CHANGE OF DIRECTION SPEED IN SOCCER: HOW MUCH BRAKING IS ENOUGH?

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Abstract:

The aims of the present study were to examine: 1) the validity and reliability of a new timing system to assess running kinematics during change of direction (COD), and 2) the determinants of COD-speed. Twelve young soccer players performed three 20-m sprints, either in straight line or with one 45º- or 90º-COD. Sprints were monitored using timing gates and two synchronized 100-Hz laser guns, to track players' velocities before, during and after the COD. The validity analysis revealed trivial-to-small biases and small-to-moderate typical errors of the estimate with the lasers compared with the timing gates. The reliability was variable-dependent, with trivial- (distance at peak speed) to-large (distance at peak deceleration) typical errors. Kinematic variables were angle-dependent, with likely lower peak speed, almost-certainly slower minimum speed during the COD and almost-certainly greater deceleration reached for 90º-COD vs. 45º-COD sprints. The minimum speed during the COD was largely correlated with sprint performance for both sprint angles. Correlations with most of the other independent variables were unclear. The new timing system showed acceptable levels of validity and reliability to assess some of the selected running kinematics during COD sprints. The ability to maintain a high speed during the COD may be the determinant of COD-speed.

Key words: *acceleration, deceleration, speed profile, sprint, laser gun, soccer*

Introduction

The ability to sprint and change direction while sprinting is an essential component of physical performance in team and racquet sports, as evidenced by time and motion analyses, for example in soccer (Bloomfield, Polman, & O'Donoghue, 2007) or handball (Karcher & Buchheit, 2014). While acknowledging that the majority of sprints leading to a goal might actually be linear in soccer (Faude, Koch, & Meyer, 2012), sprints with a single change of direction (COD) represented ~8.5% of total powerful actions (Faude, et al., 2012) and single COD-sprints may represent a larger percentage, since COD-angles less than ~50° were not taken into account. In addition, pre-planned COD speed training is still an important component of players' training routine (Brughelli, Cronin, Levin, & Chaouachi, 2008) and COD speed performance may discriminate players of different playing standards (Brughelli, et al., 2008).

The physiological, neuromuscular, kinematic and locomotor determinants of COD speed have been largely reviewed and include sprint technique, dynamic balance, whole-body coordination, locomotor speed, eccentric strength and concentric power, reactive strength, between-leg balance in strength and body dimensions (Brughelli, et al., 2008; Sheppard & Young, 2006). More specifically, the ability to reach a high speed and then to decelerate quickly before the COD is believed to be critical for COD speed by practitioners (Hewit, Cronin, Button, & Hume, 2011; Lockie, Schultz, Callaghan,

& Jeffriess, 2013). In fact, the ability to optimally decrease the body's momentum before a COD may allow players to adopt an appropriate 'cuing' (e.g. decrease steps length, apply greater lateral forces to the ground and keep the torso up) and, in turn, improve COD speed performance (Hewit, Cronin, & Hume, 2013). While the beneficial effect of a 'good' deceleration capacity for COD speed performance is intuitive, the actual magnitude of an optimal deceleration is still unknown. For instance, with extreme decelerations, the beneficial effect of slowing down on COD ability *per se* might not compensate for the greater time requirement to re-accelerate, so that the overall COD speed performance may be impaired. Accordingly, the respective importance of peak acceleration, peak speed, peak deceleration and the distance to/from COD when deceleration/acceleration occurs is also unknown. Finally, since performance (Brughelli, et al., 2008; Sheppard & Young, 2006), physiological and neuromuscular (Buchheit, Haydar, & Ahmaidi, 2012; Hader, Mendez-Villanueva, Williams, Ahmaidi, & Buchheit, 2014) responses during COD speed are likely COD angle-dependent, the optimal acceleration/peak speed/deceleration strategies may also be COD-angle dependent. However, this has still to be examined.

Assessing the center of mass (COM) related running kinematic profile of linear speed is simple, using either multiple timing gates with splits (Krzysztof & Mero, 2013) or laser guns (Morin, Jeannin, Chevallier, & Belli, 2006). When it comes to the assessment of COD speed in the field, timing gates (Buchheit, et al., 2012; Young, Hawken, & McDonald, 1996) and GPS technologies (Jennings, Cormack, Coutts, Boyd, & Aughey, 2010) have been generally used. However, both technologies have limitations for COD speed, such as the inability to properly examine the different running phases with gates, and a limited validity and reliability for such short and intense movement patterns with GPS (Buchheit, et al., 2014; Jennings, et al., 2010). In an attempt to describe the detailed COM-related running kinematics of COD speed in the field, we have recently developed a new timing system combining two laser guns, which allows the continuous tracking of the players before, during and after the COD (Figure 1). This procedure allows, for the first time in the field, the examination of the different phases of COD-sprints (i.e. acceleration, deceleration and re-acceleration phases) and their COM-related running kinematic variables (e.g. speed during the COD, peak speed, peak acceleration, peak deceleration, distance at peak deceleration, distance at peak speed). For coaches, as well for strength and conditioning coaches, knowledge about acceleration, deceleration and re-acceleration phase characteristics (e.g. start and end of deceleration) would be interesting with important implications for specific training prescription in soccer (e.g. training and improving especially the deceleration and/or re-acceleration phases). The aims of the present study were to examine: 1) the validity and reliability of our new timing system to assess the COM-related running kinematic profiles of two different COD speed tests (45° and 90°) in the field, and 2) the COM-related running kinematic determinants of COD speed performance.

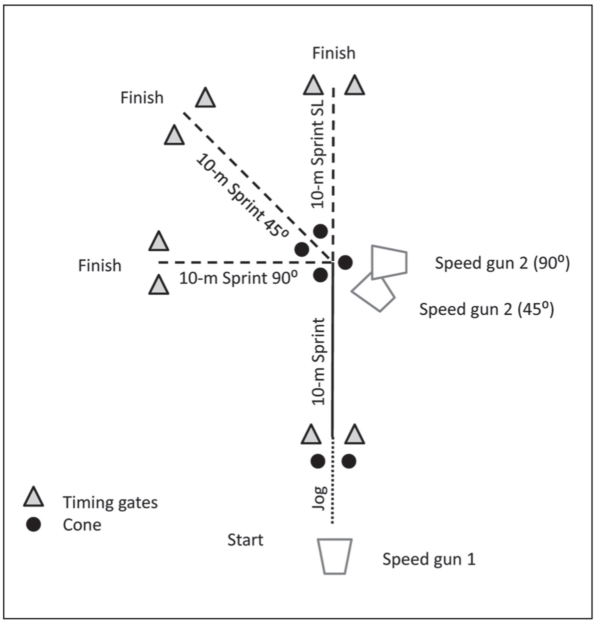

Figure 1. Experimental set up with the new timing methodology combining two laser guns synchronized. See Methods section for details.

Methods

Participants

Twelve highly-trained young soccer players (age: 16.5±0.4 years, age from the estimated peak height velocity: 2.1±0.6 years old, height: 170.3±6.4 cm, body mass 60.0±6.3 kg, sum of seven skinfolds 45.6±16.0, 10-m sprint time 1.76±0.05 s, and maximal sprinting speed 29.9±1.2 km·h^{-1}) from an elite academy were involved. Anthropometric and performance data were collected as previously described (Buchheit & Mendez-Villanueva, 2013). All the players participated on average in ~14 hours of combined soccer-specific training and competitive play per week (6-8 soccer training sessions, one strength training session, one to two conditioning sessions, one domestic game per week and two international club games every three weeks). All players had a minimum of three years prior soccer-specific training and were well familiar with the testing procedures. Written informed consent was obtained from the players and their parents. The study was approved by the local research ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Experimental overview

Following a 15-min standardized warm-up, including eight consecutive COD-runs with progressive speed for familiarization, players randomly performed twice three different 20-m sprints, either in straight line (SL) or with one left 45º- or 90º-COD after 10 meters. Since the majority of COD-runs in soccer matches occur with angles between 0 and 90° (Bloomfield, et al., 2007), the chosen 45°- and 90°-angles in the present study are likely soccer-specific. The use of a single COD during the sprints was also chosen for specificity with regard to soccer practice during matches (Faude, et al., 2012). As a part of the academy performance screening (i.e. three times per year), players' anthropometric measures and maximum sprinting speed (Buchheit & Mendez-Villanueva, 2013) were available and then included as possible determinants of COD-sprint performance. In addition, all the players were familiarized with this type of COD-sprint while being routinely tested during the academy performance screening on a similar 90°-COD sprint. Players were required to initiate the left turn with a strong impulse of their right foot, positioned in the centre of the running course, at the level of the turn. *A posteriori*, it appeared that all the players performed naturally the 90°-COD sprints as requested (i.e. strong right foot impulse to initiate the turn). Players' dominant leg (i.e. the kicking leg) was the right one for all. In the present study, all players turned to the left during the COD-sprints. Whether different responses could have been observed with a right turn could not be examined in the present study, which is a limitation. However, Castillo-Rodriguez, Fernandez-Garcia, Chinchilla-Minguet, and Carnero (2012) observed that amateur players kicking with their right foot were very likely to present a greater COD-sprint performance on the left side. All players turned largely faster (i.e. effect size=1.8) to the left side than to the right side. There was a 2-3 minutes passive recovery period between each sprint. To increase ecological validity (Varley & Aughey, 2013), players commenced each sprint from a jogging start (2 m·s^{-1}, controlled with a metronome) over 10 meters, and were instructed to initiate their sprint when reaching a cone placed one meter from the starting line (Figure 1). Participants were instructed to complete all sprints as fast as possible, and strong verbal encouragement was provided to each subject during all sprints. Tests were performed with soccer boots on an outdoor (temperature 39.5±1.5ºC and relative humidity 18.0±2.6%) grass soccer pitch.

Center of mass-related kinematic measures

Sprints were simultaneously monitored with timing gates (Brower Timing System, Draper, UT, USA, 1 ms resolution) and two cabled-synchronized 100-Hz laser guns (Laveg LDM100, Jenoptik, Germany, Figure 1). A custom-developed spreadsheet gathered both data files and calculated the whole player's running profile before, during, and after the COD (Figure 1). Individual laser measurements have shown very good validity (average velocity error of ~2%; Turk-Noack & Schmalz, 1994) and reproducibility (coefficient of variation, CV: 1-3%; Duthie, Pyne, Marsh, & Hooper, 2006; Poulos, Kuitunen, & Buchheit, 2011) when assessing linear speed.

Data treatment

Raw (position) data from the first laser gun was zeroed at the starting line, while the second was zeroed at the COD point. Velocity data was obtained by derivation and then processed using a 4th order low-pass Butterworth digital filter with a cut-off frequency of 0.6 Hz (selected after several trials judged by visual inspection). Both speed curves were then merged into a unique curve using the first laser readings at the beginning, the second at the end; the merged interval (COD) was estimated by the interpolation of both readings. Finally, data were resampled to provide an estimate of speed at each meter throughout the entire run. Acceleration and deceleration were derived from meter-to-meter changes in speed over time, and peak acceleration, peak speed, distance at peak speed, peak deceleration, distance at peak deceleration, minimum speed during the COD, and speed from 8 to 12 m were computed.

Statistical analysis

Data in text, tables and figures are presented as means with standard deviations and 90% confidence intervals/limits (CI/CL). All data were first log-transformed to reduce bias arising from non-uniformity error. The validity analysis consisted of the comparison of the sprint times measured with the new system with those measured with timing gates, used as the criterion measure (mean bias, expressed as a standardized difference based on Cohen's effect size principle, using pooled standard deviations), the typical error of the estimate (TEE, both in % and standardized units) and the magnitude of the correlations between the systems. The typical error of measurement, expressed as a CV (in % and standardized units) and the intraclass coefficient correlation (ICC) were used as measures of reliability (Hopkins, Marshall, Batterham, & Hanin, 2009).

Between-sprints standardized differences in the different running variables were also calculated, using pooled standard deviations. Uncertainty in the differences was expressed as 90% CL and as probabilities that the true effect was substantially greater or smaller than the smaller practical difference (between-subjects SD/5) (Hopkins, et al., 2009).

These probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect. The scale was as follows: 25–75%, possible; 75–95%, likely; 95–99%, very likely; >99%, almost certain.

The respective kinematic determinants of performance during COD sprints were assessed using multiple linear regression models (stepwise backward elimination procedure); with sprint time as the dependent variable, and peak acceleration, peak speed, peak deceleration, minimum speed during COD, speed from 8 to 12 m, body mass, body height, leg length, the sum of seven skinfolds, 10-m sprint time and maximal sprinting speed as the independent variables. Variables with at least large CVs (based on the standardized values) were

Table 1. Validity of the new timing methodology during sprints with and without change of direction

	Bias (%)	TEE (%)	r
Straight line	1.9 (0.7;3.2)#	2.5 (1.8;3.7)#	.94 (.83; .97)***
45°	-1.5 (-2.9;0.0)#	3.5 (2.8;4.8)##	.74 (.51; .87)**
90°	-0.6 (-1.3;0.0)	1.7 (1.4;2.4)#	.91 (.82; .96)***

Mean bias (90% confidence limits), typical error of the estimate (TEE, 90% confidence limits) and correlation coefficient (r, 90% confidence limits). One or two '#' symbols refer to small and moderate standardized bias and TEE, respectively. For r values, the number of '*' symbols refers to moderate, large and very large correlations, respectively.

Table 2. Reliability of the different variables collected with the new timing methodology and timing gates during sprints with and without change of direction

		Difference (%)	CV (%)	ICC
Time (Timing gates)	Straight line	0.4 (-1.6; 2.4)	1.9 (1.3; 3.7)#	.94 (.76; .99)***
	45°	0.1 (-3.8; 4.1)	4.3 (3.0; 7.8)##	.23 (-.41; .72)
	90°	0.4 (-1.5; 2.2)	2.0 (1.4; 3.5)#	.82 (.46; .95)***
Time (Laveg)	Straight line	-0.3 (-3.2; 2.7)	2.9 (2.0; 5.6)#	.84 (0.45; .96)**
	45°	0.0 (-4.0; 4.0)	4.9 (3.0; 7.8)##	.15 (-.47; .62)
	90°	0.2 (-2.3; 2.9)	2.8 (2.0; 5.0)#	.72 (.23; .92)*
Peak acceleration	Straight line	-1.1 (-8.4; 7.2)	8.9 (5.9; 14.6)##	.43 (-.11; .78)
	45°	0.5 (-4.7; 5.9)	6.6 (4.8; 11.1)##	.60 (.11; .90)*
	90°	0.6 (-5.9; 7.6)	8.5 (6.2; 11.4)##	.42 (-.13; .77)
Peak speed	Straight line	-0.6 (-3.7; 2.6)	2.8 (1.9; 5.9)##	.92 (.67; .98)***
	45°	0.6 (-4.0; 5.5)	5.9 (4.3; 9.9)##	.50 (.28; .70)
	90°	0.2 (-1.7; 2.2)	2.4 (1.7; 4.0)#	.72 (.32; .90)*
Distance at peak speed	Straight line	0.0 (0.0; 0.0)	0.0 (0.0; 0.0)	-
	45°	2.8 (-14.6; 23.9)	24.0 (17.0; 42.5)###	.40 (-.14; .77)
	90°	1.3 (-12.7; 17.5)	13.7 (9.8; 23.5)###	.45 (.11; .90)
Peak deceleration	Straight line	-	-	-
	45°	25.1 (-61.7;46.5)#	117.3 (76.1; 278.4)##	.78 (.43; .93)**
	90°	-4.1 (-33.9; 39.4)	38.0 (26.5; 69.9)##	.75 (.37; .95)**
Distance at peak deceleration	Straight line	-	-	-
	45°	-0.3 (-11.7; 12.4)	15.0 (10.7; 28.8)####	.06 (-.44; .57)
	90°	0.3 (-12.6; 15.1)	12.6 (9.0; 21.5)###	.49 (.04; .88)
Minimum speed during COD	Straight line	-	-	-
	45°	-0.5 (-5.7; 4.9)	6.2 (4.4; 10.9)##	.58 (.05; .86)*
	90°	0.9 (-5.8; 7.9)	6.0 (4.4; 10.1)##	.82 (.51; .97)**
Speed from 8 to 12 m	Straight line	-0.1 (-1.4; 1.2)	1.8 (1.3; 1.9)##	.90 (.72; .96)***
	45°	-0.3 (-4.6; 4.2)	5.2 (3.8; 8.7)##	.64 (.18; .88)*
	90°	1.0 (-4.8; 7.3)	5.3 (3.8; 8.9)##	.96 (.87; .99)****

Mean bias (90% confidence limits), typical error expressed as a coefficient of variation (CV, 90% confidence limits) and intraclass correlation coefficient (ICC, 90% confidence limits). The number of '#' symbols stands for small, moderate, large and very large standardized difference and CV, respectively. For ICC values, the number of '*' symbols refers to moderate, large and very large magnitudes, respectively.

not included in the analysis. In the backward procedure, variables with an F value greater than 4 were removed from the model.

Threshold values for standardized differences, typical error and TEE were >.2 (small), >.6 (moderate), >1.2 (large), and very large (>2) (Hopkins, et al., 2009). The magnitude of the ICC was assessed using the following thresholds: >.99, extremely high; .99-.90, very high; .90-.75, high; .75-.50, moderate; .50-.20, low; <.20, very low. Finally, the following criteria were adopted to interpret the magnitude of the Pearson's product-moment correlation analysis: ≤.1, trivial; >.1-.3, small; >.3-.5, moderate; >.5-.7, large; >.7-.9, very large; and >.9-1.0, almost perfect. If the 90% CI overlapped small positive and negative values, the magnitude was deemed unclear; otherwise that magnitude was deemed to be the observed magnitude (Hopkins, et al., 2009).

Results

The validity analysis revealed trivial-to-small biases compared with timing gates and small-to-moderate TEE (Table 1). The level of reliability was variable-dependent, with trivial (distance at peak speed during the straight line sprint) to very large (distance at peak deceleration) CVs (Table 2).

The speed profile of each sprint is shown in Figure 2. Speed-related variables were angle-dependent during sprints with COD, with likely lower peak speed, almost certainly slower speed during COD and almost certainly greater deceleration reached during the 90º-COD trial compared with the 45º-COD sprint (Table 3).

The minimum speed reached during COD was a large-to-very-large determinant of sprint performance for both sprint angles, while peak acceleration and peak speed additionally contributed to 45º-COD and 90º-COD performance, respectively (Figure 3). The overall fit (r^2) for the regression models were nearly perfect (r = .90) and very large (r = .75) for 45º-COD and 90º-COD performance, respectively. Correlations with all the other independent variables (Table 2) were unclear and rejected from the multiple regression model.

Table 3. Running variables during sprints with and without changes of direction

	Straight line	45º	90º
Time (s)	2.89 ± 0.13	3.30 ± 0.16****4	3.70 ± 0.16****4††††4
Peak acceleration (m·s^{-2})	3.32 ± 0.29	3.38 ± 0.26	3.19 ± 0.36**1††2
Peak speed (m·s^{-1})	8.06 ± 0.46	6.65 ± 0.32****4	6.40 ± 0.30****4††2
Distance at peak speed (m)	20 ± 0	7.73 ± 1.67****4	4.33 ± 0.62****4††††4
Peak deceleration (m·s^{-2})	-	-1.12 ± 0.82	-3.00 ± 0.78††††4
Distance at peak deceleration (m)	-	10.29 ± 1.38	9.00 ± 1.04†††2
Minimum speed during COD (m·s^{-1})	-	6.06 ± 0.54	4.25 ± 0.47††††4
Speed from 8 to 12 m (m·s^{-1})	7.36 ± 0.39	6.36 ± 0.54****3	4.90 ± 0.64****4††††4

COD: change of direction; SL: straight line. The number of '*' and '†' refer to possible, likely, very likely and almost certain difference versus straight line and 45°, respectively. This associated number refer to the magnitude of the difference, with 1 standing for a small, 2 for moderate, 3 for large and 4 for very large magnitude.

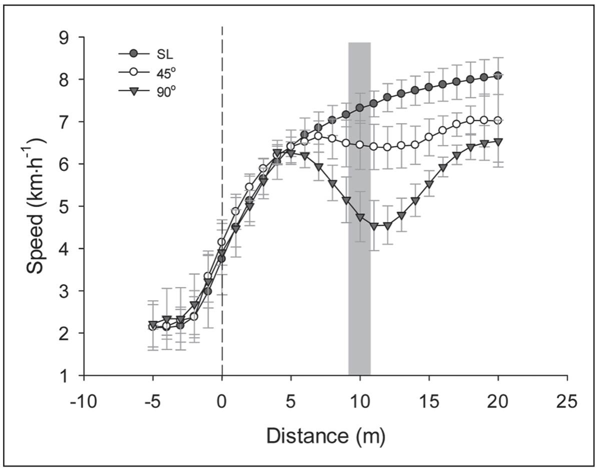

Figure 2. Running speed during 20-m sprints with (45° and 90°) or without (straight line, SL) change of direction. The grey area represents the change of direction.

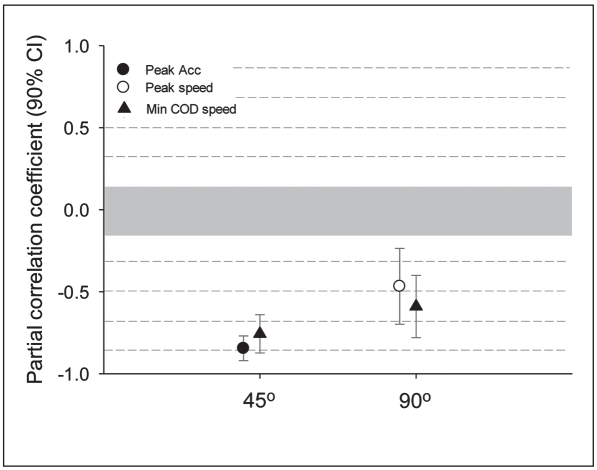

Figure 3. Partial correlations (90% confidence intervals, CI) between sprint times and peak acceleration (Peak Acc), peak speed and the minimum speed during the change of direction (Min COD speed).

Discussion and conclusions

The aims of the present study were to examine the validity and reliability of a new timing system to assess COM-related running kinematic profiles during field-based COD speed, and to determine the kinematics determinants of COD speed performance. Our results are as follow: 1) there were trivial-to-small biases between the new timing system and timing gates and small-to-moderate typical errors of the estimate, 2) the reliability of the different COM-related kinematic variables was variable-dependent with small-to-very large CVs, 3) kinematic variables were also angle-dependent during COD sprints, with likely lower peak speed, almost certainly slower speed during COD and almost certainly greater deceleration reached during the 90º-COD trial compared with the 45º-COD sprint, 4) the minimum speed during COD was largely correlated with sprint performance for both sprint angles, while peak acceleration and peak speed additionally contributed to 45º-COD and 90º-COD sprint performance, respectively.

The validity analysis revealed trivial-to-small biases for the new timing system compared with timing gates, and small-to-moderate TEEs (Table 1). Importantly, the TEE was greater for the 45º-COD trial, and while the correlations between the new timing system and the timing gates were nearly perfect for straight line and 90º-COD sprints (both r >.90), there was only a very large correlation for 45º (both r >.74). There is, to our knowledge, no comparable data on the use of laser guns to measure COD speed in the literature. However, the TEE for linear speed in the present study (2.5%) was similar to the ~2% reported previously (Turk-Noack & Schmalz, 1994). The greater TEE for the 45º trial may be related to the fact that compared with the straight line or 90º-COD sprints, players could adopt slightly different running patterns when passing the cones. While the players had learnt in the academy to clearly position their right foot to initiate the left turn with a strong impulse on the ground during the 90º-COD sprint, turning at 45º at high speed could be achieved using either the right or the left foot. This may be associated with greater variations in the actual running path and/or body position, which may have increased the possible time differences between the two different timing systems.

With respect to the reliability analysis, there were large differences between the different variables, with small-to-very large CVs and very large ICCs for linear and 90º-COD sprints (Table 2). The CV for linear (2.5%) and COD (2-4%) sprint times as measured with the timing gates were similar to those reported previously (~2% for short linear (Buchheit & Mendez-Villanueva, 2013) and 2-3% for 90º-COD (Brughelli et al., 2008) sprints). These results show that the reliability was unlikely affected by the running surface (grass), as the large majority of previous reliability studies were conducted on synthetic surfaces. Interestingly, the reliability for sprint times using the new timing system was not very different than with the timing gates (CV 2-5% and moderate-to-large ICCs, Table 2), which highlights the usefulness of the new timing system. The reliability of the other kinematic variables was variable-dependent, with trivial (distance at peak speed during the straight line sprint) to very large (distance at peak deceleration) CVs. There is limited data in the literature with respect to COD speed, but the CV reported for linear speed (1.9%, Table 2) tended to be slightly greater than the 1% CV reported by Duthie et al. (2006), but similar to the 2-3% reported by Poulos, Kuitunen, and Buchheit (2010). While in these latter studies athletes sprinted from a standing start, our players initiated their sprint from a jog, which is likely to increase within-players variability in sprint times. The reliability data on peak acceleration (CV: 6-9%) measured with the laser gun was actually better than that reported for linear sprints using GPS technology (16%; Varley, Fairweather, & Aughey, 2012) and may be related to the higher sampling frequency of the laser gun and/or the possible between-GPS units discrepancies (Buchheit, et al., 2014). The CV for the distance at peak speed during the sprints with COD (14-24%) is in the range of that reported during linear sprints (18%; Poulos, et al., 2010). The CV for peak deceleration (38-120%) were similar (38% for 90º-COD) and greater (117% for 45º-COD) than that after linear sprints (32%; Varley, et al., 2012). Again, the likely larger variability in running patterns during the 45º-COD sprint may explain the lower reliability. It is however worth noting that some variables showed large-to-very large CVs (Table 2) and may be considered as poorly reliable (e.g. distance at peak deceleration, distance at peak speed). It is, however, important to examine and provide the reliability of all the variables available with the new system, so that readers can select the most useful ones. Following this reasoning, we have not used the least reliable data in the regression analysis (see below). In overall, present results show the acceptable level of validity and reproducibility of the new timing system to assess some (but not all) kinematic variables during linear and COD speed, which opens the door for the examination of the locomotor determinants of COD speed in the field.

There were substantial differences in almost all COM-related running kinematics between the three types of sprints (Figure 2 and Table 3). Despite the large body of research on COD speed (Brughelli, et al., 2008), the detailed COM-related running kinematics during field sprinting with COD have never been reported (e.g. peak acceleration, deceleration, speed during the COD). The longer sprint times and lower peak speed with COD were nevertheless consistent with previous studies, where the sharper the angle, the longer the sprint times and the slower the peak speeds (Buchheit, et al., 2012; Young, et al., 1996). Compared with the 45º-COD angle, the *very largely* slower running speed during the 90º-COD trial is consistent with the fact that the greater the angle, the greater the need to decrease the body's momentum (Hewit, et al., 2013; Hewit, et al., 2011) which is required to adjust stride characteristics, maintain an optimal whole-body dynamic balance and, in turn, apply greater lateral forces. This was achieved through i) a *moderately* slower acceleration, which was in turn related to ii) a *very largely* shorter distance to peak speed and, finally iii) a *very largely* greater peak deceleration with the 90º-COD sprint. These data show that the COM-related running kinematics during COD speed are angle-dependent, and may explain both i) the *moderate-to-large* but not perfect relationship between COD sprints with different angles (Buchheit, et al., 2012; Young, et al., 1996), and ii) the fact that physiological, neuromuscular and performance responses are also likely angle-dependent (Buchheit, et al., 2012; Young, et al., 1996).

While correlation does not imply causation, the multiple regression analysis results showed the minimum speed during the COD to be the strongest determinant of sprint performance for both sprint angles (Figure 3). Peak acceleration and peak speed additionally contributed to 45º-COD and 90º-COD sprints performance, respectively (Figure 3). Surprisingly, variables such as peak deceleration and distance at peak deceleration showed unclear association with COD speed performance. To our knowledge, such COM-related running kinematic analyses have never been reported during sprints with COD in the field, so that comparison with the literature is difficult. Taken together, present data suggest that acceleration and/or deceleration *per se* may not be the most important factors, but rather the overall speed regulation before, during and after the turn through well balanced levels of acceleration, peak speed, deceleration and re-acceleration (Figure 2). In practice, appropriate adjustments of stride length and frequency and body position may allow optimizing COD ability (e.g. application of greater lateral forces) while minimizing the time lost to COD (Hewit, et al., 2013). Finally, COD speed performance also failed to be substantially associated with anthropometric variables, as well as with players' acceleration capacity and maximal sprinting speed assessed via standardized field tests. This confirms that linear and COD speeds are likely specific physical qualities (Salaj & Markovic, 2011; Sheppard & Young, 2006). Another explanation for the lack of association with players' acceleration capacity may be related to the fact that in the present study, all sprints were initiated from a jog, which somewhat decreases the importance of acceleration for the overall sprint performance.

The new timing system shows, in overall, acceptable levels of validity and reliability to assess some of the COM-related running kinematic profiles during COD speed in the field. The ability to maintain a high speed during the COD (i.e. not to extremely brake) may be a large determinant of COD speed. This suggests that any training strategies that may increase players' ability to maintain a high speed during the turn, while still maintaining an appropriate body balance should be prioritized. This may include technical and whole-body coordination work (Hewit, et al., 2013) and/or training programs targeting strength-related variables (Keiner, Sander, Wirth, & Schmidtbleicher, 2014) which may all translate into a better ability to control the body during the braking phase, apply lateral forces and (re)accelerate after the turn. Further studies should investigate the kinematic responses to (and determinants of) more soccer-specific COD sprints, i.e. including decision-making. A better understanding of the effects of different types of strength/technical training programs on the different kinematic variables during COD speed is also warranted.

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