Effects of the sprint curve on spatiotemporal parameters: a systematic review

Elí O. Paz Paz, Pedro Pérez Soriano, Alberto Encarnación Martínez

Research Group in Sports Biomechanics (GIBD). Department of physical education and sports. University of Valencia. Valencia.

doi: 10.18176/archmeddeporte.00175

Recibido: 12/03/2023
Aceptado: 02/04/2024

Summary

Introduction: During the curve sprinting the velocity decreases proportionally to the radius. It has been documented that athletes in inner lanes could be at a biomechanical disadvantage compared to outer lanes.
Objective: Describe if there are any differences between legs distribution in spatiotemporal parameters when curve sprinting.
Material and method: Following the basis of the PRISMA statement, was carried out using PubMed, SportDiscus and MEDLINE databases. Study selection: The selection of articles was carried out by two authors, and in case of discrepancy a third author would intervene. The selection of the articles was carried out by two authors, and in case of discrepancy a third author would intervene. The inclusion criteria were established in which studies focused on analyzing spatiotemporal parameters in the center of the curve such as step frequency, step length, flight time and ground contact time were included.
Results: 982 studies were found but only 6 fulfilled the inclusion criteria. These studies analyzed race in external track curve in at least one radius/ track with elite athletes. Analysis was reported in 5 different radius and only one study reported significant differences in velocity, two studies in step frequency and step length, one in flight time, and 5 studies reported significant differences in ground contact time in lanes: one, two, four, five and eight (radius 36.5, 37.72, 41.41, 45.10 track approved by Word athletic). Ground contact time was greater for the inside leg in seven different study conditions. Only one study showed significant different between lane: 2, 4 and 8 (radius 37.72, 41.41 and 45.10) to ground contact time, showing greater times for the internal lanes in both legs.
Conclusions: The ground contact time was longer for the inside leg, which suggests that the inside leg decreases its performance during sprint curve. No relevant results were shown in velocity, step frequency, step length and flight time.

Key words:
Sprinters. Sprint curve. Track and field. 200 m.

Efectos de la carrera en curva en variables espaciotemporales: una revisión sistemática

Resumen

Introducción: Durante la carrera en curva la velocidad disminuye de forma proporcional al radio. Se ha documentado que los atletas en los carriles interiores podrían tener una desventaja biomecánica en comparación con los carriles exteriores.
Objetivo: Describir si existen diferencias en la distribución entre piernas en parámetros espaciotemporales cuando se realiza la carrera en curva.
Material y método: Siguiendo las bases de la declaración PRISMA, se realizó una búsqueda en las bases de datos PubMed, SportDiscus y MEDLINE. La selección de los artículos fue realizada por dos autores, y en caso de discrepancia intervendría un tercer autor. Se establecieron los criterios de inclusión en los que se incluyeron estudios enfocados en analizar parámetros espaciotemporales en el centro de la curva como frecuencia de paso, longitud de paso, tiempo de vuelo y tiempo de contacto con el suelo.
Resultados: Se encontraron 982 estudios, solo 6 cumplieron con los criterios de inclusión. Se observó análisis en cinco radios diferentes y solo un estudio mostró diferencias significativas en velocidad, dos estudios en frecuencia de paso y longitud de paso, uno en tiempo de vuelo, y cinco estudios encontraron diferencias significativas en tiempo de contacto con el suelo en carriles: uno, dos, cuatro, cinco y ocho (radio 36,5, 37,72, 41,41, 45,10 aprobados por la Word Athletic). El tiempo de contacto con el suelo fue mayor para la pierna interior en siete condiciones de estudio diferentes. Solo un estudio observó diferencias significativas entre carriles: 2, 4 y 8 (radio 37,72, 41,41 y 45,10) en el tiempo de contacto con el suelo, mostrando mayores tiempos para los carriles internos en ambas piernas.
Conclusiones: El tiempo de contacto con el suelo fue mayor para la pierna interior, lo que sugiere que la pierna interna disminuye su rendimiento durante la carrera en curva. No se mostraron resultados relevantes en velocidad, frecuencia de paso, longitud de paso y tiempo de vuelo.

Palabras clave:
Corredores de velocidad. Carrera en curva. Pista externa. 200 m.

Correspondence: Elí O. Paz Paz
E-mail: epazpaz@alumni.uv.es

Introduction

The biomechanical demands of the lower extremity during running in a straight line are described in a symmetrical way[1-3]. However, on the running track, from more than 100 m, 50 percent of the race is in a curve, in this way, it has been indicated that the maximum velocity reached in a curved decreases when compared with straight line condition[4-6], and it was indicated that this effect is proportional to the radius[7-10].

Around the official events of track in athletics, in its two modalities the races in indoor 200 m and outdoor 400 m[11] and due to the geometrical characteristics of the track, discrepancy has been evident during indoor track race[6,12,13]. In outdoor track it has been documented by mathematical models how the radius of the curve influences the potential velocity reached by an athlete, it has been indicated that from lane 1 to 7 there is a difference of 0.069 s and 0.123 s[4,5], a more recent mathematical model indicated a difference of 0.15 to 0.23 s for events of 200 m and 0.22 to 0.35 s for the 400 m[9].

Some studies have empirically addressed the dynamics of sprint curve at official athletics track events, it has been indicated that the time differences from 8th lane to 2nd lane can be up to 0.180 s for events of 200 m[10]. It has been documented that the implications of radius on velocity can be reflected from the acceleration phase[14,15], as the athlete reaches higher velocities the biomechanical changes between the legs accumulate[14-16]. Specific studies for the central phase of the curve have found biomechanics differences in inside leg and outside leg between lanes and by lane[10,17,18], it has been indicated that the inside leg generates greater lateral force than the outside leg and, contributing to the change of direction[17,19]. It´s assumed that athletes in internal lanes may be at a biomechanical disadvantage, and some athletes are more capable than other to sprint on bend[10].

Spatiotemporal variables such as step frequency, step length, and ground contact time have been seen modified during the sprint curve[13,18-20]. A higher ground contact time has been reported for the inside leg compared to the outside leg[17,18,20], however, for step frequency and step length there is not a good basis to be able to assure differences, it is not entirely clear if the differences that some studies[18,20] show in these variables is a natural effect of the sprints curve and it changes according to the lane, contrary to other studies[10,17] have shown no difference athletes in step frequency and step length, which may be indicate a high level of performance. The studies are not conclusive that if these changes are constant on different lanes, the scientific literature seems to be limited. So, the purpose of this study is to describe if there are differences between inside leg and outside leg in spatiotemporal variables in sprint curve on outdoor track.

Material and method

Literature search strategy

The present systematic review study followed the principles proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[21]. The search was conducted in the PubMed databases, SportDiscus and MEDLINE, studies published from 1st January 1951 to 1st January 2023 were searched. The terms that were established for the search were: sprint curve, sprint bend, track, biomechanics, kinematics, running curve, running bend. The following search strategy was used for all the databases: "Sprint curve OR sprint bend AND track", "sprint curve OR sprint bend AND kinematics", "running curve OR running bend AND track", "running curve OR running bend AND kinematics", "sprint curve OR sprint bend AND biomechanics" "running curve OR running bend AND biomechanics".

Selection criteria

Only quasi-experimental or cross-sectional studies were included. Research studies were included if they match the following inclusion criteria: 1) evaluated healthy elite athletes, regardless of gender, 2) report on the anthropometric characteristics of the athletes (mass, height and age), 3) to be sprinters from 200/400m outdoor track, 4) studies that specify the radius/lane where the analysis was made, 5) studies focused on analyzing spatiotemporal parameters on the center of the curve, 6) studies that reported the following stride parameters: a) velocity; b) step frequency; c) step length; d) flight time; e) ground contact time, 7) studies that reported most of the values differentiated by inside leg and outside leg. Those studies whose intervention was not done on the official 400m track were excluded, including in this criterion the material covering the track, which must be polyurethane (tartan); nor were conference documents and studies collected that do not provide data on the empirical phase.

Selection of studies

The selection of articles was carried out by two authors (E.O.P. and A.E.-M.), and in case of discrepancy a third author would intervene (P.P.-S.)[21]. We preceded to the selection of the articles carried out in two phases, in the first instance the screening by reading the title and abstract to identify the relevance of the study and the eligibility of the articles in the present systematic review. The preselected studies were extracted by each search, creating in this way a spreadsheet with the name of the article, author and the link of the database from which it was extracted and then eliminate duplicate studies, once the duplicates were eliminated, the potentials articles were stored in the Mendeley tool, after that, the inclusion and exclusion criteria described above in the selected studies were applied.

Assessing methodologic quality

The methodological quality of the studies was assessed using the 27-item list proposed by Berra & Sanchez (2008)[22] an instrument to assess the quality of cross-sectional studies. It consists of 8 denominated dimensions: 1) Question or object of investigation; 2) participants; 3) comparability between the groups studied; 4) definition and measurement of the main variables; 5) statistical analysis and confusion; 6) results; 7) conclusions, external validity and applicability of the results; 8) conflict of interests. Possible scores were "Very good", "Good", "Fair", "Bad", "Not reported" and "Not applicable". The internal validity is based on the compendium of scores based on the original sections 1-6. External validity is based on the score in section 7.

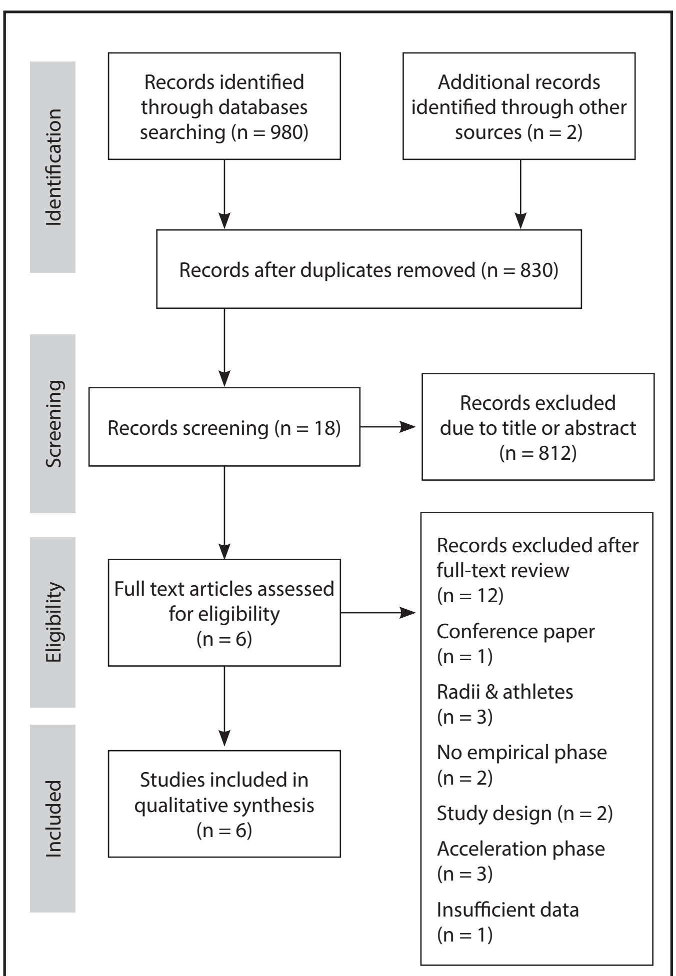
Then the qualitative synthesis of the results of the articles was carried out by means of a flowchart where the search and selection process of the articles was identified, through a table the characteristics of the studies included in the review were extracted, their respective scores of the methodological quality assessment and the relevant results on the parameters of stride in the curve race.

Results

Literature search

A total of 982 articles were identified; once the duplicate studies were eliminated, 830 were included, 830 were included after reading the title and abstract, 18 studies were identified for an exhaustive reading of the full text. After the full-text evaluation, 12 articles were excluded because they did not meet the inclusion criteria: Conference paper[23], acceleration phase[14-16], radius and athlete[7,24,25], no empirical phase[26,27], study design[12,28] and insufficient data[13]. A total of 6 articles[10,17-20,29] were selected for the analysis and qualitative synthesis, the publications comprise from 2015 to 2018 (Figure 1).

Figure 1. PRISMA flow chart of the article selection process.



Methodologic quality

All the studies received a high or medium rating, since in most of the items they received a good to very good score when they were submitted to the instrument for critical reading and evaluation of transversal epidemiological studies.

Description data

All studies were descriptive with a cross-sectional design, only the Ishimura´s study[18] included women in the sample, the range of subjects in the sample was 6 to 12 men and 8 women, a total of 51 men and 8 women was evaluated. All the athletes were of minimum national competitive level and curve racing specialists on the 400 m official track. Ohnuma[29] included long jumpers, including a division into two groups, good and poor runners in curve. For the purposes of the current study, we have only considered analyzing the values for good runners, so some aspects of Ohnuma's study[29] are beyond our reach. The study of Ishimura[18] does not specify the specialty of the athletes (Table 1).

Protocol and instrumentation used in the studies

The series were carried out at maximum[10,18-20,29] and submaximal[17] effort, at least 2 series per condition, between 5 and 10 minutes of rest between repetitions, from 45 to 60 m of running including the acceleration phase, typical sprinters warm-ups were carried out and all ran with specific clothing including spikes and *World athletics* approved standard track. The studies do not report weather conditions such as wind, temperature and humidity. All the studies coincide in using 3D kinematic analysis. Churchill *et al.* and Ohnuma *et al*. included force platforms[19,20], and in the study of Ishimura et al included photocells[18]. The instrumentation used in the studies has been well detailed by the authors and have the scientific support for research of this type[28].

Spatiotemporal parameters

The evaluations were made in 5 different lanes. The study of Alt *et al.* evaluated in the lane 1 with a radius of 36.5 m[17]; Churchill *et al.* and Ohnuma *et al.* evaluated in the lane 2, with a radius of 37.72 m, 37.9 m respectively[19,20,29]; Churchill *et al*. evaluated at three different radius[10], lane 2 with a radius of 37.72 m, lane 5, with a radius of 41.41m and on lane 8 with a radius of 45.10 m. Finally, Ishimura *et al*. evaluated on lane 4, with a radius of 43.51 m, not being a standard track[18].

Critical level of significance was set at $P \leq 0.05$ for all the studies. Thus, no significant differences were found in velocity between legs for the studies of Alt *et al.*[17], Churchill *et al.*[19,20] and Ishimura *et al.*[18]. Since Ohnuma *et al.*[29] did not provide specific information for each leg, this author only reported the average velocity between legs. However, Churchill *et al.*[10] on 5 and 8 lane found significant differences in velocity between legs, being the inside leg reaches greater velocity.

For the step frequency and step length variables Churchill *et al.*[19] on lane 2 and Ishimura *et al.*[18] on lane 4 showed significant differences. Concretely, a greater step frequency and shorter step length was presented in the outside leg respectively, Ishimura *et al.*[18] reported significant differences in flight time to the inside leg. Regarding the

Table 1. Characteristics of the studies included in the review and scores of the methodology evaluation.

First author, Year	Type Study	Study design	Sample M / F	Age (Years) M / F	Height (m) M / F	Mass (kg) M / F	Level	Experience in bend	TA	SQ
Alt *et al.* 2015[17]	Descriptive	Cross-sectional	6	20.2 ± 2.6	1.86 ± 0.06	76.3 ± 8.2	N	200 m	VA 3D	IE: G EE: H GE: H
Churchill *et al.* 2015[20]	Descriptive	Cross-sectional	7	23.6 ± 1.9	1.81 ± 0.07	80.5 ± 9.2	N/I	200/400 m	VA 3D	IE: H EE: H GE: H
Churchill *et al.* 2015[19]	Descriptive	Cross-sectional	7	22.6 ± 4.2	1.76 ± 0.06	70.7 ± 9.2	N/I	200/400 m	VA 3D / FP	IE: H EE: H GE: H
Ohnuma *et al.* 2018[29]	Descriptive	Cross-sectional	12	20.3 ± 0.9	1.74 ± 0.04	66.7 ± 4.6	N	200 m / LJ	VA 3D / FP	IE: G EE: H GE: H
Churchill *et al.* 2018[10]	Descriptive	Cross-sectional	9	21.5 ± 3.2	1.82 ± 0.06	79.4 ± 10.1	N/I	200/400 m	VA 3D	IE: H EE: H GE: H
Ishimura 2016[18]	Descriptive	Cross-sectional	10 / 8	20.8 ± 2.0 / 19.3 ± 0.5	1.74 ± 0.05 / 1.65 ± 0.06	67 ± 6.2 / 56.1 ± 2.6	N	NR	VA 3D/PCL	IE: G EE: H GE: H

M/F: Male/Female; N/I: National/International; LJ: Long Jumper; NR: Not reported; TA: Type of analysis; VA 3D: Video analysis 3 Dimensions; PCL: Photocells; FP: Force Plate; SQ; Study Quality; IE: Internal Evaluation; EE: External Evaluation; GE: General Evaluation; H: High; G: Good; HF: Half; R: Regular

Table 2. Results in spatiotemporal variables of the articles included in the review.

Author, Year	L/r	Velocity (m/s)			SF (Hz)			SL (m)			FT (s)			GCT (s)		
		IL	OL	p	IL	OL	p	IL	OL	p	IL	OL	p	IL	OL	p
Alt *et al.* 2015[17 a]	1/36.5m	9.26 ± 0.45	9.39 ± 0.25		4.13 ± 0.21	4.35 ± 0.23		2.2 4 ± 0.10	2.24 ± 0.08		0.133 ± 0.087	0.136 ± 0.013		0.107 ± 009	0.096 ± 008	*
Churchill *et al.* 2015[20]	2/37.72m	9.39 ± 0.45	9.33 ± 0.44		4.39 ± 0.26	4.46 ± 0.31		2.14 ± 0.11	2.10 ± 0.14		0.116 ± 0.009	0.112 ± 0.014		0.116 ± 0.004	0.109 ± 0.005	*
Churchill *et al.* 2015[19]	2/37.72m	9.34 ± 0.43	9.29 ± 0.47		4.44 ± 0.25	4.59 ± 0.23	*	2.11 ± 0.05	2.02 ± 0.07	*	0.118 ± 0.011	0.108 ± 0.016		0.117 ±0.006	0.104 ± 0.005	*
Ohnuma *et al.* 2018[29 a,b]	2/37.9m[c]	9.63 ± 0.14[d] 9.49 ± 0.27[d]			4.63 ± 0.27 4.39 ± 0.28	4.84 ± 0.48 4.73 ± 0.55		2.09 ± 0.14 2.15 ± 0.11	2.01 ± 0.20 2.03 ± 0.23		0.105 ± 0.11 0.113 ± 0.11	0.105 ± 0.022 0.114 ± 0.020		0.112 ± 009 0.116 ± 0.06	0.104 ± 004 0.100 ± 0.08	
Churchill *et al.* 2018[10]	2/37.72m 5/41.41m 8/45.10	9.34 ± 0.61 9.36 ± 0.52 9.56 ± 0.43	9.30 ± 0.63 9.30 ± 0.52 9.49 ± 0.41	 * *	4.35 ± 0.25 4.45 ± 0.21 4.48 ± 0.19	4.36 ± 0.22 4.43 ± 0.17 4.48 ± 0.19		2.15 ± 0.09 2.10 ± 0.11 2.13 ± 0.08	2.13 ± 0.12 2.10 ± 0.10 2.12 ± 0.11		0.117 ± 0.012 0.112 ± 0.010 0.113 ± 0.009	0.111 ± 0.008 0.109 ± 0.006 0.109 ± 0.009		0.121 ± 0.008 0.119 ± 0.009 0.116 ± 0.006	0.111 ± 0.008 0.111 ± 0.009 0.109 ± 0.006	* * *
Ishimura *et al.* 2016[18 a]	4/43.51m[c]	8.83 ± 0.64	8.84 ± 0.63		4.39 ± 0.19	4.71 ± 0.18	*	2.01 ± 0.13	1.88 ± 0.11	*	0.116 ± 0.008	0.108 ± 0.008	*	0.113 ± 0.007	0.105 ± 0.005	*

L/r: Lane/radii; IL: Inside Leg; OL: Outside Leg; SF: Step Frequency; SL: Step Length; FT: Flight Time; GCT: Ground Contact Time; NR: Not reported; p: Significance ≤0.05.
*Significant difference; [a]In these studies the unit of measurement used for FT and GCT was milliseconds (ms), so it was converted to seconds (s), unit used in the SI; [b]This study included two groups in the sample, over dates to good sprinters on bend and under date to poor sprinters on bend; [c]Corresponds to lane 4 of a non-standard track, but endorsed by the World athletics; [d]corresponding to mean between legs.

ground contact time 5 studies[10,17-20] reported significant differences for all lanes, all the differences indicate a longer ground contact time for the inside leg compared to the outside leg, and Ohnuma *et al.*[29] no reported significance differences (Table 2).

Discussion

The purpose of this systematic review was to describe if there are differences between inside leg and outside leg in spatiotemporal variables in curve sprinting on outdoor track. The spatiotemporal variables as velocity, step frequency, step length, flight time and ground contact time were analyzed.

Significant differences (*P* ≤0.05) was reported for inside leg in velocity at radius 41.41 and 45.10 m lane 5 and 8 respectively[10], contrary to the other studies[17,20] include in this review who do not show changes in velocity between legs in radius less than 37.72 m. Due to velocity is the product of step frequency and step length, there may be compensatory changes that are not shown in velocity but are reflected in step length and step frequency. However, significant differences in step length and step frequency only shown in two studies[18,19] at different radius (37,72 m y 43,51 m). It is not clear if these changes correspond to the individual technique of the athletes or if it is a natural effect that occurs when sprint in a curve.

Five studies[10,17-20] showed significant differences for the ground contact time in seven lanes with different radius, which was greater in the inside leg at radius from 36.5 m to 45.10 m in which, only two studies[18,19] showed significant differences in step frequency and step length, at the same time longer ground contact time in the inside leg was related to less step frequency for that same leg and, a greater step length to this leg[18,19]. However, three studies[10,17,20] in five lanes with different radius did not show significant differences in step frequency and step length that were related to changes in ground contact time. A longer ground contact time in the inside leg showed greater velocity for that same leg in two lanes (5 and 8, radius 41.4 and 45.10 respectively)[10] without there having been significant changes in step frequency and step length.

Previous studies suggest that the differences in ground contact time are related to the function of each leg, with the inside leg generating greater inward force than the outside leg[6,15], maybe the fact that to avoid being drawn into the tangent, in sprint curve the center of mass is inclined towards the inside of the curve[6] may explain the increase in ground contact time for the inside leg. Furthermore, these changes could be related to a greater vertical force production of the outside leg compared to the inside leg[19], compared to soccer players, it has been suggested that the inside leg could limit performance during sprint curve[30,31].

In addition, it has been determined that the outside leg is responsible for generating stabilization and change of direction[15,18], Alt *et al*.[17] suggests that the flexion movement of the knee joint causes an increase in the ground contact time for the inside leg, according to this author a greater adduction angle is needed in the left hip if the landing occurs with the same flexion of the knee, this has led to indicate that the modulations between legs are different in the curve race for this parameter, this is also corroborated in studies where the acceleration phase was analyzed[14,16].

Conclusion

The ground contact time was longer for the inside leg, this could suggest that the inside leg requires more time to generate force than the outside leg, the inside leg supports greater mass on the sprint, so it requires greater power generation. It is not clear that sprinting on inner lane can affect spatiotemporal variables; only one study evaluated this effect. Thus, there is no clear evidence that step frequency and step length between legs change during curved sprinting, since only two studies observed differences.

Practical implications

Specific training must be carried out to counteract asymmetries in ground contact time. Strong consideration should be given to including women in future studies as they may show changes compared to men during sprint curve. Due to the biomechanics of the curved sprint in athletes could have incidences in other sports where the curved sprint can be determinant in the game actions, this opens a new line of study.

Limitations

There is not a broad scientific base on which to support, so the analysis may be limited. Studies focus on men, there is not enough data on women. The studies had limited sample data.

Conflict of interest

No potential conflict of interest was reported by the authors.

Bibliography

1. Morin J, Bourdin M, Edouard P, Peyrot N, Samozino P, Lacour J. Mechanical determinants of 100-m sprint running performance. *Eur J Appl Physiol.* 2012;1121:3921-30.
2. Hunter JP, Marshall RN, McNair PJ. Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *J Appl Biomec.* 2005;211:31-43.
3. Haugen T, McGhie D, Ettema G. Sprint running: from fundamental mechanics to practice-a review. *Eur J Appl Physiol.* 2019;119(6):1273-7.
4. Greene P. Running on flat turns: experiments, theory, and applications. *J Biomechanical Engine.* 1985;107(2):96-103.
5. Jain PC. On a discrepancy in track races. *Res Q Exerc Sport*. 1980;51(2):432-46.
6. Usherwood JR, Wilson AM. Accounting for elite indoor 200 m sprint results. *Biol Lett*. 2006;2(1):47-50.
7. Chang YH, Kram R. Limitations to maximum running speed on flat curves. *J Exp Biol.* 2007;210 Pt 6:971-82.
8. Greene P. Sprinting with banked turns. *J of Biomechanics.* 1987;7:667-80.
9. Quinn MD. The effect of track geometry on 200- and 400-m sprint running performance. *J Sports Sci.* 2009;27(1):19-5.
10. Churchill SM, Trewartha G, Salo AIT. Bend sprinting performance: new insights into the effect of running lane. *Sports Biomech*. 2019;18(4):437-47.
11. IAAF. Reglamento de competición. 2018; Available at: https://www.iaaf.org/about-iaaf/documents/rules-regulations.
12. Ferro A, Floria P. Differences in 200-m sprint running performance between outdoor and indoor venues. *J Strength Cond Res.* 2013;27(1): 83-8.
13. Gary R, Andrew H. Technical adaptations of competitive sprinters induced by bend running. *New stud atlh*. 2003;18(4):57-67.
14. Judson LJ, Churchill SM, Barnes A, Stone JA, Wheat J. Joint moments and power in the acceleration phase of bend sprinting. *J Biomech.* 2020;632:101-9
15. Judson LJ, Churchill SM, Barnes A, Stone JA, Brookes IGA, Wheat J. Horizontal force production and multi-segment foot kinematics during the acceleration phase of bend sprinting. *Scand J Med Sci Sports.* 2019;29(10):1563-71.
16. Judson LJ, Churchill SM, Barnes A, Stone JA, Brookes IGA, Wheat J. Kinematic modifications of the lower limb during the acceleration phase of bend sprinting. *J Sports Sci.* 2020;38(3):336-42.
17. Alt T, Heinrich K, Funken J, Potthast W. Lower extremity kinematics of athletics curve sprinting. *J Sports Sci.* 2015;33(6):552-60.
18. Ishimura K, Sakurai S. Asymmetry in Determinants of Running Speed During Curved Sprinting. *J Appl Biomech*. 2016;32(4):394-410.

19. Churchill SM, Trewartha G, Bezodis IN, Salo AI. Force production during maximal effort bend sprinting: Theory vs reality. *Scand J Med Sci Sports.* 2016;26(10):1171-9.

20. Churchill SM, Salo AI, Trewartha G. The effect of the bend on technique and performance during maximal effort sprinting. *Sports Biomech.* 2015;14(1):106-21.

21. Bonfill X, Urrútia G. Declaración PRISMA: una propuesta para mejorar la publicación de revisiones sistemáticas y metaanálisis. *Med Clínic.* 2010;135:507-11.

22. Berra S, Elorza-Ricart JM, Estrada M, Sánchez E. Instrumento para la lectura crítica y la evaluación de estudios epidemiológicos transversales. *Gac Sanit.* 2008;225:492-7.

23. Ishimura K, Takumi T, Sakurai S. Relationship between sprint performance and stride parameters in curved sprinting. 2013;b11-1 id188.

24. Tottori N, Kurihara T, Otsuka M, Isaka T. Relationship between lateral differences in the cross-sectional area of the psoas muscle and curve running time. *J Physiol Anthropol.* 2016;35:3.

25. Taboga P, Kram R, Grabowski AM. Maximum-speed curve-running biomechanics of sprinters with and without unilateral leg amputations. *J Exp Biol.* 2016;219 Pt 6:851-8.

26. Aftalion A, Martinon P. Optimizing running a race on a curved track. *PLoS One.* 2019;14(9): e0221572.

27. Taboga P, Kram R. Modelling the effect of curves on distance running performance. *Peer J.* 2019;7: e8222.

28. Judson LJ, Churchill SM, Barnes A, Stone JA, Brookes IGA, Wheat J. Measurement of bend sprinting kinematics with three-dimensional motion capture: a test-retest reliability study. *Sports Biomech.* 2020;19(6):761-7.

29. Ohnuma H, Tachi M, Kumano A, Hirano Y. How to Maintain Maximal Straight Path Running Speed on a Curved Path in Sprint Events. *J Hum Kinet.* 2018;62:23-31.

30. Filter A, Olivares-Jabalera J, Santalla A, *et al*. Curve Sprinting in Soccer: Kinematic and Neuromuscular Analysis. *Int J Sports Med.* 2020;41(11):744-60.

31. Loturco I, Pereira LA, Fílter A, *et al.* Curve sprinting in soccer: relationship with linear sprints and vertical jump performance. *Biol Sport.* 2020;37(3):277-83.