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ORIGINAL

ASSOCIATION FOOT MORPHOLOGY AND PERFORMANCE IN RHYTHMIC GYMNASTICS

ASOCIACIÓN ENTRE MORFOLOGÍA DEL PIE Y RENDIMIENTO EN GIMNASIA RÍTMICA

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ABSTRACT

The objectives of the study were to determine the influence of foot morphology on performance in Rhythmic Gymnastics and to analyze the influence of years of practice. The sample consisted of 48 gymnasts who had practiced federated gymnastics and competed during the last year. The results indicate that the gymnasts have predominantly a neutral foot and with a normal footprint, presenting enough asymmetry between feet, not significant, which may be a consequence of asymmetric work and should be corrected in training. Only the range of amplitude of the talocrural joint seems to be a characteristic of foot morphology that affects technical performance and seems more an innate characteristic. The practice of rhythmic gymnastics might not be as decisive a factor as could be supposed in the morphological modifications of the footprint.

KEY WORDS: Rhythmic gymnastics; performance; foot morphology.

RESUMEN

Los objetivos del estudio fueron determinar la influencia de la morfología del pie en el rendimiento en Gimnasia Rítmica y analizar la influencia de los años de práctica. La muestra estaba compuesta por 48 gimnastas que habían practicado gimnasia federada y competido durante el último año. Los resultados indican que las gimnastas tienen predominantemente un pie neutro y con huella normal, presentando bastante asimetría entre pies, no significativa, lo que puede ser consecuencia de un trabajo asimétrico y debería ser corregido en el entrenamiento. Sólo el rango de amplitud de la articulación talocrural parece ser una característica de la morfología del pie que incida sobre el rendimiento técnico y parece más una característica innata. La práctica de la Gimnasia Rítmica podría no ser un factor tan decisivo como podía suponerse en las modificaciones morfológicas de la huella plantar.

PALABRAS CLAVE: Gimnasia Rítmica; rendimiento; morfología del pie.

INTRODUCTION

The anthropometric characteristics of the foot is an interesting topic of research for sport, given the clinical and technical implications that their functionality involves. The normal foot and associated muscles guarantee the static and dynamic functions of the lower body, not only fulfilling an important role in preventing injuries but also playing a part in sports performance. A foot with no morphological alterations within the ranges considered normal is deemed “safer” for taking part in sports activities, as biomechanically it is better designed to absorb impacts, thus avoiding the appearance of injuries, not only to the foot itself, but to other lower limb articulations and the spinal column as well. On the contrary, in “unnormal” feet, exertion is more likely to be concentrated on certain parts of the foot, increasing the risk of injury (Queen, Mall, Nunley and Chuckpaiwong, 2009). In the same way, a “normal” foot favours the biomechanics of all of the actions of the foot as protagonist and, consequently, improved performance by the athlete when carrying out these actions.

There are a number of studies that focus on evaluating the characteristics of sportspeople’s feet with relation to injuries (Alfaro, 2017; Martinez-Amat et al., 2016; Cimelli and Curran, 2012; Padilla, 2011; Bennell et al, 1999). However, there has been some limited research on evaluating the structure of the foot in relation with the level of experience, the specificity of the training and sporting success (Spink et al.,2011; Jeanna, 2009). Specific sport and the subsequent training requirements ultimately determine the ground reaction forces and the mechanical demands placed on the body, which leads us to assume that such demands are capable of influencing the structure of the foot, or vice versa.

Rhythmic Gymnastics (RG) is a sport with highly-difficult technical content, being almost unique in that gymnasts train bare-footed or with gymnastics shoes that offer little protection. During competition exercises, as well as handling apparatus, gymnasts perform chosen from within the three most important body groups with the best execution possible, a value that is determined by a jury. The three main body actions that determine performance in RG (FIG, 2017) are Jumps/Leaps, Balances and Pivots/Turns, and in all three correct foot biomechanics are essential for perfect technical execution. Furthermore, not only is the behaviour of the foot analysed and evaluated by judges in the time spent interacting with the floor, but it still continues working when off the ground and not in contact with any surface.

The starting and performance age in sports such as gymnastics has become increasingly lower and, bearing in mind the intense training programmes gymnasts follow from an early age, it would only be reasonable for them to show skeletal muscle adaptations, as they begin intensive training regimes, involving the stretching and strengthening of foot muscles, before other athletes do, and when the skeletal muscle system is immature.

Research in other sports has found that elite male artistic gymnasts had a significantly lower foot arch in comparison with athletes from other sports, as well as with a non-athletic control group (Aydog et al., 2005a). Fascione (2005) found that distance runners had higher arches than sprinters. A study of sprinters (Jeanna et al., 2009) discovered a link between performance and some foot parameters that may suggest a competitive advantage or a consequence of an extensive training regime that may or may not be advantageous. These findings lead us to conclude that it could be an advantage for an athlete to have a specific type of foot for a particular sport, depending on the demands of that sport. We have found no specific RG study on the link between the plantar print and the gymnast’s level of experience and performance success. The aim of this research is to determine this link:

- To determine the morphology of the foot of our gymnasts and the influence of its characteristics on RG body technique execution.
- To find some podiatric pattern linked to body technique performance.
- To analyse the influence of experience as gymnasts on foot morphology.

METHODOLOGY

We carried out a cross-sectional, observational prevalence study among a group of gymnasts of different ages and levels. The sample was made up of 48 gymnasts who complied with the following inclusion criteria: to have been affiliated in the year prior to the study and to have competed in RG in the 2016-2017 season, not to have played any other sport outside RG, to sign the informed consent form to take part in the study and to have done gymnastics for at least a year.

The exclusion criteria adhered to was as follows: non-signature of the informed consent form, feet that are non-asymptomatic at the time of the study or having had surgery in the ankle and foot or knee complex.

Table 1. Gymnasts general description

		Mean±SD
Years		14±2,8
Years practicing Rythmic Gymnastic		7,15±3,339
BMI	Healthy	91,7%
	Overweigth	8,3%
Dominance	Rigth	81,3%
	Left	18,8%

SD: Standard deviation; BMI: Body mass index

We determined the body weight status (healthy and overweight) from the BMI, taking the Cole standards as a reference (Cole, Bellizzi, Flegal and Dietz, 2000).

Justification of sample size: The total number of gymnasts affiliated in Galicia in 2017 was 205. A sample size of 48 was considered necessary. Such a size enabled us to estimate the prevalence of the variables studied with a margin of error of ±15% and a 95% confidence level.

The sample selection was made via inclusion or convenience, as we included all of the gymnasts who wanted to take part, in compliance with the inclusion criteria, without selecting them randomly.

Procedure: Prior to measuring, a document was filled out with all of each participant's data, and then height and weight were measured. The following variables were determined:

Weight and height: A *SECA* height measuring rod (*SECA* Ltd, Germany) and *SECA* stand-on scales (*SECA* Ltd, Germany) were used to describe the anthropometric characteristics of a population. Weight was measured twice with an error of margin of 0.1 kg. Height was measured twice and rounded to the nearest millimetre.

Foot morphology: In order to analyse foot morphology, the following parameters were determined:

Static foot morphology evaluated via the six-category Foot Posture Index (FPI-6, Vijayakumar and Senthil Kumar, 2016). This is a method to classify the foot in five sections: highly supinated, supinated, neutral, pronated and highly pronated.

The six categories used to determine classification are: talar head palpation, supra and infra lateral malleoli curvature, calcaneal frontal plane position, prominence in region of TNJ, congruence of medial longitudinal arch and abduction/adduction of forefoot on rearfoot. Each one of these categories are valued on a scale from -2 to +2, where supinated features are given negative values (-2 and -1), neutral features 0 and pronated features positive values (+1 and +2). The value of this test will be verified via their sum in each foot (Vijayakumar and Senthil Kumar, 2016). In order to make comparisons of other variables with the FPI-6, we included the “highly pronated” in “pronated” and the “highly supinated” in “supinated”.

Type of print: We took the plantar print of both feet using a Harris mat. Participants stood on the rubber membrane of the Harris mat imprinter and the pressure exerted by the weight of the leg transferred the ink to the membrane, recording the image of the insole surface area (Gómez et all., 2003). This procedure enabled us to classify the print as normal, flat or cavus, following the criteria of the HC method (Hernández Corvo, 1989).

Foot length and width: Length was established via the foot-measuring device from the heel to the longest toe; and width by using a ruler placed perpendicular to a wall, with participants standing on the ruler with the outside of the foot against the wall and measuring the visibly widest point of the inner foot. Both measurements are in centimetres (cm).

Talocrural articulation (tibia, fibula, talus) range: this is determined by the Lunge test (Jeon, Kwon, Cynn, and Hwang, 2015), whose procedure is as follows:

1. Place a piece of sticky tape on the floor to the wall and another on the wall itself to form a 90% angle. Using a ruler, make a mark on the tape on the floor 10 cm from the wall.

2. Place one foot on the tape on the floor with the longest toe at the 10 cm mark. Place the other leg in a comfortable position behind. Hands must be placed on the wall.

3. Move the knee towards the tape on the wall without lifting the heel from the floor.

4. If the heel lifts, move the foot further forward until the test can be completed without lifting it.

5. Once this has been successfully achieved, an inclinometer is used to measure the angle in degrees of the tibial tubercle, thus marking the ankle joint dorsiflexion.

The distance at which the test is carried out with respect to the wall depends on height, so doing it at the stipulated 10 cm would not necessarily mean there is articular limitation. The test would be negative (limitation of talocrural articulation) in the event the angle in degrees marked by the inclinometer was less than 35º (Jeon et all., 2015).

Body technique

In order to evaluate the variables relating to body technique, an observational methodology was used by applying an observation checklist to five technical elements: two jumps/leaps, two balances and one turn/pivot. Elements with a lower level of difficulty (Code of Points, FIG 2017) were chosen to minimise to the greatest extent possible the influence that other variables, such as technical level or physical qualities, might have. The jumps used were the “split leap forward” and the “deer leap”, the balances, “passé releve” and passé balance with slow turn on the ball of the foot and, as a turn, “full turn in passé”.

The gymnasts carried out two repetitions of each of the technical elements, which were recorded on video and then given scores in accordance with the current Code of Points (FIG, 2017) by two widely-experienced international judges.

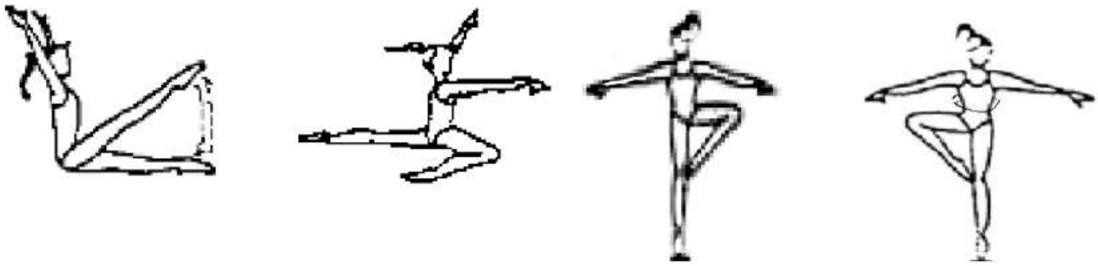

Fig 1. Technical elements performed

The parameters evaluated in the body elements in accordance with the Code of Points were:

- Jumps: Height and a defined and fixed shape during the flight.
- Balances: A defined and fixed shape (1 second).
- Turns: Degrees rotation in a defined and fixed shape.

Each parameter was evaluated starting from a maximum score of 10 points, and penalty points were deducted (Code of Points, FIG, 2017) in accordance with the deviations in gymnasts' executions in respect of the correct technical execution, adding together the score achieved for each body group and for the total score corresponding to body technique. The intra and inter-observer reliability was evaluated with the intraclass correlation coefficient (ICC), with a 95% confidence interval (CI), obtaining values of 0.91 and 0.80, respectively.

Statistical analysis

A descriptive analysis of study variables has been carried out: the qualitative variables are represented through frequency and percentage and the quantitative variables through mean ± standard deviation. The homoscedasticity and normality of the variables were tested using the Levenne and Kolmogorov-Smirnov tests, respectively. An independent *t*-test was used to evaluate differences between the two feet.

All of the possible associations between qualitative variables via the statistical analysis of variance (one-way Anova) were analysed. In order to analyse the relationship between the quantitative variables, the Pearson correlation coefficient (*r*) and linear regression was used.

Ethical aspects

All of those who took part did so voluntarily, having been informed previously of the aim and purpose of the study and the types of tests they were going to be subjected to in an information booklet. The informed consent on behalf of the subjects in the study was required. Authorisation from the legal guardian was required if the subject was a minor.

The confidentiality of the information obtained in the study was guaranteed by the existing law (Organic Law 15/1999, of 13 December, on Personal Data Protection), anonymising the record sheets and the questionnaires for data handling and dissemination of results.

The Declaration of Helsinki's good clinical practice guidelines were followed and the study was given a favourable report by the Office of the Vice-Chancellor for Scientific Policy, Research and Knowledge Transfer at A Coruña University (UDC).

RESULTS

With regard to the gymnasts' foot morphology (table 2), the frequencies on the FPI-6 for the right foot were as follows: 72.9% had a neutral foot, 2.1% a supinated foot and 25% a pronated foot. The FPI-6 for the left foot showed that 75% had a neutral foot, 2.1% a supinated foot and 22.9% a pronated foot.

Table 2. Foot morphology and plantar print frequency (FPI-6)

	Rigth		Left			Rigth		Left	
Foot morphology *p* 0,569	**n**	**%**	**n**	**%**	**Plantar print** *p* 0,659	**n**	**%**	**n**	**%**
Neutral	36	72,9	35	75	**Normal**	34	70,8	35	72,9
Supinated	1	2,1	1	2,1	**Flat**	1	2,1	1	2,1
Pronated	11	25	12	22,9	**Cavus**	13	27,1	12	25

In respect of the type of plantar print (table 2), for the right foot we found 70.8% had normal prints, 2.1% were flat and 27.1% cavus. For the left foot, 72.9% were normal, 2.1% flat and 25% cavus. The differences between the right and left foot were not significant, either with regard to the type of foot or the type of print.

If we analyse the relationship between the type of foot, the print and years spent doing the sport (table 3), we can find differences that are only significant for the type of foot between the two groups. We can see that 74.4% of gymnasts with more than five years in the sport have neutral feet as opposed to 66.7% in those with less than five years. The percentage of pronated feet is higher in gymnasts who have been in the sport fewer years, 33.3% opposed to 23.1%.

Table 3. Type of foot frecuency, type of print and years of practice

		Rigth foot		Left foot			Rigth foot		Left foot	
		p 0,008*		*p* 0,007*			*p* 0,585		*p* 0,469	
	Type of foot	n	%	n	%	**Type of print**	n	%	6	66,7
Less tan 5 years	Neutral	6	66,7	6	66,7	Normal	5	55,6	3	33,3
	Pronated	3	33,3	3	33,3	Cavus	4	44,4	9	100,0
	Total	9	100,0	9	100,0	Total	9	100,0	29	74,4
More tan 5 years	Neutral	29	74,4	30	76,9	Normal	29	74,4	1	2,6
	Supinated	1	2,6	1	2,6	Falt	1	2,6	9	23,1
	Pronated	9	23,1	8	20,5	Cavus	9	23,1	39	100,0
	Total	39	100,0	39	100,0	Total	39	100,0	6	66,7

*p: significative

The remaining qualitative variables (length, width of both feet and talocrural articulation range) are shown (table 4) via their mean, median and standard deviation. Although differences between the right and left foot exist, they are not significant for length, width and the lunge test.

Table 4. Statistical of length, width of booth feet and talocrural articulations range

	Mean and SD	**p**
Rigth foot length	23,050±1,2167	0,020
Left foot length	22,931±1,2656	
Rigth foot width	8,185±0,7949	0,030
Left foot width	8,285±0,8508	
Lunge Test rigth foot	48,625±3,3633	0,556
Lunge Test left foot	48,844±4,1932	

SD: Standard deviation; *p: significative

Table 5. Statistical of length, width of booth feet and talocrural articulations range and years of practice

		Mean and SD	**p**
Less tan 5 years	Rigth foot length	22,211±0,8023	0,159
	Left foot length	22,067±0,7263	
	Rigth foot width	7,944±0,7248	0,272
	Left foot width	8,078±0,8363	
	Lunge Test rigth foot	46,133±3,36674	0,907
	Lunge Test left foot	47,178±4,4488	
More tan 5 years	Rigth foot length	23,244±1,2208	0,046
	Left foot length	23,131±1,2854	
	Rigth foot width	8,241±0,8087	0,866
	Left foot width	8,333±0,8576	
	Lunge Test rigth foot	49,200±3,0577	0,471
	Lunge Test left foot	49,228±4,0953	

SD: Standard deviation.

Table 5 shows results for the length, width and lunge test variables according to years of training. Although differences in the two groups can be observed, they are not significant.

And, lastly, we show the results that correspond to the variables relating to body technique (table 6), reflected in the three main groups of body elements pertaining to RG: Jumps/Leaps, balances and rotations. Each body element executed was evaluated under two criteria, determined by the current Code of Points (FIG, 2017) from 10 to 0 points. The summations of the data from the overall rating of the Jump/Leap, Balance and Rotation elements are shown as the summation of all the body elements.

Table 6. Statistical of the body technique elements

		Mean and SD
Leap body group	Height Scissors Leap	6,38±,981
	Defined and Fixed shape Scissors Leap	6,79±1,010
	Height Stag Leap	6,52±,967
	Defined and Fixed shape Stag Leap	6,83±1,209
	Total Leap Body Technique	26,8750±3,55
Balance body group	Cleary Fixed Passé Balance	6,56±1,303
	Shape Passé Balance	6,77±,994
	Cleary Fixed Tour Lent Passé	6,10±1,153
	Shape Tour Lent Passé	6,23±1,036
	Total Body Balance Technique	25,9583±3,97
Rotation body group	Degrees of rotation Passé Rotation	6,40±1,250
	Shape and fixation Passé Rotation	6,46±1,148
	Total Body Rotation Technique	12,9792±2,14
	Total Body Technique	65,0417±9,84

SD: Standard deviation.

The results of studying the associations between qualitative variables and body technique (Table 7, one-way Anova) show us that there is no significant relationship between foot morphology, the type of plantar print and the body technique results.

Table 7. Results of association between body technique, foot morphology and type of foot print

	F BT Global		**F BT Leaps/Jumps**		**F BT balance**		**F BT Rotations**	
	Rigth F	**Left F**	**Rigth F**	**Left F**	**Rigth F**	**Left F**	**Rigth F**	**Left F**
Foot Type	0,572 p:0,569	0,998 p:0,377	0,607 p:0,549	0,654 p:0,525	0,603 p:0,551	1,102 p:0,341	0,514 p:0,602	0,855 p:0,432
Footprint Type	1,309 p:0,280	0,465 p:0,631	0,476 p:0,247	0,883 p:0,625	0,684 p:0,510	0,542 p:0,585	0,837 p:0,440	0,399 p:0,674

BT: Body technique; F: foot; **: p significative ≤ 0,01; *: p significative ≤ 0,05

The results of studying the associations between quantitative variables and body technique (the Pearson correlation) are not significant for foot length and width, although there is a significant result between the lunge test with overall technique, jump technique, balance technique, and with rotation technique in both feet. And the results are always higher for the right foot than for the left.

Table 8. Pearson correlation results between body technique and morpho-structural changes in the feet and the Lunge test

r	**BT Global**	**BT Leaps/Jumps**	**BT Balance**	**BT Rotations**
Lunge Test RF	,406**	,387**	,371**	,390**
Test de Lunge LF	,351*	,310*	,290*	,330*

r : Pearson Correlation; BT: Body technique; RF: Rigth foot; LF: Left foot; **: p significative ≤ 0,01; *: p significative ≤ 0,05

The linear regression analysis shows us that the lunge test has a low predictive value with regard to the body technique results (R squared 0.165 right foot and R squared 0.123 left foot).

DISCUSSION

The foot morphology and footprint of the female gymnasts studied show non-significant asymmetries in a similar way to other studies (Lichota, Plandowska and Mil, 2013), (Elvira, Vera-García, Meana and García, 2008) which obtained significant differences between both feet. Franco, Nathy, Valencia and Vargas (2009), in a study with a sample of sedentary subjects and athletes, also found a high percentage of non-symmetrical individuals (58% as opposed to 42%), higher in the sample of athletes. The explanation of Elvira et al. (2008) as to why this was so was that the athletes were always forced to run or walk in the same direction round the circuit. However, in a study carried out with 497 boys and 534 girls of school age, Delgado (2015) found no significant differences in the comparison between the two feet in the majority of the variables analysed. In our study, although the differences are not significant either, they could be due to the type of specific technical effort involved, which causes the gymnasts to bear the weight on one foot (the good leg) more than on the other (Batista, Bobo, Lebre and Ávila-Carvalho, 2015). This one-sided effort can put gymnasts' harmonious development at risk and possibly lead to injury (Zetaruk, Violan, Zurakowski, Mitchell and Michell, 2006) on account of imbalances, which is why it should be corrected in training.

Our results with respect to the type of foot (FPI-6) show that the neutral foot is predominant (75%), followed by the pronated foot (22.9%). Martínez Nova et al. (2014) evaluated the foot posture index (FPI) in different sporting groups, finding similar results to ours in respect of the normality of static foot morphology, although with a greater tendency towards pronation in basketball players and runners than in handball players, who show a greater tendency towards supination.

Our gymnasts show a mainly normal footprint (72.9%), followed by a pes cavus print (25%), as opposed to other studies, such as the one by Berdejo-del-Fresno, Lara, Martínez-López, Cachón and Lara (2013), which found that the imprints of both feet tended towards flat in female hockey players, and modifications in the dominant foot of female indoor football players, whereas sedentary females showed no footprint differences. Another study makes reference to a significantly lower arch in elite gymnasts (artistic gymnastics) in comparison with athletes from other sporting fields, as well as a non-athletic control group (Aydog et al., 2005b). These authors found significant differences not only in the arch but also in the muscular strengths of the ankle dorsiflexion, which are lower in gymnasts than in healthy non-athletic controls. The type of surface artistic gymnasts exercise on, which is elastic, may explain these differences. Other authors (Franco et al., 2009) compared the foot imprints of sportspeople from different sports, such as swimming, weightlifting, athletics and sedentary students. The results coincide with those found in our study, in that both sportspeople and sedentary subjects tend towards a normal-cavus type of foot and that doing sport is not an influential factor in the modifications relating to symmetries or asymmetries in an individual's footprint.

Hernández Guerra (2006) evaluated the type of foot in the group comprising boys and girls from 9-12 years of age, ages near those in our study, finding a greater prevalence of normal and cavus feet since the childhood stage. Other studies (Elvira et al., 2006), (Wegener, Burns and Penkala, 2008) found a prevalence of cavus feet, and conclude that the activities carried out in the terrestrial environment, especially if they are repetitive and lasting, involve an extra work load and more stress for the foot and that certain muscular skeletal adaptations to the sportsperson's foot that tend to mould it, creating a higher foot arch than that found in sedentary subjects, are necessary. Martinez-Amat et al. (2016) point out in their study that the participants, both trained and untrained, were mainly shown to have pes cavus, although they specify that this could be a controversial result given the high degree of variability between the measurement techniques used to evaluate the footprint that could alter the results. This variability might provide an explanation for the contradictory data between the different studies in the bibliography and ours.

The results obtained by our gymnasts with regard to foot width and length are slightly lower than those shown by Delgado (2015) and Mazoteras (2017) in samples of Spanish schoolchildren younger than our gymnasts. The reason for this could lie in the constitution required for this particular sports discipline, that is, to be slim and not very tall. Other authors (Martinez-Amat et all., 2016), (Elvira et all. 2008) obtain significant differences in foot length and width as opposed to non-sportspeople, which could be due to the mechanical demands they are subjected to. These kinds of adaptations would not seem to occur in gymnastics. It could be that the work of the bare foot on a non-deformable non-elastic surface is the cause and this would require a more in-depth study.

We have found significant differences between foot morphology and years of experience in our study for the type of foot and not for the type of print. And although there are differences related to experience in foot width and length, they are not significant and it could be that the more years spent in the sport, the older the gymnast and, therefore, the bigger the foot. Jeanna et al. (2009) found significant differences between the measurements of the footprint (length and width) and the experience and results in runners and between quicker and slower sprinters. These results may suggest an adaptation of the type of foot to the specific demands of a particular sport. Martinez-Amat et al. (2016) found that the years spent training in sprinters, distance runners and swimmers have not caused modifications to foot curvature or type. Other studies within one sport (Berdejo et all., 2013, López, Alburquerque, Santos, Sánchez and Domínguez, 2005) concluded that there were no differences between the type of foot in footballers from different categories. In our study, the age of the gymnasts may be a factor that, together with the years spent in the sport, explains the morphological alterations found.

The relationship of the foot with sports performance variables was only significant for the lunge test with the three body groups characteristic of this sport's body technique. The lunge test measures the talocrural articular range during dorsal flexion (Jeon et al., 2015). Dorsiflexion (DF) of the talocrural articulation allows dorsal flexion movement in the sagittal plane and is one of the foot's most important and complex articulations. An adequate DF range is necessary to enable the correct execution of sports activities whose protagonist is the lower body. Evaluation of the range of motion for talocrural dorsiflexion is essential to identify the risk factors involved in a number of injuries to the lower limbs (Alfaro et al., 2017), (Matthew and Patrick, 2011). However, there are few references in literature that link it to performance factors. Spink et al. (2011) showed that the range of motion for dorsiflexion is significantly linked to balance and functional ability in basic movements such as climbing a step and walking quickly.

Hamilton, Hamilton, Marshall and Molnar (1992) found greater ankle dorsiflexion range in professional dancers. In a study of dancers, Bennet et al. (1999) produced similar results to ours, finding a 25% greater ankle dorsiflexion than in non-dancers. And they did not find significant correlations between range of motion and years of training and number of hours per week of training, which was similar to our study's findings and, therefore, we cannot consider it to be a case of the foot adapting to training. On the contrary, Russell, Kruse, Nevill, Koutedakis and Wyon (2010) make reference to the loss of ankle dorsiflexion range with experience, a relationship not observed in our gymnasts, perhaps because of their young age, and the result, among other causes, of the specificity of pointe work in ballet.

The results for the lunge test obtained by our sample are clearly higher than those referenced in the bibliography (Morales 2017, Jeon et al., 2015, Matthew and Patrick, 2011), which could represent an advantage when gymnasts are executing technical elements in which talocrural dorsiflexion is of vital importance, such as jumps, leaps or turns.

CONCLUSIONS

Our study's results show that gymnasts predominantly have one neutral foot with a normal print, showing a fair degree of asymmetry between one foot and the other, which could be the consequence of asymmetric work and should be corrected in training. Foot width and length are slightly lower than the average for schoolchildren of similar ages.

None of these variables is significantly linked to performance and would not seem to respond to adaptations to training as a consequence of years of practice. The ankle dorsiflexion range of motion is greater in our gymnasts than that referred to in literature and does have a significant link to technical performance but not to the years of training.

RG might not be as decisive a factor in the morphological modifications of the footprint as might be assumed. Only a greater talocrural dorsiflexion range would seem to represent a foot morphology characteristic that could affect technical performance, and it would not appear to be an adaptation to training or years' experience in the sport.

A wider sample and greater age range would enable us to carry out a more in-depth analysis of gymnasts' foot morphology. More detailed information on the quality and quantity of training would allow us to better understand the specific effects of dose-response on such training, instead of being inferred from self-reporting by the subjects. A cross-sectional study design makes causal attribution problematic and a longitudinal study design would be better suited to enable us to confirm the nature of the results found.

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