Rev.int.med.cienc.act.fís.deporte - vol. X - número X - ISSN: 1577-0354

Latorre-Román, P.A.; Soto Hermoso, V.M.; García-Pinillos, F.; Gil-Cosano, J.J.; Robles Fuentes, A.; Muñoz Jiménez, M. y Molina-Molina, A (202x) Fatigue's Effects on Spatiotemporal Parameters and Footstrike Patterns During a Half Marathon. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. X (X) pp. xx. Http://cdeporte.rediris.es/revista/___*

ORIGINAL

DOES FATIGUE AFFECT THE KINEMATICS OF ENDURANCE RUNNING?

¿AFECTA LA FATIGA A LA CINEMÁTICA DE LA CARRERA DE RESISTENCIA?

Latorre-Román, P.A.[1]; Soto Hermoso, V.M.[2]; García-Pinillos, F.[2,3]; Gil-Cosano, J.J.[4]; Robles Fuentes, A.[2]; Muñoz Jiménez, M.[1] & Molina-Molina, A.[2,5]

[1] Universidad de Jaén, Departamento de Didáctica de la Expresión Musical, Plástica y Corporal, Jaén (Spain) platorre@ujaen.es, mmjimene@ujaen.es

[2] Instituto Mixto Universitario Deporte y Salud (iMUDS), Departamento de Educación Física y Deportiva, Facultad de Ciencias del Deporte, Universidad de Granada, Granada (Spain) vsoto@ugr.es, fegarpi@gmail.com, saltodemanos@yahoo.es, amolinam@ugr.es

[3] Departamento de Educación Física, Deportes y Recreación. Universidad de La Frontera, Temuco (Chile) fegarpi@gmail.com

[4] PROFITH "PROmoting FITness and Health through Physical Activity" Research Group, Instituto Mixto Universitario Deporte y Salud (iMUDS), Departamento de Educación Física y Deportiva, Facultad de Ciencias del Deporte, Universidad de Granada, Granada (Spain) josejuangil@ugr.es

[5] Universidad San Jorge, Facultad de Ciencias de la Salud, Villanueva de Gállego, Zaragoza (Spain) amolinam@usj.es

Spanish-English translator: Katie Uniacke, katie@katieuniacke.com

Código UNESCO / UNESCO code: 240602, Biomecánica / Biomechanics
Clasificación Consejo de Europa / Council of Europe classification: 3. Biomecánica del deporte / Sport'sBiomechanics

Recibido 27 de noviembre de 2020 **Received** November 27, 2020
Aceptado 29 de mayo de 2021 **Accepted** May 29, 2021

ABSTRACT

The purpose of this study was to determine the footstrike pattern (FSP), inversion (INV) and spatial-temporal variables in a large sample of recreational runners during a long-distance competition, according to sex and changes in the classification race. A total of 368 men and 67 women, who participated in the XVII International Half Marathon of Cordoba (Spain) were analysed. It was recorded at km 5 and km 15, where high-speed camcorder and 2D-photogrammetric techniques were used to measure FSP, INV, contact time (CT) and flight time (FT). The group that worsened their classification at km 15 increase RFS prevalence and INV asymmetry. A Pearson analysis indicates that variation of the classification in the race between the marks km 5 and km 15 is related with CT ($r=0.429$, $p<0.001$) and FT ($r=-0.360$, $p<0.001$). RFS prevalence and spatial-temporal parameters showed different patterns depending on whether the runners improved or worsened their ranking.

KEYWORDS: running; long distance; endurance; biomechanics; performance.

RESUMEN

El objetivo de este estudio fue determinar el patrón de pisada, inversión y variables espaciotemporales para una amplia muestra de corredores amateurs, durante una carrera de larga distancia, según sexo y posición de clasificación. Se analizaron 368 hombres y 67 mujeres, que participaron en la XVII Media Maratón Internacional de Córdoba (España). Se registró el km 5 y km 15, utilizando técnicas de fotogrametría 2D de alta velocidad para medir la pisada, la inversión, el tiempo de contacto (TC) y el tiempo de vuelo (TV). El grupo que empeoró su clasificación en el km 15 aumentó la prevalencia de FSP y la asimetría del INV. Un análisis de Pearson indica que la variación de la clasificación en la carrera está relacionada con TC ($r=0,429$, $p<0,001$) y TV ($r=-0,360$, $p<0,001$). La prevalencia de retropié y los parámetros espaciotemporales mostraron diferentes patrones dependiendo de si los corredores mejoraron o empeoraron su clasificación.

PALABRAS CLAVE: carrera; larga distancia; resistencia; biomecánica; rendimiento.

INTRODUCTION

Running as an activity to improve health and personal performance has become increasingly widespread among the recreational population. Today, the number of participants in popular endurance races has increased, along with the number of organized running races. For instance, in the half marathon of Valencia 2020, Spain, 19,076 runners (19.51% women) finished the race. The popular phenomenon of running is due, among other factors, to the satisfaction of physical and psychological health needs, goal achievement, tangible rewards, social influences, and easy availability (Carmack & Martens, 2016; Urbaneja & Farias, 2018). Advances in the description of the physiological, psychological and especially biomechanical characteristics of these runners is necessary in term of injury prevention and performance improvement. In this context, the spatiotemporal gait parameters such as: contact time (CT), flight time (FT), step frequency, kinematics parameters such as: foot strike patterns (FSPs) and kinetics variables such as: impact loading rate, ground reaction force, etc., have been widely studied, although with controversial results (Kim et al., 2018).

Today, runners sustain injuries at a high rate: Despite the scientific and technological advances around running, training control, technique or footwear, between 27% and 70% of recreational and competitive distance runners are injured during any period of the year (Daoud et al., 2012; Fields et al., 2010; Van Gent et al., 2007). The etiology of these injuries is multifactorial. Several intrinsic and extrinsic factors have been implicated as risk factors of lower extremity injury, for instance: 1) age, sex, physical fitness, anatomic misalignments; and 2) body mass index, previous injury, inadequate rehabilitation, level of competition, number of weekly sessions of training, shoe type, running surface, respectively (Benca et al., 2020; Murphy et al., 2003; Salas Sánchez et al., 2013; Tauton et al., 2002; Van Gent et al., 2007).

However, there is controversial debate regarding what are the most important factors of injury risks for runners. Issues related to risk factors and optimal FSP are the subject of prominent discussion, such as, for example, the dynamics of the foot in contact with the ground, and the ideal running shoes (Davis & Hollander, 2020). Recently, Kulmala et al. (2018) that highly cushioned shoes increase leg stiffness, impact loading and change the spring-like mechanics of running in athletes who run with rearfoot strike (RFS). In turn, running in conventional and maximalist footwear may increase demands on the musculoskeletal structures to reduce impact transients, which may be detrimental to passive tissues. Therefore, running with cushioned shoes influences injury risk in recreational runners overall (Malisoux et al., 2020). In addition, modern running shoes have altered our FSP from a predominantly forefoot strike (FFS), landing with the ball of the foot to a predominantly RFS, landing with the half or rear third part of the sole only (Davis et al., 2017). Consequently, the sudden force of loading is distributed across the runner's musculoskeletal system, making FSP a significant predictor of injuries (Cheung & Davis, 2011; Daoud et al., 2012; Pohl et al., 2008, 2009). In this regard, although running with FFS seems to be a characteristic of human evolution (Daoud et al., 2012), adult amateur endurance runners exhibit a high prevalence — between 74.9% and 95.4% — of RFS (Hasegawa et al., 2007; Kasmer et al., 2013; Larson et al., 2011; P. A. Latorre-Román et al., 2015). RFS is associated with higher vertical loading, ankle stiffness and knee stiffness (Cheung & Davis, 2011) and some previous studies have suggested its association with injury risk (Daoud et al., 2012; Lieberman et al., 2010). Lieberman et al. found higher force collision at foot-strike on RFS than midfoot strike (MFS) and FFS (Lieberman et al., 2010). According to several studies, RFS and FFS usually have different patterns of ground reaction force; RFS landings generate a rapid and high-impact peak in the ground reaction force, just after foot strike against the ground; FFS also generates an impact, although there is not a clear and accentuated impact peak (Lieberman et al., 2010; Williams et al., 2000; Wit et al., 2000).

The use of the different FSPs also depends on the running speed, running surface, fatigue (Daoud et al., 2012) and runners' levels (Latorre-Román et al., 2015). In particular, an FFS may become difficult to maintain in longer endurance events (Jewell et al., 2017). Accordingly, Ogueta-Alday et al. (2018) note that among long-distance runners there is a relationship between athletic level in the half marathon and the type of FSP; in this sense, high-level runners showed the highest percentage of MFS/FFS (~ 73%) and a lower CT compared to the other three lower-level groups. The increase in CT shows a strong relationship with the increase in step length during a run to exhaustion at VO2max speed.

Consequently, the ability to maintain a short ground CT appears to be absolutely necessary to maintaining performance during a run to exhaustion (Hayes & Caplan, 2014). In addition, a shorter CT with inversion at the initial foot contact allows the use of elastic energy and stiffness of the leg muscle to increase running economy (Hasegawa et al., 2007). However, Latorre-Román et al. (2017) indicated that there were no significant changes in the kinematics [CT and FT] and FSP characteristics in endurance runners after fatigue induced by a long high-intensity intermittent training (HIIT) consisting of 5x2000 m with 120 s recovery between runs and high fatigue levels. Likewise, García-Pinillos et al. (2016) report that neither athletic performance nor exhaustion level reached seems to be determinant in the kinematic variables such as CT, FT and step length and FSP response during a HIIT consisting of 4×3×400 m repeats with a passive recovery period of 1 minute between runs and 3 minutes between sets.

Therefore, despite numerous studies trying to define the advantages and disadvantages of certain foot-striking patterns and footwear (Kasmer et al., 2013), few studies have been conducted regarding FSPs in large samples of recreational runners during a long-distance race competition (Hasegawa et al., 2007; Kasmer et al., 2013; Latorre-Román et al., 2015). The disadvantage of these studies is that they did not carry out an intra-participant analysis during the race. Consequently, little is known about the evolution of FSP and kinematic variables during a long-distance race through measures in several marks of the race in recreational runners. Recently, Bovalino et al. (2020) and Larson et al. (2011) showed that a large percentage of runners modified their FSP from non-RFS to RFS, from the initial phase to the later phase of the race. However, these studies did not analyze the effect of changes in the classification of the runners during the race on kinematic variables, i.e. intra-participant differences.

Considering the above information, this study focused on fatigue-induced changes on kinematic parameters in recreational long-distance runners. Therefore, the purpose of this study was to determine FSP, inversion and spatial-temporal variables in a large sample of mostly recreational runners during a long-distance road competition, according to sex and changes in the classification during the race between two kilometric marks (km 5−km 15).

MATERIALS AND METHODS

PARTICIPANTS

Four hundred thirty-five athletes (368 men and 67 women) who participated in the XVII International Half Marathon of Cordoba were analyzed. The runners were recorded at two different kilometer marks over the course of the race: km 5 and km 15. These localizations were chosen by considering the space between athletes (i.e. avoiding the crowd at the start) and the lack and presence of fatigue in km 5 and km 15 marks, respectively. The study was approved by the ethics committee of the University of Jaen.

PROCEDURES

Sagittal plane videos (240 Hz) were recorded using a high-speed camcorder (Casio Exilim EXF1, Shibuyaku, Tokyo 151–8543, Japan) at km 5 and km 15. Videos were taken from a lateral view, with the camera perpendicularly placed 5 meters from the participant so that they could be filmed in the sagittal plane. The filming location was set along a 5-meter corridor. Video data were analyzed using a 2D video editor (VideoSpeed vs1.38, Granada, Spain). The 2D video-based determination of the FSP has been used in other studies (Hollander et al., 2018) and, despite not being as exact as the biomechanical determination, it is practical for the assessment of a large cohort (Hollander et al., 2016) and is valid and highly reliable regardless of the experience of the assessor (de Oliveira et al., 2019). The dependent variables selected for the kinematics analysis are in line with previous studies (Hasegawa et al., 2007; Larson et al., 2011; Latorre Román et al., 2017) and are as follows: FSP at first contact with the ground, from rearfoot to forefoot: RFS, where initial contact is made somewhere in the heel or back third of the foot; MFS, where the heel and sole make contact almost simultaneously; and FFS, where initial contact is made with the metatarsal heads. Figure 1 shows pictures that illustrate different FSPs. According to the procedure used in previous studies (Hollander et al., 2018), the FSP was rated as RFS or non-RFS since this dichotomous variable shows very high accuracy in determining an RFS (inter-rater accordance: 0.981) and lower accuracy in deciding between an FFS and MFS (0.893)(Hollander et al., 2018). In turn, the inversion (INV) in stance phase was observed in relation to rotation on the antero-posterior axis and was registered when the shoe contacts the ground in its lateral part. In addition, using 2D photogrammetric techniques, contact time (CT) (time for which the foot is in contact with the ground) and flight time (FT) (time during which there is no contact with the ground) were analyzed. Moreover, asymmetries between the right and the left foot were also analyzed. Filming locations, both at km 5 and km 15 marks were characterized by relatively flat ground surfaces so that FSP would not be influenced by incline or decline of ground surface. For each runner, approximately four acceptable foot strikes were captured on film (two right and two left).

Figure 1. Foot strike type and inversion of the foot. From left to right: Rearfoot strike, midfoot strike, forefoot strike, and inversion.

STATISTICAL ANALYSES

Descriptive statistics are represented as mean, standard deviation, frequency and percentage. To analyze the differences between quantitative and nominal variables, analysis of variance (ANOVA) and McNemar's test were used, respectively. The average of both feet (left and right steps) was used for spatial-temporal variables. In addition, in a sample of 80 runners, intra-observer and inter-observer reliability were calculated using Cohen's Kappa and proportion of agreement for FSP and INV. These observations were performed by three experienced observers between the changes in the classification in the race between km 5 and km 15 marks and CT and FT. The level of significance was $p < 0.05$. Data analysis was performed using SPSS (version 21, SPSS Inc., Chicago, Ill, USA).

RESULTS

The intra-observer reliability obtained for FSP was Kappa = 0.904 value and for inversion Kappa = 0.732 value. The inter-observer reliability obtained for FSP was Kappa = 0.801 ± 0.09 value, and for inversion Kappa = 0.727 ± 0.11 value. Table 1 shows the proportion of agreement for FSP and inversion.

The classification in the race from km 5 to km 15 mark got worse both in men (187.51±109.11 vs. 210.71±119.56 rank, p<0.001) and women (385.44 ±63.88 vs. 450.89±71.59 rank, p<0.001). Table 2 shows FSP, INV and the asymmetry for the whole group and regarding sex at km 5 and km 15 marks. In the total sample and in men there is a significant increase of RFS prevalence from km 5 to km 15 mark. However, women did not show significant changes. Likewise, INV asymmetry displayed the same behavior. Taking into account the runners who improve (range Δ22.37) and worsen (range Δ46.27) their classification from km 5 to km 15 mark, Table 3 shows that the group whose classification worsens at km 15 mark increases RFS prevalence and INV asymmetry. Moreover, significant differences were found in CT and FT both in men and in women (Figure 2). Women increased CT (p<0.001) and reduced FT (p<0.01) at km 15 mark. However, men increased FT (p<0.001) at km 15 mark. In addition, the runners who improved ranking at km 15 mark reduced CT (p<0.01) and increased FT (p<0.001) (Figure 3). The runners whose ranking worsened, increased CT (p<0.05). A Pearson correlation analysis indicated that variation of the classification in the race between km 5 and km 15 mark was related to CT (r=0.429, p<0.001) and FT (r=-0.360, p<0.001).

Table 1. Proportion of agreement for FSP and inversion (intra-observer)

	RFS	MFS	FFS	INV
RFS	88.66%			
MFS		83.3%		
FFS			100%	
INV				85%

RFS: rearfoot; MFS: midfoot; FFS: forefoot; INV: inversion.

Table 2. FSP, INV and the asymmetry according to the total sample and sex at km 5 and km 15 marks

	All				Men				Women			
	Km 5		Km 15		Km 5		Km 15		Km 5		Km 15	
	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot
RFS	400 (92.0)	401 (92.2)	416 (96.1)***	412 (95.2)*	336 (91.3)	337 (91.6)	351 (9.9)***	349 (95.1)*	64 (95.5)	64 (95.5)	64 (95.5)	65 (97.0)
RFS asymmetry	17 (3.9)		17 (3.9)		15 (4.1)		13 (3.6)		2 (3.0)		4 (6.0)	
INV	210 (48.3)	210 (48.3)	215 (50.2)	214 (49.7)	193 (52.4)	190 (51.6)	210 (48.3)	210 (48.3)	215 (50.2)	214 (49.7)	193 (52.4)	190 (51.6)
INV asymmetry	30 (6.9)		50 (11.8)**		27 (7.3)		45 (12.6)**		3 (4.5)		5 (7.6)	

RFS: rearfoot strike; INV: inversion; *p<0.05, **p<0.01, p<0.001. Data is displayed as n (%).

Table 3. FSP, INV and the asymmetry according to the classification at km 5 and km 15 marks

	Runners who improved their ranking				Runners who worsened their ranking			
	Km 5		Km 15		Km 5		Km 15	
	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot	Left foot	Right foot
RFS	94 (89.5)	93 (88.6)	98 (95.1)	97 (93.3)	306 (92.7)	308 (93.3)	318 (96.4)**	318 (96.4)*
RFS asymmetry	7 (6.7)		3 (2.9)		10 (3.0)		10 (3.0)	
INV	59 (56.2)	57 (54.3)	62 (60.2)	58 (56.3)	151 (45.8)	153 (46.4)	153 (47.1)	156 (47.6)
INV asymmetry	10 (9.5)		13 (12.9)		20 (6.1)		37 (11.5)**	

RFS: rearfoot strike; INV: inversion; *p<0.05, **p<0.01, p<0.001. Data is displayed as n (%).

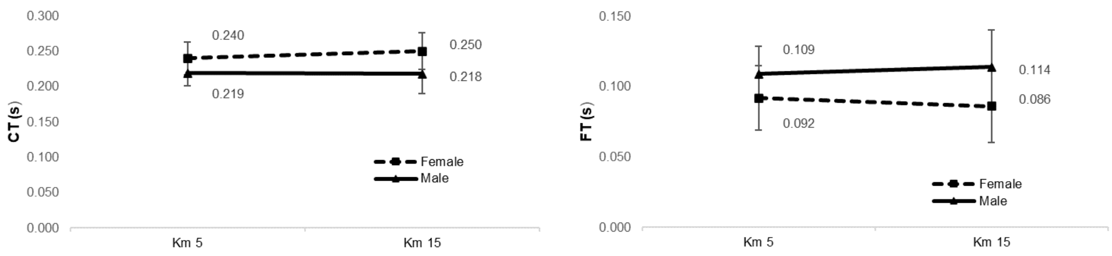

Figure 2. Contact time and flight time in men and women according to classification from km 5 to km 15 mark

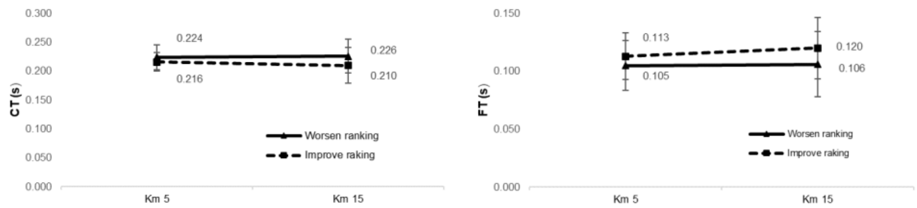

Figure 3. Contact time and flight time in the runners that worsened or improve their classification from km 5 to km 15 mark.

DISCUSSION

The official website of the 2011 International Half Marathon of Cordoba reported that 3,124 athletes finished the competition; the fastest time for men was 1 h 05’08” and for women was 1 h 22’31”, with a mean time of 1 h 43’50”. This study population is representative of the current average- to long-distance runner. The purpose of this study was to determine FSP, inversion and spatiotemporal variables in a large sample of mostly recreational runners during a long-distance road competition, according to sex and changes in the classification during the race between two kilometric marks (km 5−km 15).

The main finding of this study was that there was an increase of RFS prevalence from km 5 to km 15 mark only in the men’s group. In addition, the runners whose classification worsened in the race at km 15 mark, displayed greater RFS prevalence and INV asymmetry. Regarding the spatial-temporal parameters, women increased and reduced CT and FT, respectively at km 15 mark. In addition, the runners who improved ranking at the km 15 mark reduced CT and increased FT and a positive and negative relationship was found between the variation of the classification in the race from the km 5 to the km 15 mark and CT and FT, respectively.

Although very few studies have investigated this topic, in accordance with the current study, Hanley et al. (2019) showed that in elite marathon runners the most usual FSP was RFS, with proportions never less than 54% of men or 67% of women at any distance; moreover, the proportion of RFS increased during the race in the men, although more than 75% of athletes kept their FSP. In this regard, a recent study noted that of the runners that use a non-RFS early, a large proportion change to RFS as distance increases (Bovalino et al., 2020). FFS presents greater muscle activity in medial and lateral gastrocnemius compared to RFS (Valencia et al., 2020), over the course of a competition, accumulated fatigue may reduce the number of FFS. Likewise, Hasegawa et al. (2007) noted an increase in RFS frequency in relation to the worst positions in the competition. In turn, Larson et al. (2011) found an increase in RFS frequency between the km 10 and km 32 of an international marathon, presumably due to fatigue; however, foot asymmetry was less common at km 32. A recent study observed no spatiotemporal asymmetries between dominant and non-dominant leg for recreational runners (Ortega et al., 2021). These findings in accordance with that noted change from FFS to MFS over an exhaustive run due to a muscular fatigue resulting from an increase in eccentric loading of the ankle plantar−flexor muscles at touchdown in forefoot runners, which may contribute to a decreased torque output by the end of the run (Jewell et al., 2017). In an ultramarathon (161-km), Kasmer et al. (2014) an increase in RFS prevalence by race midpoint due to higher muscular demands reflected in high concentration post-race blood creatine kinase concentrations among non-RFS. Likewise, Salas Sánchez et al. (2013) in a laboratory setting, indicated that the frequency of RFS increases with fatigue. Therefore, the changing of FSP in long-distance runners may be due to compensating for neuromuscular fatigue because a reduced maximum voluntary contraction during plantar flexion of the ankle was observed after the race; although that does not indicate more efficiency in the race (Kim et al., 2018). In this context, RFS and MFS runners exhibit greater impact load than FFS over the course of a marathon. In addition, this impact load increases with speed for both RFS and MFS, but not FFS, although, both speed and impact load were reduced between the km 10 and km 40 race marks of the marathon (Ruder et al., 2017). Recently, Bovalino et al. (2020) reported an significant increase in RFS prevalence from km 3 to km 13 mark (76.9% vs. 91%, respectively) and that race completion time differed by FSP, where faster runners were more consistent with non-RFS than the slowest runners (62.64 ± 11.20 min vs. 72.58 ± 10.84 min; $p < 0.001$). These findings are according to a study by Hasegawa et al. (2007) and Latorre-Román et al. (2015), who remark that the percentage of RFS increases with a decreasing running speed; consequently, RFS overall was more common among the slower population of runners.

In relation to sex, unlike men, women did not modify their FSP and INV, results similar to those of Larson et al. (2011) between km 10 and km 32 marks of the marathon, who find a greater increase of RFS prevalence in men than women. In the elite marathon runners at the 2017 IAAF World Championships, Hanley et al. (2019) showed that there were no sex differences for proportion of FSP. Although they found the proportion of RFS increased with distance run in the male runners, women did not exhibit differences between km 19 and km 40 marks in FSP. However, Kasmer et al. (2014) found no significant differences between men and women in FSP and during a 161-km ultramarathon, considering several filming locations. Recently, Boccia et al. (2018) indicated that a half-marathon run incited both central and peripheral fatigue, without significant differences between men and women. Therefore, this is a controversial topic or a knowledge gap in the field of study.

With respect to spatial and temporal variables, there were significant changes, both in CT and FT, from km 5 to km 15 mark, taking into account both sex and position in the race, men and the runners who improve rank at km 15 mark, reducing CT

and increasing FT. These results differ from Chan-Roper et al. (2012), who demonstrate increased CT between km 8 and km 40 of a marathon.
In this regard, longer FT and step length seem to be the main running characteristics of high-level runners compared to their low-level counterparts (Felipe García-Pinillos et al., 2019). Therefore, shorter CT seems to be very consistent among highly trained endurance runners (Ogueta-Alday et al., 2018). However, CT and FT presented contradictory results regarding their association with running economy in long-distance runners (Pizzuto et al., 2019). Runners with RFS are more economical than those who exhibit MFS at submaximal running speeds (57%–81% of V̇O2max) and this difference could be explained due to CT being longer and FT shorter in runners with RFS (Ogueta-Alday et al., 2014). Consistent with this, a longer CT involved a lower V̇O2max in MFS and RFS; and at a given CT, RFS runners were less economical than MFS (Di Michele & Merni, 2014). Finally, a shorter CT and a higher frequency of INV at the foot contact might contribute to higher running economy (Hasegawa et al., 2007).

Some limitations in this study must be mentioned. The main limitation of this study was not providing sociodemographic and anthropometric variables, which could have helped with the discussion. A second limitation is the use of a video analysis system to measure FSP, which is less accurate than a 3-D motion capture system. Thirdly, footwear was not controlled or assessed. Notwithstanding these limitations, the current study includes a large population sample of runners, so these results provide high statistical power. From a practical point of view, the results of the current study may be used to characterize typical running of recreational long-distance runners during a half marathon, which provides useful information for athletes and coaches to gain a better understanding of how the impact of FSP could influence the athlete's performance or injuries' risk. Significant differences between FSP and spatial-temporal parameters according to sex and changes in the position in the race, suggested by this study, make an original contribution to the biomechanical analysis of endurance running from an ecological paradigm (outside the laboratory). However, the current study cannot determine with precision whether more experienced well-trained runners, fatigue or pacing control are responsible for changes in FSP and of spatial-temporal parameters during the race.

CONCLUSIONS

There was a high prevalence of RFS among most recreational distance runners, which increased from km 5 to km 15 only in the men groups and in runners, whose classification worsened in the race at km 15. In turn, spatial-temporal parameters during a half marathon were affected by sex, with women increasing and reducing CT and FT, respectively, from km 5 to km 15 mark. In addition, the runners who improved their position in the race at km 15 mark reduced CT and increased FT. These findings suggest that maintaining a non-RFS, not increasing contact time, and not decreasing flight time could be beneficial in improving performance during a long-distance race in the last kilometers. Further research could clarify the causes and consequences of current findings on running performance and injuries.

REFERENCES

Benca, E., Listabarth, S., Flock, F. K. J., Pablik, E., Fischer, C., Walzer, S. M., Dorotka, R., Windhager, R., & Ziai, P. (2020). Analysis of Running-Related Injuries: The Vienna Study. *Journal of Clinical Medicine*, *9*(2), 438. https://doi.org/10.3390/jcm9020438

Boccia, G., Dardanello, D., Tarperi, C., Festa, L., La Torre, A., Pellegrini, B., Schena, F., & Rainoldi, A. (2018). Women show similar central and peripheral fatigue to men after half-marathon*. *European Journal of Sport Science*. https://doi.org/10.1080/17461391.2018.1442500

Bovalino, S. P., Cunningham, N. J., Zordan, R. D., Harkin, S. M., Thies, H. H. G., Graham, C. J., & Kingsley, M. I. C. (2020). Change in foot strike patterns and performance in recreational runners during a road race: A cross-sectional study. *Journal of Science and Medicine in Sport*, 10–13. https://doi.org/10.1016/j.jsams.2019.12.018

Carmack, M. A., & Martens, R. (2016). Measuring Commitment to Running: A Survey of Runners' Attitudes and Mental States. *Journal of Sport Psychology*. https://doi.org/10.1123/jsp.1.1.25

Chan-Roper, M., Hunter, I., W Myrer, J., L Eggett, D., & K Seeley, M. (2012). Kinematic changes during a marathon for fast and slow runners. *Journal of Sports Science & Medicine*, *11*(1), 77–82.

Cheung, R. T. H., & Davis, I. S. (2011). Landing Pattern Modification to Improve Patellofemoral Pain in Runners: A Case Series. *Journal of Orthopaedic & Sports Physical Therapy*, *41*(12), 914–919. https://doi.org/10.2519/jospt.2011.3771

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: A retrospective study. *Medicine and Science in Sports and Exercise*, *44*(7), 1325–1334. https://doi.org/10.1249/MSS.0b013e3182465115

Davis, I. S., & Hollander, K. (2020). The Interaction of Foot Strike and Footwear in Runners. *Clinical Care of the Runner*, *1*(1), 87–94. https://doi.org/10.1016/B978-0-323-67949-7.00009-4

Davis, I. S., Rice, H. M., & Wearing, S. C. (2017). Why forefoot striking in minimal shoes might positively change the course of running injuries. In *Journal of Sport and Health Science* (Vol. 6, Issue 2, pp. 154–161). Elsevier B.V. https://doi.org/10.1016/j.jshs.2017.03.013

de Oliveira, F. C. L., Fredette, A., Echeverría, S. O., Batcho, C. S., & Roy, J. S. (2019). Validity and Reliability of 2-Dimensional Video-Based Assessment to Analyze Foot Strike Pattern and Step Rate During Running: A Systematic Review. In *Sports Health*. https://doi.org/10.1177/1941738119844795

Di Michele, R., & Merni, F. (2014). The concurrent effects of strike pattern and ground-contact time on running economy. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2013.05.012

Fields, K. B., Sykes, J. C., Walker, K. M., & Jackson, J. C. (2010). Prevention of running injuries. *Current Sports Medicine Reports*, *9*(3), 176–182. https://doi.org/10.1249/JSR.0b013e3181de7ec5

García-Pinillos, F., Soto-Hermoso, V. M., & Latorre-Román, P. Á. (2016). Do Running Kinematic Characteristics Change over a Typical HIIT for Endurance Runners? *Journal of Strength and Conditioning Research*, *30*(10). https://doi.org/10.1519/JSC.0000000000001380

García-Pinillos, Felipe, García-Ramos, A., Ramirez-Campillo, R., Latorre-Román, P. Á., & Roche-Seruendo, L. E. (2019). How do spatiotemporal parameters and lower-body stiffness change with increased running velocity? A comparison between novice and elite level runners. *Journal of Human Kinetics*, *in press*(December), 25–38. https://doi.org/10.2478/hukin-2019-0036

Hanley, B., Bissas, A., Merlino, S., & Gruber, A. H. (2019). Most marathon runners at the 2017 IAAF World Championships were rearfoot strikers, and most did not change footstrike pattern. *Journal of Biomechanics*. https://doi.org/10.1016/j.jbiomech.2019.05.024

Hasegawa, H., Yamauchi, T., & Kraemer, W. J. (2007). Foot strike patterns of runners at the 15-km point during an elite-level half marathon. *Journal of Strength and Conditioning Research*, *21*(3), 888–893. https://doi.org/10.1519/R-22096.1

Hayes, P. R., & Caplan, N. (2014). Leg stiffness decreases during a run to exhaustion at the speed at VO2max. *European Journal of Sport Science*. https://doi.org/10.1080/17461391.2013.876102

Hollander, K., De Villiers, J. E., Venter, R., Sehner, S., Wegscheider, K., Braumann, K. M., & Zech, A. (2018). Foot Strike Patterns Differ between Children and Adolescents Growing up Barefoot vsShod. *International Journal of Sports Medicine*. https://doi.org/10.1055/s-0043-120344

Hollander, K., van der Zwaard, B. C., de Villiers, J. E., Braumann, K.-M., Venter, R., & Zech, A. (2016). The effects of being habitually barefoot on foot mechanics and motor performance in children and adolescents aged 6–18 years: study protocol for a multicenter cross-sectional study (Barefoot LIFE project). *Journal of Foot and Ankle Research*, *9*(1), 36. https://doi.org/10.1186/s13047-016-0166-1

Jewell, C., Boyer, K. A., & Hamill, J. (2017). Do footfall patterns in forefoot runners change over an exhaustive run? *Journal of Sports Sciences*. https://doi.org/10.1080/02640414.2016.1156726

Kasmer, M. E., Liu, X. C., Roberts, K. G., & Valadao, J. M. (2013). Foot-strike pattern and performance in a marathon. *International Journal of Sports Physiology and Performance*, *8*(3), 286–292. https://doi.org/10.1123/ijspp.8.3.286

Kasmer, M. E., Wren, J. J., & Hoffman, M. D. (2014). Foot strike pattern and gait changes during a 161-km ultramarathon. *Journal of Strength and Conditioning Research*, *28*(5), 1343–1350. https://doi.org/10.1519/JSC.0000000000000282

Kim, H. K., Mirjalili, S. A., & Fernandez, J. (2018). Gait kinetics, kinematics, spatiotemporal and foot plantar pressure alteration in response to long-distance running: Systematic review. *Human Movement Science*. https://doi.org/10.1016/j.humov.2017.09.012

Kulmala, J. P., Kosonen, J., Nurminen, J., & Avela, J. (2018). Running in highly cushioned shoes increases leg stiffness and amplifies impact loading. *Scientific Reports*. https://doi.org/10.1038/s41598-018-35980-6

Larson, P., Higgins, E., Kaminski, J., Decker, T., Preble, J., Lyons, D., McIntyre, K., & Normile, A. (2011). Foot strike patterns of recreational and sub-elite runners in a long-distance road race. *Journal of Sports Sciences*, *29*(15), 1665–1673. https://doi.org/10.1080/02640414.2011.610347

Latorre-Román, P. A., Muñoz Jiménez, M., Soto Hermoso, V. M., Salas Sánchez, J., Molina Molina, A., Robles Fuentes, A., & García-Pinillos, F. (2015). Acute effect of a long-distance road competition on foot strike patterns, inversion and kinematics parameters in endurance runners. *International Journal of Performance Analysis in Sport*, *15*(2), 588–597. https://doi.org/10.1080/24748668.2015.11868816

Latorre-Román, P., García Pinillos, F., Bujalance-Moreno, P., & Soto-Hermoso, V. M. (2017). Acute effects of high-intensity intermittent training on kinematics and foot strike patterns in endurance runners. *Journal of Sports Sciences*, *35*(13), 1247–1254. https://doi.org/10.1080/02640414.2016.1218038

Latorre Román, P. Á., Balboa, F. R., & Pinillos, F. G. (2017). Foot strike pattern in children during shod-unshod running. *Gait & Posture*, *58*, 220–222. https://doi.org/10.1016/j.gaitpost.2017.07.121

Lieberman, D. E., Venkadesan, M., Werbel, W. A., Daoud, A. I., D'Andrea, S., Davis, I. S., Mang'Eni, R. O., & Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*, *463*(7280), 531–535. https://doi.org/10.1038/nature08723

Malisoux, L., Delattre, N., Urhausen, A., & Theisen, D. (2020). Shoe Cushioning Influences the Running Injury Risk According to Body Mass: A Randomized Controlled Trial Involving 848 Recreational Runners. *American Journal of Sports Medicine*, *48*(2), 473–480. https://doi.org/10.1177/0363546519892578

Murphy, D. F., Connolly, D. a J., & Beynnon, B. D. (2003). Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine*, *37*(1), 13–29. https://doi.org/10.1136/bjsm.37.1.13

Ogueta-Alday, A., Morante, J. C., Gómez-Molina, J., & García-López, J. (2018). Similarities and differences among half-marathon runners according to their performance level. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0191688

Ogueta-Alday, A., Rodríguez-Marroyo, J. A., & García-López, J. (2014). Rearfoot striking runners are more economical than midfoot strikers. *Medicine and Science in Sports and Exercise*, *46*(3), 580–585. https://doi.org/10.1249/MSS.0000000000000139

Ortega, D. R., Berral Aguilar, A. J., & de la Rosa, F. J. B. (2021). Bilateral asymmetries and sex differences in the kinematics of running gait cycle of a group of Andalusian recreational runners. *Retos*, *2041*(41), 512–518.

https://doi.org/10.47197/retos.v0i41.85934

Pizzuto, F., de Oliveira, C. F., Soares, T. S. A., Rago, V., Silva, G., & Oliveira, J. (2019). Relationship Between Running Economy and Kinematic Parameters in Long-Distance Runners. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000003040

Pohl, M. B., Hamill, J., & Davis, I. S. (2009). Biomechanical and anatomic factors associated with a history of plantar fasciitis in female runners. *Clinical Journal of Sport Medicine*, *19*(5), 372–376. https://doi.org/10.1097/JSM.0b013e3181b8c270

Pohl, M. B., Mullineaux, D. R., Milner, C. E., Hamill, J., & Davis, I. S. (2008). Biomechanical predictors of retrospective tibial stress fractures in runners. *Journal of Biomechanics*, *41*(6), 1160–1165. https://doi.org/10.1016/j.jbiomech.2008.02.001

Ruder, M., Jamison, S. T., Tenforde, A., Hannan, M., & Davis, I. (2017). Relationship of Footstrike Pattern and Landing Impacts During a Marathon Race. *Medicine & Science in Sports & Exercise*. https://doi.org/10.1249/01.mss.0000517200.37366.12

Salas Sánchez, J., Latorre Román, P., Soto Hermos, V., Santos e Campos, M., García Pinillos, F., Latorre Román, P., Soto Hermoso, V., Santos Campos, M., & García Pinillos, F. (2013). Características sociodemográficas del corredor popular veterano español . *Kronos: Revista Universitaria de La Actividad Física y El Deporte*.

Tauton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine*, *36*, 95–101. https://doi.org/10.1136/bjsm.36.2.95

Urbaneja, J. S., & Farias, E. I. (2018). Trail running in Spain. Origin, evolution and current situation; natural areas. *Retos*, *2041*(33), 123–128.

Valencia, O., Cristi, I., Ahumada, D., Meza, K., Salas, R., Weinstein, A., & Guzmán-Venegas, R. (2020). The initial impact with forefoot increases the muscular activity of gastrocnemius during running. A quantitative study of electromyographic activity. *Retos*, *83*, 271–275.

Van Gent, R. N., Siem, D., Van Middelkoop, M., Van Os, A. G., Bierma-Zeinstra, S. M. A., & Koes, B. W. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. *British Journal of Sports Medicine*, *41*(8), 469–480. https://doi.org/10.1136/bjsm.2006.033548

Williams, D. S., McClay, I. S., & Manal, K. T. (2000). Lower extremity mechanics in runners with a converted forefoot strike pattern. *Journal of Applied Biomechanics*, *16*(2), 210–218. https://doi.org/10.1123/jab.16.2.210

Wit, B. De, Clercq, D. De, & Aerts, P. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics*, *33*.

Número de citas totales / Total references: 45 (100%)
Número de citas propias de la revista / Journal's own references: 3 (7%)