Curve sprinting in Soccer: Kinematic and Neuromuscular Analysis

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ABSTRACT

Sprinting in curvilinear trajectories is an important soccer ability, corresponding to ~85 % of the actions performed at maximum velocity in a soccer league. We compared the neuromuscular behavior and foot contact-time between outside leg and inside leg during curve sprinting to both sides in soccer players. Nine soccer players (age = 23 ± 4.12 years) performed: 3 × Sprint linear, 3 × Sprint right curve, and 3 × Sprint left curve. An ANOVA with repeated measures was used to compare the differences between inside and outside leg, and Cohen's d was used to calculate the effect-size. Considering the average data, the performance classification (from best to worst) was as follows: 1. Curve "good" side (2.45 ± 0.11 s), 2. Linear (2.47 ± 0.13 s), and 3. Curve "weak" side (2.56 ± 0.17 s). Comparing linear with curve sprinting, inside leg recorded significant differences ("good" and "weak"; effect size = 1.20 and 2, respectively); in contrast, for outside leg, there were no significant differences ("good" and "weak"; effect size = 0.30 and 0.49, respectively). Electromyography activity showed significant differences ($p \leq 0.05$) during curve sprinting between outside (higher in biceps femoris and gluteus medius) and inside leg (higher activity in semitendinosus and adductor). In summary, inside and outside leg play different roles during curved sprints, but inside leg is more affected by the change from straight to curve sprint.

Introduction

Soccer can be characterized as a high-intensity, complex, and intermittent sport, which simultaneously requires different aspects of strength, power, speed, and endurance qualities [1, 2]. Although the spectrum of soccer-specific tasks is very extensive, the predominant actions are walking, jogging, sprinting, cutting, jumping, tackling, heading, and kicking [3]. Through the use of time-motion analysis, it has been revealed that soccer players typically cover a total distance of 9–12 km during a match [4], depending on playing position and game characteristics [5].

Maximum short sprints (i.e., < 10 m) account for approximately 12 % of the total distance covered within a game [5], but they appear to be a key element of elite soccer performance [6]. Accordingly, it has been demonstrated that soccer players competing at higher competitive levels execute more high-intensity running activities during a match than their less skilled peers (i.e., players competing at lower levels) [5]. Among these actions, the vast ma-

jority of studies focused on examining maximum linear efforts [7, 8] or sprints with successive changes of direction (COD) [9, 10]. Indeed, these previous works assessed COD performance using "cutting" or "turning" maneuvers between sequential straight lines, without considering the curve sprinting in their evaluations. Specifically, a curve sprint is a curvilinear sprint effort, with a discrete and continuous directional change [11].

The ability to effectively sprint in curvilinear trajectories is an important soccer skill, which is used to evade, track, or draw an opponent and, remarkably, ~85% of the actions performed at maximum velocity in a professional soccer league are curvilinear sprints [12]. In this regard, it has been shown that sprint activities during official soccer matches are rarely linear [13] and usually occur at a curve radius ranging from 3.5 m to 11 m [14]. Therefore, in a recent study with highly experienced soccer players, the authors [11] observed that players who ran faster in linear sprints were not necessarily faster in curvilinear trajectories (i.e., ~35% shared variance). In a more applied sense, this means that coaches and sport scientists must consider curved sprinting as a necessary and specific training and testing tool [11, 13]. As a result, a previous study [11] proposed the use of a novel and valid curve sprint test to assess elite soccer players (i.e., 9.15-m radius and 17-m distance).

From a mechanical standpoint, when compared to linear efforts, curve sprints require the ability to generate centripetal forces and provoke different mechanical and neuromuscular behaviors. The aforementioned research reported that performance in a standardized curve sprint test has a limited relationship with straight sprinting and suggested that these abilities are different and independent physical qualities [11]. This notion can be reinforced by observing the differences in body position, force application, joint angles, and running mechanics when athletes sprint in linear or curvilinear trajectories [15–20]. For example, it is known that contact time in the inside leg (IL) is higher than in the outside leg (OL) [16, 19, 20]. Nevertheless, it is not clear which of the legs compromise performance during curved sprints. Some authors have advocated that the IL plays a critical role in limiting speed during curve sprints because of a slightly smaller peak ground reaction force and muscle activation when compared to the OL [17, 21]. However, the aforementioned studies were performed with sprinters, using a "single one-sided curve sprint test." Therefore, assessing soccer players for both sides (i.e., "good" and "weak" sides) may shed light on the mechanisms behind this fundamental soccer skill.

Although soccer curve sprints are usually performed at high or very high intensities [12, 13], previous research has analyzed only curve displacements at submaximal velocities (i.e., jogging or moderate running) [8, 19]. Hence, to our knowledge, no studies have examined the kinematic and neuromuscular patterns of soccer players during maximum-effort curved sprints or compared EMG measures collected from both legs in order to determine the causes and consequences of "good" and "weak" sides. The aim of this study was to compare the neuromuscular and kinematic behavior between the outside leg (OL) and inside leg (IL) (interlimb) and intralimb during curve sprinting to both sides and linear sprinting in soccer players. We hypothesized that there would be significant differences between: 1) the foot contact time between OL and IL (interlimb) during curve sprints but not during linear sprints, 2) the foot contact time between IL "good" and IL "weak" side (intralimb),

and 3) the electromyography (EMG) activity in both legs across the different muscle groups during curve sprinting.

Materials and Methods

Study design

In this cross-sectional study, we compared the mechanical behavior between the OL and IL during curve sprinting to both sides and linear sprinting in soccer players. Forty-eight hours before the data collection, athletes participated in a familiarization session. Subsequently, during the experimental session, they performed 2 different maximum sprint tests: 1) a 17-m linear sprint, and 2) the standardized curve sprint test (9.15-m radius and 17-m distance) [11]. Both measurements were performed on artificial grass under optimal conditions of humidity and weather (i.e., 15–17 °C and 35% relative humidity). The soccer players performed each test three times, completing a total of nine sprint efforts as follows: 3 × linear sprints + 3 × right curve sprints + 3 × left curve sprints. Three minutes of recovery were allowed between efforts. The best attempt of each test was considered for statistical analysis.

Subjects

Nine semiprofessional Spanish soccer players (age = 23 ± 4.12 years; height = 168 ± 6.12 m; mass = 72.1 ± 4.67 kg) were recruited for this investigation. All subjects met the following inclusion criteria: 1) being involved in a semiprofessional soccer league, 2) training at least twice a week, and 3) not presenting any medical condition that could affect the physical measurements. Before participating in the study, athletes signed an informed consent form. This research was approved by the local Ethics Committee. The current investigation also adhered to the standards of the International Journal of Sports Medicine [22].

Linear sprint test

Linear sprint velocity was assessed using a linear 17-m sprint test, with photoelectric timing gates (Witty; Microgate, Bolzano, Italy) placed at the starting line and 17 m. The front foot was placed 1 m behind the starting line.

Curve sprint test

The trajectory used to measure velocity during curved sprints was the penalty arc of an official soccer field (▶ **Fig. 1**) and started from a standing position. Running velocity was assessed over 17 m, with timing gates placed at the starting line and 17 m. The front foot was placed 1 m behind the first timing gate following the line of the penalty arc. This curve sprint test was found to be valid and reliable in a recent study [11]. "Good" and "weak" sides (best and worst attempts, respectively) were considered for further analysis.

EMG measurement

The mDurance (mDurance, Granada, Spain) system was used to assess EMG activity. This electronic system leverages the use of wearable inertial sensors to track the selected muscle and portable electromyography sensors to seamlessly measure the electrical activity produced by the selected muscles. All of the information registered through these sensors is intelligently managed by a mo-

bile application [23]. The sampling rate used was 1024 Hz. The EMG activity was computed using a full-wave rectified, filtered, and normalized EMG signal, calculated during curved and linear sprints. We calculated the root-mean-square peak percentage (%RMS) by normalizing the mean values obtained from the five highest peaks observed in every task [24]. As the main focus of the research was to examine the mechanical differences between linear and curvilinear sprints, four muscle groups directly involved in movements outside the sagittal plane were specifically selected: (a) gluteus medius (GMed), (b) semitendinosus (ST), (c) biceps femoris long head (BF), and (d) adductor (ADD). Electrodes were placed according to SENIAM (Surface ElectroMyoGraphy, procedures for the non-invasive assessment of muscles) [25]. These recommendations were programmed in the mDurance mobile app used in the tests.

Kinematic variable

During the tests the players were recorded with a digital camera (GoPro Hero5 + Black, GoPro Inc., San Mateo, USA, California) and sampled at 240 frames per second. The camera was located on the penalty spot at 9.15 m from the running lane and perpendicular to the acquisition space and the subjects' sagittal plane [26]. Foot contact time (FCT) was obtained during analyses and defined as the time from touchdown to take-off of the foot, as previously proposed [26].

Statistical analyses

The statistical analysis was performed using SPSS 21.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics are expressed as mean ± standard deviations (SD), within 95% confidence limits (95% CL). Data normality was checked using the Shapiro-Wilk test. Intra- and interlimb (OL and IL) FCT values were compared between straight and both curvilinear trajectories. An ANOVA with repeated measures with Bonferroni adjustments (condition: curve versus straight; sides: "weak" versus "good") was used to compare each leg (OL and IL). Cohen's d was used to calculate the effect size (ES). The ES magnitudes were interpreted using the following thresholds: <0.2, 0.2–0.6, 0.6–1.2, 1.2–2.0, and 2.0–4.0, for trivial, small, moderate, large, and very large; respectively [27]. The level of significance was set at $P < 0.05$. Pearson's correlation coefficient was calculated and categorized [27] to ascertain the relationship between the "weak" side curve sprint performance and the time difference between sides.

Results

Performance analysis

Mean ± SD times of all sprint efforts (linear, and right and left curve times) were measured. The results showed that players were faster during curve sprints for the "good" side (2.446 ± 0.112 s) in com-

▶ **Fig. 1** Curve sprint test performed by soccer players [11].

▶ **Table 1** Sprint performance (mean ± SD, p value, effect size) during linear (best data) and curvilinear path.

	Mean ± SD (s)		Linear sprint	Curve sprint "good" side
Linear sprint	2.47 ± 0.1 s	p value		
		ES		
Curve sprint "good" side	2.45 ± 0.12 s	p value	0.117	
		ES	0.17 (trivial)	
Curve sprint "weak" side	2.56 ± 0.17 s	p value	0.001 *	0.001 *
		ES	0.73 (small)	1.07 (moderate)
* Significant (p ≤ 0.05) differences between variables; †Significant (p ≤ 0.01) differences between variables; ES: effect size.				

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parison with linear sprints (2.468 ± 0.132 s); however, there were no significant differences (▶ **Table 1**). In contrast, there were significant differences (p ≤ 0.05) between linear sprints and the "weak" side curve sprint, as well as between the "good" and "weak" side curve sprints (p ≤ 0.01 and ≤ 0.01, respectively). According to mean values, the performance classification, from best to worst results, was as follows: 1) "good" side curve sprint (2.45 ± 0.11 s), 2) linear sprints (2.47 ± 0.13 s), and 3) "weak" side curve sprint (2.56 ± 0.17 s). The Pearson correlation coefficient showed a "moderate" relationship (r = 0.73) between "weak" side curve sprint performance and time difference between sides.

Kinematic analysis (FCT)

Interlimb analysis

Mean ± SD FCT (s) values of all subjects are plotted in ▶ **Table 2** for each of the three conditions (i.e., linear sprints, curve sprint right side, and curve sprint left side). During linear sprints, players had a similar FCT for both the right (0.134 ± 0.009 s) and left (0.135 ± 0.010 s) legs, without significant differences between them. In curve sprinting, significant differences were observed in FCT between the right and left sides. Specifically, FCT was higher in the right leg during the curve sprint right side (0.148 ± 0.009 s, 0.137 ± 0.009 s), and higher in the left leg during curve sprint left side in comparison to the other leg, respectively (0.148 ± 0.009 s, 0.137 ± 0.007 s). Thus, the IL (0.148 ± 0.009 s) presented a longer FCT than the OL (0.137 ± 0.008 s).

Intralimb analysis between curve sprint sides

Regarding the "good" and "weak" sides of the curve sprints, we observed significant differences (p ≤ 0.05) between FCT IL during curve sprints to the "good" (0.146 ± 0.008) and "weak" sides (0.150 ± 0.009 s) (▶ **Table 3**). The FCT in the IL in the "good" side

was lower than in the "weak" side, and the ES was considered "small" (ES = 0.57). There were no significant differences between the OL for the "weak" (0.137 ± 0.009 s) and "good" sides (0.135 ± 0.007 s), and the ES was "trivial" (ES = 0.19).

Intralimb analysis between curve (both sides) and straight sprints

The FCT IL showed significant differences between the "good" side curve sprint and linear sprint (ES ≥ 1.20, considered "large"), and between the "weak" side curve sprint and linear sprint (ES ≥ 2, considered "very large") (▶ **Table 3**). Conversely, for the OL, there were no significant differences between curved and linear sprinting in relation to the FCT.

EMG activity

▶ **Table 4** shows the results of the EMG activity during linear and curve sprints, for both right and left sides. In summary, we observed similar EMG activities (%RMS) in GMed and BF (GMed: 44.25 % and 43.37 %; BF: 51.03 % and 51.31 %) in both legs during linear sprints. However, there were significant differences between legs during linear sprints in ST (p ≤ 0.05) and ADD (p ≤ 0.05) EMG activity, although the ES was considered "small" for both variables (ES = 0.23 and 0.21, respectively).

During curve sprints, we found significant differences between the OL and IL in all analyzed muscle groups (p ≤ 0.05) (▶ **Table 4**). EMG activity was higher in both GMed and BF (external rotation muscles) in the OL, and, conversely, the IL recorded higher EMG activity in both ST and ADD (internal rotation muscles) (▶ **Table 4**). This means that the neuromuscular behavior during curved sprints is significantly different between IL and OL.

Discussion

The main findings of the present study were: 1) soccer players presented similar performances during curve sprints ("good" side) and linear sprints, 2) the IL displayed higher FCT than the OL throughout curvilinear trajectories, 3) the IL demonstrated greater modifications in FCT when comparing "weak" and "good" sides, and 4) the OL and IL presented different EMG activity during curve sprinting.

Performance analysis

According to the performance achieved in curved and linear sprints, the majority of players (6 of 9 players) obtained slightly better results in (from the highest to the lowest performances): 1) "good" side curve sprint, 2) linear sprints, and 3) "weak" side curve sprint

▶ **Table 2** Foot contact times (FCT) (mean ± SD) and confidence limits (95 %) during linear and curvilinear sprint (17 m).

	Right foot contact time (s)	Left foot contact time (s)
Linear sprint	0.134 ± 0.009 (0.127–0.139)	0.135 ± 0.01 (0.128–0.144)
Curve sprint (right)	0.148 ± 0.009 (0.141–0.151)	0.137 ± 0.009 * (0.129–0.142)
Curve sprint (left)	0.137 ± 0.007 (0.132–0.142)	0.148 ± 0.009 * (0.142–0.152)

* Significant (p ≤ 0.05) differences between variables; †Significant (p ≤ 0.01) differences between variables.

▶ **Table 3** Foot contact times (ES) during linear and curvilinear sprint to "good/weak" side (17 m).

		Curve sprint "good" side		Curve sprint "weak" side	
		Outside leg	Inside leg	Outside leg	Inside leg
Linear sprint	Outside leg	0.3		0.49	
	Inside leg		1.57†		2.04†
Curve sprint "good" side	Outside leg			0.19	
	Inside leg				0.57 *

* Significant (p ≤ 0.05) differences between variables; † Significant (p ≤ 0.01) differences between variables.

(▸ **Table 1**). However, there were no significant differences between the "good" side and linear sprint, but there were significant differences between the linear and "weak" side curve sprint (1.2% difference), as well as between the "good" vs. "weak" side curve (1.6% difference) (▸ **Table 1**). Previous research reported similar results between curve and linear performance with no differences between both actions [28]. Conversely, a study [17] reported superior performances in linear sprints (30 m) in comparison with curve sprints. This small difference is possibly due to the different protocols (i.e., 17-m curve sprint with 9.15-m radius vs. full circle with radii of 1, 2, 3, 4, and 6 m) and samples (i.e., soccer player vs. sprinter athletes) used in both investigations. In fact, the degree of turning curve in the valid and reliable test used herein [11] is higher than the turning degree commonly observed in previous studies [17, 20]. Together, these data suggest that, different from sprinters, soccer players, as a direct result of their specific requirements, may potentially exhibit similar performances in both curved ("good" side) and linear trajectories (0.4% difference).

Performance analysis can provide an overview of the relationships that exist between "weak" side curve sprinting and their respective differences between sides (r = 0.73, "moderate"). In summary, this means that players who run slower during curve sprinting "weak" side are prone to present higher differences. This indicates that the "weak" side plays a pivotal role in the differences magnitude that cannot be confirmed by our cross-sectional data and must be explored in future investigations.

Kinematic analysis (FCT)

Interlimb analysis

Several studies [16, 17, 29, 30] reported longer FCTs in the IL in comparison to the OL during curve sprinting actions. Similar results were confirmed in the present study: 1) during curve sprints, IL FCT was longer than in the OL.

Intralimb analysis between curve sprint sides

The results confirmed that IL displayed longer FCT in the curve sprint toward the "weak" than "good" side. The aforementioned studies were performed with track and field athletes, thereby assessing curve sprints only to one side (i.e., counter-clockwise). This is the first study that assessed FCT during curve sprints to both sides ("weak" and "good"), because in soccer both sides are equally important for successful performance. In this sense, we showed that the IL registered a greater change from the "good" to the "weak" side (▸ **Table 3**) and, notably, the OL was barely affected. This suggests that IL, in accordance with previous work [17], might be a determining factor in regulating the decrements in performance from the "good" to "weak" side.

Intralimb analysis between curve (both sides) and straight sprints

The results confirmed that IL obtained longer FCT during curve sprint than straight sprint (▸ **Table 3**). Although the OL did not show significant differences in FCT (% differences = 1.5% and 2.9%), the IL demonstrated significant and higher differences (% differences = 8.9% and 11.3%) for the "good" and "weak" sides, respectively (▸ **Table 3**). These data are in accordance with a previous work [16] that presented similar OL FCT during linear and curve sprints. How-

▲ **Table 4** Mean ±SD and confidence limits (95%), EMG activity expressed as a %RMS during linear and curvilinear sprint (17 m).

	GMed (%)		BF (%)		ST (%)		ADD (%)	
	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside
Linear sprint	43.37±2.10 (42.0–44.74)	44.25±1.52 (43.26–45.24)	51.31±3.52 (49.01–53.61)	51.03±2.57 (49.35–52.71)	49.76±4.93 (46.54–52.98)	52.39±6.2* (48.35–56.44)	51.72±2.32 (50.2–53.24)	50.65±3.01* (48.68-52.61)
Curve sprint	53.89±4.18 (51.16–56.62)	43.94±9.85† (37.51–50.38)	44.21±12.08 (36.32–52.1)	35.03±10.44* (28.21–41.85)	43.94±6.63 (39.61–48.27)	53.51±5.76* (49.75–57.27)	43.45±8.4 (37.96–48.94)	49.66±6.94† (45.13–54.19)

* Significant (p ≤ 0.05) differences between legs; †Significant (p ≤ 0.01) differences between legs; RMS, root mean square; GMed, gluteus medius; BF, biceps femoris long head; ST, semitendinosus; ADD, adductor.

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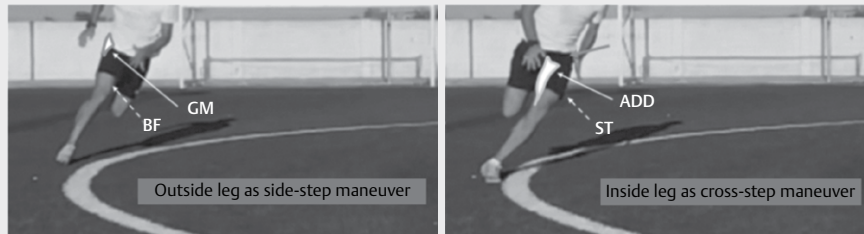
▶ **Fig. 2** Similarity between the roles of each leg during the maneuvers curve sprint analyzed.

ever, the present study showed an added value in relation to previous research, because we also assessed the "weak" side. Therefore, rather than solely producing greater peak forces, faster velocities depend more on the ability to rapidly generate these forces, which means that the production of high vertical forces over short contact times is an issue [31]. The longer FCT IL suggests that the mechanical conditions to apply and generate forces rapidly in this leg throughout curved sprints are not appropriate [17]. Future studies with soccer players that take into account kinetic variables during curve sprinting can better elucidate these performance-limiting factors.

EMG activity

EMG activity during straight sprint

No differences between legs were observed in the activation (%RMS) during linear sprints when both legs are compared with equal prominence (▶ **Table 4**).

EMG activity during curve sprint

This is the first study to analyze both legs. Therefore, a comparison with similar maneuvers is crucial to contrast the results with other studies. We can find a similarity between the IL role as a "continuum cross-step maneuver" (i.e., the travel direction is towards the same side of the body as the pivot leg), and the OL role as a "continuum side-step maneuver" (i.e., the travel direction is towards the side of the body opposite the pivot leg) (▶ **Fig. 2**).

During OL/side-stepping, activation of hip external rotation muscles (BF, GMed) will increase compared to IL/cross-stepping cut to counter the applied valgus and hip internal rotation moments at the knee [21, 32, 33]. Conversely, during IL/cross-stepping cut, activation of hip internal rotation muscles (ST, ADD) will increase compared to OL/sidestepping cut to counter the applied varus and hip external rotation moments at the knee (▶ **Table 4**) [32, 33]. These data add more evidence to confirm that each leg plays a different role during curve sprinting.

COD, linear and curve sprinting analysis

Some data about FCT and angle were presented for different CODs that indicated a longer FCT with increased angles [34] and shorter FCTs as determinants of faster COD performance [35]. During COD maneuvers, one of the limiting factors of performance is OL [10] through its role in decelerating and accelerating during clear lateral push-off actions and with higher FCT. Conversely, in accordance with another study [17], our results suggest that at maximal effort, an increment in FCT and a reduction in peak resultant ground reaction force by IL likely play a significant role in limiting speed during curve sprinting.

The previous data suggest that as the degree of turn decreased (from COD maneuvers to curve to linear sprint), the FCT of the legs is gradually distributed from the OL to the IL until both legs share the same FCT during the linear sprint. Although this seems controversial, it is an additional finding to indicate that COD, linear, and curve sprinting are different qualities.

This study is inherently limited by its cross-sectional design, which precludes conclusions regarding causality. In addition, we did not assess or consider kinetic variables (i.e., vertical and horizontal peak forces) in our analysis, which undoubtedly limits the extent of our findings. Finally, the small sample size (which can be explained by the complex methodology implemented) and the lack of kinetic data (e.g., rate of force development) may limit the clarity and strength of our findings. Nevertheless, this is the first study to describe the kinematic and neuromuscular behavior of lower limbs during maximum curved sprints in soccer players. Further studies should be conducted to examine the mechanical and neuromuscular differences between faster and slower athletes, as well as to analyze the effects of different training strategies on curved sprint performance.

Conclusions

Soccer players achieved similar performances during curve sprinting to the "good" side and linear sprinting. The IL displayed longer FCT in the curve than linear sprint, and the IL obtained longer FCT during the sprint curved toward the "weak" than "good" side. During curved sprints, IL EMG activity was higher in ST and ADD, and conversely, OL EMG activity was higher in GMed and BF. Lastly, we showed that IL is more affected (FCT) by the change from straight to curve sprinting and from the "good" to "weak" side. Thus, soccer coaches are strongly recommended to include specific curve sprint training strategies in their professional training routines, especially for the purpose of enhancing the mechanical efficiency of the IL (i.e., increase its ability to apply greater forces in shorter times). According to our data, the inside leg possibly plays a determinant role in limiting the maximum running speed during curvilinear sprints. These findings should be confirmed with further stud-

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ies, preferably performed with the use of equipment able to measure and collect kinetic data.

Acknowledgements

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Marios CA, Smilios I, Sotiropoulos K et al. Effects of resistance training on the physical capacities of adolescent soccer players. J Strength Cond Res 2006; 20: 783–791

[2] Prieske O, Muehlbauer T, Borde R et al. Neuromuscular and athletic performance following core strength and training in elite youth soccer: Role of instability. Scand J Med Sci Sports 2016; 26: 48–56

[3] Ade J, Fitzpatrick J, Bradley PS. High-intensity efforts in elite soccer matches and associated movement pattern, technical skills and tactical actions. Information for position-specific training. J Sports Sci 2016; 34: 2205–2214

[4] Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. J Sports Sci 2003; 21: 519–528

[5] Suarez Moreno-Arrones L, Torreño N, Requena B et al. Match play activity profile in professional soccer players during official games and the relationship between external and internal load. J Sport Med Phys Fitness 2015; 55: 1417–1422

[6] Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 2017; 30: 625–631

[7] Buchheit M, Samonizo P, Glynn J et al. Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. J Sport Sci 2014; 32: 1906–1913

[8] Morin JB, Petrakos G, Jiménez-Reyes P et al. Very heavy sled training for improving horizontal force output in soccer players. Int J Sports Phy Perform 2017; 12: 840–844

[9] Brughelli M, Cronin J, Levin G et al. Understanding change of direction ability in soccer: A review of resistance training studies. Sports Med 2008; 38: 1045–1063

[10] Young W, James R, Montgomery I. Is muscle power related to running speed with change of direction? J Sports Med Phys Fitness 2002; 42: 282–288

[11] Filter A, Olivares J, Santalla A et al. New curve sprint test for soccer player: Reliability and relationship with linear sprint. J Sports Sci 2019; 1–6

[12] Caldbeck P. Contextual Sprinting in Football [DSportExSci thesis]. Liverpool, UK: John Moores University; 2019

[13] Fitzpatrick JF, Linsley A, Musham C. Running the curve: A preliminary investigation into curved sprinting during football match-play. Sport Perform Sci Reports 2019; 1:■■

[14] Brice P, Smith N, Dyson R. Frequency of curvilinear motion during competitive soccer play. Communications to the Fourth Congress of Science and Football. J Sports Sci 2004; 22: 504

[15] Brice P, Smith N, Dyson R. Curved running in soccer: Kinematics differences between the inside and outside limbs. Proceedings of the XXVI Int Conf Society Biomech Sports 2008;■■

[16] Churchill S, Salo A, Trewartha G. The effect of the bend on technique and performance during maximal effort sprinting. Sport Biomech 2015; 14: 106–121

[17] Chang Y, Kram R. Limitations to maximum running speed on flat curve. J Exp Biol 2007; 210: 971–982

[18] Judson LJ, Churchill SM, Barnes A et al. Horizontal force production and multi-segment foot kinematic during acceleration phase of bend sprinting. Scan J Med Sci Sports 2019; 29: 1563–1571

[19] Smith N, Dyson R, Hate T. Lower extremity muscular adaptations to curvilinear motion in soccer. J Hum Mov Studies 1997; 33: 139–159

[20] Smith N, Dyson R, Hale T et al. Contributions of the inside and outside leg to maintenance of curvilinear motion on a natural surface. Gait Posture 2006; 24: 453–458

[21] Rand M, Ohtsuki T. EMG analysis of lower limb muscle in humans during quick change in running directions. Gate Posture 2000; 12: 169–183

[22] Harriss DJ, Macsween A, Atkinson G. Ethical standards in sport and exercise science research: 2020 update. Int J Sports Med 2019; 40: 813–817

[23] Banos O, Moral-Muñoz JA, Díaz-Reyes I et al. mDurance: A novel mobile health system to support trunk endurance assessment. Sensors 2015; 15: 13159–13183

[24] Albertus-Kajee Y, Tucker R, Derman W et al. Alternative methods of normalising EMG during running. J Electromyogr Kinesiol 2011; 21: 579–586

[25] Hermens H, Freriks M, Disselhorst-klug M et al. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000; 10: 361–374

[26] Miyamoto A, Takeshita T, Yanagiya T. Differences in sprinting performance and kinematics between preadolescent boys who are force/mid and rear foot strikers. Plos One 2018; 13: e0205906

[27] Hopkins W, Marshall S, Batterham A et al. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009; 41: 3–13

[28] Ohnuma H, Tachi M, Kumano A et al. How to maintain maximal straight path running speed on a curved path in sprint events. J Hum Kinet 2018; 62: 23–31

[29] Churchill S, Trewartha G, Bezodis I et al. Force production during maximal effort bend sprinting: Theory vs. reality. Scand J Med Sci Sports 2016; 26: 1171–1179

[30] Churchill S, Trewartha G, Salo AI. Bend sprinting performance: New insights into the effect of running lane. Sports Biomech 2018; 18: 437–447

[31] Weyand P, Sandell R, Prime D et al. The biological limits to running speed are imposed from the ground up. J Appl Physiol 2010; 108: 950–961

[32] Besier T, Lloyd D, Cochrane J et al. External loading of the knee joint during running and cutting maneuvers. Med Sci Sports Exerc 2001; 33: 1168–1175

[33] Besier T, Lloyd D, Ackland T. Muscle activation strategies at knee during running and cutting maneuvers. Med Sci Sports Exerc 2000; 35: 119–127

[34] Dos Santos T, Thomas C, Comfort P et al. The effect of angle and velocity on change of direction biomechanics: an angle-velocity trade-off. Sports Med 2018; 48: 2235–2253

[35] Dos Santos T, Thomas C, Jones PA et al. TMechanical determinant of faster change of direction speed performance in male athletes. J Strength Cond Res 2017; 31: 696–705

Filter A et al. Curve Sprinting in Soccer… Int J Sports Med 2020; 41: 1–7

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