athletes scored higher in most footprint indices values than subjects in the control group. This is in agreement with the results of Kulthanan, Techakampuch, and Donphongam (2004), Elvira, Riera, García, and Roca (2006), and also with Franco et al. (2009), who measured the plantar footprints of sedentary individuals and compared it to those of athletes. Franco et al. (2009) attributed these differences to environmental and genetic conditions, or even to the continued use of sports shoes during training. On the other hand, other studies have rejected the use of a particular shoe type as a cause for foot modification, and have concluded that foot type is not a factor in performance and does not necessarily have an influence on the onset of injuries (Oestergaard et al., 2013). Berdejo-del-Fresno et al. (2013), also found adaptations in the footprints of left and right feet in elite female hockey and futsal players. They found that, in the case of hockey players, both feet tended to flatten, and that in futsal only the dominant foot flattened. In their study, however, sedentary women did not show any sign of footprint modification.

Judging by the indices measured in our study, athletes have wider and longer feet than the control group, which could be an adaptation to the need to stabilize and distribute weight loads during physical activity. As stress is applied to bone, muscle, and tendon groups a reaction is triggered to overprotect and adapt the locomotor system. Sport involves a continuous source of stress and a strain of foot architecture, if we judge by past research in which the feet and plantar footprint of athletes appears as significantly different from those of non sport-practicing subjects (Jones and Hunt, 1985). According to Sirgo et al. (1997), chronic adaptations might develop from the temporary adaptations to the strain of sport, as well as adaptations in gait as a way to prevent potential injuries caused by the strike of feet. This conclusion can also be applied to more demanding activities like high-performance sports.

The untrained female subjects in this study scored lower than males in the foot index, midfoot index, and calcaneus index measurements. According to Gómez, Franco, Nathy, Valencia, Vargas, and Jiménez (2009), sport-practicing women tend to have longer and wider feet than sedentary women, regardless of their height. More specifically, McWhorter, Landers, Wallmann, Altenburger, Berry, and Tompkins (2006) analyzed the effects of walking and running and observed that the feet of men and women responded differently to the effort of walking: the feet of men showed no difference after a twelve-minute walk, whereas the feet of women adapted to the exercise. Their results seem to point at the feet of men and women reacting differently to physical activity.

Despite the fact that some researchers have found a higher prevalence of subjects with a normal foot type (Zurita et al., 2007), in our study the most common type was the cavus foot in all groups, which agrees with the findings of Franco et al. (2009) and Gómez et al. (2009). Elvira et al. (2006) also found a prevalence of the cavus foot, and concluded that activities that take place on ground imply an additional strain for feet and require certain adaptations in the musculoskeletal structure of athletes. These adaptations usually take the form of a higher arch than in the feet of sedentary subjects. If physical activity is of a repetitive nature and extends for long periods of time the foot arch tends to become more pronounced (Wegener, Burns y Penkala, 2008). Our study, however, did not find differences between the feet of athletes and of subjects in the control group. In addition, the years of training and the age of subjects did not prove to have any influence on any of the footprint indices. We can therefore conclude that a specific sports practice is not an influential factor in the morphological adaptations of the plantar footprint, as it is not proven that a specific foot type corresponds to athletes or is the consequence of performing a certain physical activity.

Regarding the distribution of toes, the prevalent foot type in our study was the Egyptian type. According to Franco et al., (2009) this is the most common type in humans. In addition, most of our trained and untrained subjects had cavus feet. This is a controversial fact and must be considered with caution, as methods to assess the plantar footprint vary widely. For instance, if the HC index is used a foot might be considered cavus, whereas an arch-index measurement might result in categorizing the same foot as normal (Berdejo-del-Fresno et al., 2013). Clarifying this aspect is of the greatest importance, as heavily arched feet are more prone to injuries (Sánchez, 1993; Comín, 1999; Zurita et al., 2007). This is caused by a predisposition to underpronation which increases the risk of injury to the limbs (Olivera et al., 2001). Nevertheless, underpronation is not the only cause of injuries. Overpronation is linked to the eversion of feet, which causes a tibial rotation that can overload the knee, thus producing injuries at the knee and ankle (Hintermann & Nigg,1998).

It has been established that, in general, athletes have little knowledge of their foot type (Hohmann, Reaburn, y Imhoff, 2012). For their role in locomotion, and for their static and dynamic function, the morphology and structure of feet deserve great attention, in order to prevent training-related risks. The modifications of the plantar footprint of an athlete might reveal the need for plantar orthotics to avoid injuries and improve performance (Ozer and Barut, 2012; Wong, Chamari, Wisløff, and Hong, 2007). In the populations under study in this paper, runners should avoid overloads and harmful postures in their lower limbs, where over 90% of injuries are located (Fourchet et al., 2011; Nagel et al., 2008). In the case of sprinters, strength training workloads should be carefully controlled to avoid tendinopathies (Lee and Piazza, 2009). In addition, stress fractures in runners with a high arch have an incidence of 40% (Korpelainen et al., 2001), which further contributes to support the idea that knowing one's foot map helps avoid and recover from these lesions.

CONCLUSIONS

Years of training and age of sprinters, long-distance runners and swimmers are not associated with any specific footprint index (foot index, metatarsal index, midfoot index, calcaneus index, isthmus index, and HC index) or foot type (Egyptian, square, or Greek). The differences are greater between athletes and young sedentary individuals than between sports modalities. It can therefore be concluded that regular training in sprint running, long-distance running, or swimming does not exert an influence on foot curvature or foot type. Although not significantly, the most common foot type according to toe distribution is the Egyptian type, and for their curvature the most common type is the cavus foot. Gender and BMI must be taken into account in future biomechanical analyses of the foot morphology of athletes, as they are associated to different footprint indices according to the specific sport that subjects practice.

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