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Relationship between the Horizontal Force-Velocity Profile and Performance Variables obtained in Sprinting, Slalom Test, and Kicking in Amateur Soccer Players

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Abstract

This study evaluated the mechanical determinants of 30 m sprint performance in 110 amateur soccer players and identified variables of sprint, slalom, and kick tests. Associations were identified using Pearson's correlation coefficient. A p-value of 0.0007 was considered statistically significant for all analyses after performing Bonferroni correction adjustment. Relative peak running power (P_{max}) was significantly correlated ($p<0.0007$, $r=-0.875$ to -0.984) with sprint split times across all distances (5–30 m). Relative theoretical maximum horizontal force (F_0) significantly correlated with acceleration performance (0-15 m, $p<0.0007$, $r=-0.756$ to -0.951). Average ratio of forces for the first 10-m (RF_10m) was significantly correlated ($p<0.0007$, $r=-0.909$ to -0.965) with sprint split times across 20–30 m and gap time at 10-20 m and 20-30 m. Maximal value of ratio of force (RF_{max}) was significantly correlated ($p<0.0007$, $r=-0.718$ to -0.959) with sprint split times across 5–25 m. Theoretical maximum velocity (V_0) was significantly correlated , ($p<0.0007$, $r=-0.540$ to -0.684) with sprint times across 20–30 m, and gap time 10-20 m and 20-30 m ($p<0.0007$, $r=-0.880$ to -0.915). These results indicate emphasis should be placed on training protocols that improve relative peak running power (P_{max}), particularly in time-constrained environments such as team sports, focusing on maximal force production or maximal running velocity ability. Furthermore, attention should be paid to the technical component of the received force in the horizontal direction to the monitor training adjustments and further individualize training interventions.

Keywords: *horizontal F-v parameters, changes of direction, maximal kick ball velocity*

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Introduction

The ability to perform soccer-related tasks at high velocities is believed to be a key factor for reaching success in soccer (Faude et al., 2012). Sprinting is the most frequent action in goal situations in the first German national league, both for the scoring and assisting player (Faude et al., 2012). A high acceleration and a fast maximal sprint speed might allow players to overtake opponents and win balls (Mendez-Villanueva et

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al., 2012). A soccer player changes direction every 2-4 seconds (Verheijen, 1997) and makes 1,200-1,400 changes of direction during a game (Bangsbo, 1992). Kicking is one of the most frequently used skills in soccer, and the most fundamental for soccer performance (Bacvarevic et al., 2012). Ball speed could be particularly important while kicking towards the goal because the chances of scoring increase with an increased ball speed (assuming that the kick is accurate) because the goalkeeper has less time to react (Dörge et al., 2002; Markovic et al., 2006).

Recently was introduced a field-based method of assessing an athlete's sprint ability and the mechanical determinants associated with sprint performance (horizontal power, force, and velocity variables) (Samozino et al., 2016). Mechanical properties of an individual's force-velocity sprinting profile (F-v) were derived from equations that used split times, anthropometric, and spatiotemporal data of the athlete (Samozino et al., 2016). This approach was found to be highly valid ($p<0.001$, $r=0.826$ - 0.978) when compared with direct measurement methods of ground reaction forces (GRF) from in-ground force plates (Cross et al., 2017; Samozino et al., 2016). This and other laboratory-based methods of analysing sprinting have shown an athlete's ability to produce high levels of horizontal power during a sprint performance to have a very large to near perfect association ($p=<0.01$, $r=0.850$ - 0.932) with their sprint performance (Cross et al., 2015; Morin et al., 2012). However, athletes with differing F-v profiles could potentially produce similar peak horizontal running power (P_{max}) values, which could limit insight to an athletes true F-v profile and where their strength and weaknesses lie (Cross et al., 2017; Morin & Samozino, 2016). The insight into an athletes F-v sprint profile has the potential to influence individualized training interventions and the monitoring of training adaptations (Morin & Samozino, 2016; Samozino et al., 2016). Previous research examining the sprint mechanics of athletes have also shown the determinants of better acceleration (0–20-m) compared with longer distance sprint performance could potentially differ (Buchheit et al., 2014; Cross et al., 2015; Morin et al., 2012). For example, better longer distance sprint performance (≥40 m) and maximal running speeds, has been shown to have a very large association with a more velocity dominant F-v profile (greater maximum velocity and theoretical maximum velocity extrapolated to when force is 0) (Buchheit et al., 2014; Morin et al., 2012). Whereas a more force dominant F-v profile (greater maximum horizontal force and greater theoretical maximum horizontal force extrapolated to when velocity is 0) was found to have a very large association with better acceleration performance in sprints of less than 20 m in elite rugby (Cross et al., 2015) and highly trained youth soccer athletes (Buchheit et al., 2014).

Considering the strong link between game performance and sprint ability in soccer and other team sports, a simple conclusion would be to focus training to high-speed sprinting. Research in sprinters and team sport athletes has identified associations between sprint performance and various F-v characteristics (Morin et al., 2012). Researchers have been found that acceleration, speed, and agility be independent, different qualities that generate a restricted transfer to each other (Jovanovic et al., 2011). But recent study (Falces-Prieto et al., 2022) found moderate to large relationships between short sprint (10-m) performance and change of direction (COD) performance at different angles (180° or 90°). Zhang et al. (2022) find that sprinting F-v profiles parameters were weakly to moderately correlated with 505-test performance ($p<0.05$-0.001, $r=-0.47$ to -0.38) in female and male soccer players. Very large correlation between horizontal mechanical parameters (F_0 and P_{max}) and 505-test performance ($p<0.001$, $r=-0,79$ to $-0,83$) in tennis, soccer and basketball player (Baena-Raya et al., 2021). No research was found on associations between maximal kick ball velocity and F-v characteristics, but De Witt & Hinrichs (2012) find significantly correlated segmental foot velocity with ball velocity during an instep soccer kick. Therefore, the purpose of this study was to evaluate the mechanical determinants across 30 m sprint performance in amateur soccer players, using modelled inverse dynamics techniques (Samozino et al., 2016). A secondary purpose was to identify the existence of relationships between horizontal F-v variables of 30 m sprint and performance variables 30 m sprint, slalom, and soccer kick.

Methods

Experimental Approach to the Problem

A cross-sectional study design was used to determine the mechanical determinants of sprint running and the relationship with performance variables in sprinting, slalom tests, and kicking in amateur soccer player. All athletes were tested during the competitive season, minimum 72 hours after a match day or intensive training.

Subjects

One hundred ten amateur soccer players (age=22.6±3.7 years; height=1.81±0.07 m; mass=78.4±7.6 kg) were recruited for this study. The athletes were recruited from 7 clubs Croatian Third Football League. The research was aligned with the Helsinki declaration, and the Scientific and Ethical Committee of the Faculty of Kinesiology, University of Zagreb, approved the experimental protocol. All athletes provided written informed consent for the study after explanation of the purpose, benefits, and potential risks involved.

Procedures

All athletes performed a 15 min warm-up consisting of 6 run intervals of 100 m at a speed≤10 km/h, mobility exercises, athletic running exercises, proprioception exercises and dynamic stretching exercises were performed at a distance of 12 m. Exercises were performed in one direction, and running on the way back at a speed≤10 km/h. The last exercise in warm-up was a maximum sprint 30 m (3 repetitions with 1 min rest). With a 6 minute rest after the warm-up, the subjects were randomly divided into 3 test stations (sprint, slalom tests, and kick test). All tests are performed on outdoor soccer field with natural grass.

Sprint test was performed 2 maximal efforts 30 m sprint, with 3 min rest, where split times (at 5, 10, 15, 20, 25 and 30 m) were assessed by recording each sprint using an iPhone 8 and MySprint app (Romero-Franco et al., 2017). Slalom test was performed 2 maximal efforts on a 11 m long track, with 3 min rest (Sporis et al., 2010). Time is measured by photocells of the system (Witty Gate, Microgate; USA). Soccer kick was performed 3 maximal efforts, with 1 min rest (Markovic et al., 2006). Athletes kicks a stationary ball (Adidas, UCL PRO, size 5) of standard size and standard inflation approved by the International Federation of Football Associations (FIFA). Athletes himself determines the length of the run, the angle of

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the shot and the part of the foot with which hits the ball. Ball speed was measured with a radar (Stalker Pro, Applied Concepts Inc., Richardson, Texas, USA).

Statistical Analyses

Data are presented as mean ± standard deviations (SD). Normal distribution for all variables was confirmed by the Shapiro–Wilk test ($p>0.05$). Pearson's correlation coefficient was used to assess the strength of the relationship between mechanical sprint variables and sprint split times at 5, 10, 15, 20, 25, 30 m and gap times 10-20 and 20-30m, time at slalom test and ball speed at soccer kick. Evaluation of correlation coefficients were classified as: small=0.1-0.29, moderate=0.30-0.49, large=0.50-0.69, very large=0.70-0.89, nearly perfect=0.90-0.99, perfect=1.0 (Hopkins et al., 2009). Bonferroni correction was set up at $p<0.0007$.

Results

Descriptive statistics for all performance measures and calculated variables of the 30 m sprint are presented in Table 1. Relative horizontal peak running power (P_{max}) had a negative relationship with all split times across the 30 m, particularly at 10, 15 and 20 m (Table 2). Relative theoretical maximum horizontal force production at 0 velocity (F_0), showed very large to near perfect inverse relationships across split times at 5, 10 and 15 m (range, r=-0.756 to -0.951). Average ratio of forces for the first 10-m (RF_10m) showed near perfect inverse relationships with split times at 20, 25 and 30 m (range, r=-0.909

Table 1. Descriptive Statistics of 30-m Sprint, Slalom Test and Soccer Kick

Test	Measurement	Mean ± SD
30-m Sprint Performance Measures	5 m time (s)	1,32 ± 0,07
	10 m time (s)	2,06 ± 0,08
	15 m time (s)	2,70 ± 0,09
	20 m time (s)	3,33 ± 0,11
	25 m time (s)	3,92 ± 0,13
	30 m time (s)	4,50 ± 0,16
	10-20 m gap time (s)	1,27 ± 0,05
	20-30 m gap time (s)	1,17 ± 0,05
30-m Sprint Calculated Variables	P_{max} (W/Kg)	18,12 ± 1,88
	F_0 (N/Kg)	8,08 ± 0,81
	RF_10m (%)	32,57 ± 1,24
	RF_{max} (%)	52,99 ± 2,81
	D_{RF} (%)	-8,27 ± 1,08
	V_0 (m/s)	8,98 ± 0,54
	V_{max} (m/s)	8,67 ± 0,48
Slalom Test	ST time (s)	7,28 ± 0,28
Soccer Kick	SK ball speed (km/h)	110,99 ± 5,53

Note. P_{max}: relative peak power; F_0: relative theoretical maximum force at 0 velocity; RF_10m: average ratio of forces for the first 10 m; RF_{max}: maximal value of RF; D_{RF}: rate of decrease in RF with increasing speed during sprint acceleration; V_0: theoretical maximum velocity at 0 force; V_{max}: maximum velocity.

to -0.965).

Table 2. Pearson's Correlation Coefficients between the Mechanical Determinants During a 30-m Sprint with Sprint and Slalom Times and Ball Speed at Soccer Kick

	P_{max} (W/Kg)	F_0 (N/Kg)	RF_10m (%)	RF_{max} (%)	D_{RF} (%)	V_0 (km/h)	V_{max} (km/h)
5 m (s)	-0,878*	-0,951*	-0,405*	-0,953*	0,742*	0,130	0,095
10 m (s)	-0,984*	-0,880*	-0,680*	-0,959*	0,530*	-0,172	-0,210
15 m (s)	-0,981*	-0,756*	-0,825*	-0,882*	0,327*	-0,384*	-0,421*
20 m (s)	-0,945*	-0,632*	-0,909*	-0,788*	0,157	-0,540*	-0,573*
25 m (s)	-0,908*	-0,547*	-0,947*	-0,718*	0,051	-0,626*	-0,657*
30 m (s)	-0,875*	-0,482*	-0,965*	-0,663*	-0,024	-0,684*	-0,714*
10-20 m (s)	-0,569*	-0,052	-0,941*	-0,271	-0,447*	-0,902*	-0,915*
20-30 m (s)	-0,600*	-0,100	-0,936*	-0,306	-0,395*	-0,880*	-0,898*
ST (s)	-0,248	-0,129	-0,291	-0,186	-0,023	-0,196	-0,196
SK (km/h)	0,069	-0,170	0,305	-0,099	0,347*	0,418*	0,426*

Note. P_{max}: relative peak power; F_0: relative theoretical maximum force at 0 velocity; RF_10m: average ratio of forces for the first 10 m; RF_{max}: maximal value of RF; D_{RF}: rate of decrease in RF with increasing speed during sprint acceleration, V_0: theoretical maximum velocity at 0 force; V_{max}: maximum velocity; *$p<0.0007$.

to -0.965) and with gap time at 10-20 and 20-30 m (range, r=-0.936 to -0.941). Maximal value of ratio of force (RF_{max}) showed near perfect inverse relationships with split times at 5 and 10 m (range, r=-0.953 and -0.959) and very large inverse relationships with split times at 15, 20 and 25 m (range, r=-0.718 and -0.882). Rate of decrease in ratio of force with increasing speed during sprint acceleration (D_{RF}) showed large to very large relationships with split times at 5 and 10 m (r=0.530 and 0.742), and moderate with gap time at 10-20 and 20-30 m (r=-0.395 to -0.447). Theoretical maximal velocity at 0 force (V_0) and maximal velocity (V_{max}) showed large to very large inverse relationships with split times at 20, 25 and 30 m (range, r=-0.540 to -0.714) and very large to near perfect inverse relationships with gap time at 10-20 and 20-30 m (r=-0.880 to -0.915). The correlation between the time in the slalom test and the mechanical parameters of the 30 m sprint is small and statistically insignificant. At soccer kick ball speed had a positive moderate relationship with D_{RF} (r=0.347), V_0 (r=0.418), and V_{max} (r=0.426).

Discussion

This cross-sectional study evaluated the mechanical determinants of a 30 m sprint in amateur soccer players using modelled inverse dynamic methods (Samozino et al., 2016) and second, examined possible relationships between the 30 m sprint F-v variables with performance in sprint, slalom, and soccer kick. Results show that F-v variables would be a strong indicator of sprint split time performance over 30 m and some F-v variables (V_0, V_{max} and D_{RF}) would be an indicator of performance in soccer kick test. However, the association of F-v variables with performance in slalom test was not found.

The results of this study did not show great variation between athletes' sprint times, particularly over the first parts of the sprint (<15 m), with SD ± 0.07–0.09 seconds separating athletes at 5, 10, and 15 m times, suggesting a relatively homogenous population. However, greater relative horizontal forces (F_0) and maximal ratio of forces applied onto the ground (RF_{max}) what objectively represent runners' force application technique (Morin et al., 2011) were associated with athlete's acceleration performance (0-15 m) in our study. Highlighting the importance of armature soccer players to be able to produce, and effectively apply, greater relative F_0 and RF_{max} as a critical quality to better acceleration and on-field success.

In this study, the sprint ability of amateur soccer player over 20 m (3.33±0.11 s) was similar to the sprint performance of first division soccer players (3.38±0.12 s); and first division futsal players (3.36±0.09 s) (Jiménez-Reyes et al., 2019). Likewise, power and force production at the beginning of the sprint in this study was slightly better that in first division soccer and futsal player (Jiménez-Reyes et al., 2019). But application of force at high speeds (V_0 and D_{RF}) was better in in first division player (9.25±0.61 and -7.08±0.82), than in this study (8.98±0.54 and -8.27±1.08). According to the (Haugen et al., 2020) our mechanical parameters and sprint performance values are similar to player in 3rd-5th division. Disagreement in results may influence poor warm-up protocol in study (Jiménez-Reyes et al., 2019), only jogging and lower limb dynamic stretching was included. One must also keep in mind that sprint performance and mechanical properties may vary between conditions due to differences in footwear and surface (Haugen & Buchheit, 2016) as was the case between the two studies mentioned. Furthermore, (Morin et al., 2012) found that the ability to orient the resultant GRF vector effectively (i.e. forward) during the entire acceleration phase (D_{RF}) strongly differed between the fastest and slowest individuals.

The present results confirm earlier findings in which was determined highest correlation between P_{max} and RF_10m whit sprint performance (Haugen et al., 2020). Furthermore, our results confirm earlier findings that shorter the distance considered, the higher relationship between F_0 and RF_{max} and sprint performance, whereas and V_0 become more determinant as both the distance and velocity increases (Haugen et al., 2020). Overall, D_{RF} in our study significant correlation 0.742, 0.530, 0.327 with 5, 10, 15 m time, respectively. Since D_{RF} is combination of maximum velocity and relative acceleration, and therefore has an interdependence on the individual slope of the force-velocity relationship. Typically, as one value moves up (i.e., relative force), the other value will likely move down (i.e., velocity) changing the force-velocity value (Hicks et al., 2023). Because of this D_{RF} is a parameter that should be put in the context with performance at longer sprint distances and gap times. We found a correlation -0,447 and -0,395 with gap time 10-20 and 20-30 m, respectively. Oure results confirm earlier findings that D_{RF} was moderate correlation (-0.41) with 40 m time (Haugen et al., 2020), large (0.683) with 4 s distance (m), very large (0.729 and 0.875) with maximal speed and 100 m speed (ms-1) (Morin et al., 2012). Association the weakest correlations with sprint performance, which may have occurred due to the lower level of athletes in this study. Studies with national-level athletes found stronger correlations (Haugen et al., 2020; Morin et al., 2011, 2012).

Mechanical variables might add valuable information about performance of short sprint acceleration. For instance, two players may have the same 5 or 20 m split time but different F_0 or, what is more, the same F_0 but different mechanical effectiveness values which is determinant in the acceleration phase (Morin & Samozino, 2016). In this example, prescribing a similar training program for these two players with the aim to optimize athlete's acceleration ability might result in suboptimal adaptations for maximal linear velocity, since the specific F-v profile mechanical variables underlying short sprint acceleration would not be addressed. Therefore, assessing the sprint F-v profile might help coaches to describe athlete's acceleration ability and prescribe specific training program to improve the acceleration and linear velocity.

Our study found no correlation between horizontal mechanical parameters and performance in slalom test, which is in contradict with study (Baena-Raya et al., 2021), who find very large corelation between horizontal mechanical parameter (P_{max}, F_0) and performance in 505 COD test in tennis, soccer and basketball player. Conflicting findings can be explained by different COD angles, result in a different level of involvement of basic motor components, namely force or speed, when changing the direction of movement. Sigward et al. (2015) confirms that GRF magnitudes are significantly greater with sharper cuts, also direction requirements of the force are different (i.e. greater posterior and laterally directed force for sharper CODs). Therefore, it seems important to distinguish those tests in which there were numerous changes of direction based on speed (angle≅0° to ≅90°) or force (angle≅135° to ≅180°; (Nygaard Falch et al., 2019). Therefore, it was suggested that COD and linear sprint should be trained independently due to the low to moderate relationships between these abilities (Salaj & Markovic, 2011).

In fact, to the best of our knowledge, this is the first study

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that investigated relationship between horizontal mechanical parameters and maximal soccer kick. A moderate association between V_0, V_{max}, D_{RF} and ball speed suggests that velocity is a stronger determinant of maximal soccer kick than power. Respectively, application force at higher speeds is more determinant ball speed than application force at lower speeds. Which coincides with finding that ball speed of the soccer kick depends on the speed of the foot before impact (Dörge et al., 2002) and lower peak braking forces under the support leg were associated with higher ball velocities (Orloff et al., 2008).

Performance data alone provide a basis for convenient analysis on the field, but sprint mechanical outputs provide deeper insights into individual biomechanical limitations. Future studies should explore the effects of individualized sprint training based on mechanical properties. The current data provides a point of departure for this purpose.

There are several limitations that must be considered when interpreting the results of this study. The current investigation used modelled running mechanics obtained from sprint times and a validated inverse dynamics approach (Samozino et al., 2016) as opposed to directly measuring GRF. This method does not allow for evaluation of inter-limb or inter-step variability; however, the simplicity of the experimental approach along with the method's sensitivity to highlight small mechanical differences between sprinting profiles in a relatively homogenous sample group, highlights its use in many field-based settings. Furthermore, this cross-sectional design precludes establishing causal relationships and these results must be contrasted in future prospective research. Assessing whether optimizing the F-v profiles through specific training programs translates into an improved speed and kick performance (due to the improvement in acceleration capabilities) is warranted. Finally, because the sample population in this study were amateur soccer player, our results may not be generalizable to other athletes.

In summary, ability to accelerate their own mass by producing greater relative forces, over shorter periods of time and at greater velocities were important to the athletes' sprint and soccer maximal kick performance. Further research should examine the impact of individualized, orientation-specific training protocols on the orientation of an athletes' F-v sprinting profile and overall mechanical sprint ability.

References

Bacvarevic, B. B., Pazin, N., Bozic, P. R., Mirkov, D., Kukolj, M., & Jaric, S. (2012). Evaluation of a composite test of kicking performance. *Journal of Strength and Conditioning Research*, *26*(7), 1945–1952. https://doi.org/10.1519/JSC.0b013e318237e79d

Baena-Raya, A., Soriano-Maldonado, A., Conceição, F., Jiménez-Reyes, P., & Rodríguez-Pérez, M. A. (2021). Association of the vertical and horizontal force-velocity profile and acceleration with change of direction ability in various sports. *European Journal of Sport Science*, *21*(12), 1659–1667. https://doi.org/10.1080/17461391.2020.1856934

Bangsbo, J. (1992). Time and motion characteristics of competition soccer. *Science and Football*, *6*, 34–40.

Buchheit, M., Samozino, P., Glynn, J. A., Michael, B. S., Al Haddad, H., Mendez-Villanueva, A., & Morin, J. B. (2014). Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. *Journal of Sports Sciences*, *32*(20), 1906–1913. https://doi.org/10.1080/02640414.2014.965191

Cross, M. R., Brughelli, M., Brown, S. R., Samozino, P., Gill, N. D., Cronin, J. B., & Morin, J. B. (2015). Mechanical properties of sprinting in elite rugby union and rugby league. *International Journal of Sports Physiology and Performance*, *10*(6), 695–702. https://doi.org/10.1123/ijspp.2014-0151

Cross, M. R., Brughelli, M., Samozino, P., & Morin, J. B. (2017). Methods of power-force-velocity profiling during sprint running: A narrative review. In *Sports Medicine* (Vol. 47, Issue 7, pp. 1255–1269). Springer International Publishing.

De Witt, J. K., & Hinrichs, R. N. (2012). Mechanical factors associated with the development of high ball velocity during an instep soccer kick. *Sports Biomechanics*, *11*(3), 382–390. https://doi.org/10.1080/14763141.2012.661757

Dörge, H. C., Andersen, T. B., SØrensen, H., & Simonsen, E. B. (2002). Biomechanical differences in soccer kicking with the preferred and the non-preferred leg. *Journal of Sports Sciences*, *20*(4), 293–299. https://doi.org/10.1080/026404102753576062

Falces-Prieto, M., González-Fernández, F. T., García-Delgado, G., Silva, R., Nobari, H., & Clemente, F. M. (2022). Relationship between sprint, jump, dynamic balance with the change of direction on young soccer players' performance. *Scientific Reports*, *12*(1), 12272. https://doi.org/10.1038/s41598-022-16558-9

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631. https://doi.org/10.1080/02640414.2012.665940

Haugen, T. A., Breitschädel, F., & Seiler, S. (2020). Sprint mechanical properties in soccer players according to playing standard, position, age and sex. *Journal of Sports Sciences*, *38*(9), 1070–1076. https://doi.org/10.1080/02640414.2020.1741955

Haugen, T., & Buchheit, M. (2016). Sprint running performance monitoring: Methodological and practical considerations. *Sports Medicine*, *46*(5), 641–656. https://doi.org/10.1007/s40279-015-0446-0

Hicks, D. S., Drummond, C., Williams, K. J., & van den Tillaar, R. (2023). The effect of a combined sprint training intervention on sprint force-velocity characteristics in junior Australian football players. *PeerJ*, *11*, e14873.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. In *Medicine and Science in Sports and Exercise* (Vol. 41, Issue 1, pp. 3–12). https://doi.org/10.1249/MSS.0b013e31818cb278

Jiménez-Reyes, P., García-Ramos, A., Cuadrado-Peñafiel, V., Párraga-Montilla, J. A., Morcillo-Losa, J. A., Samozino, P., & Morin, J. B. (2019). Differences in sprint mechanical force–velocity profile between trained soccer and futsal players. *International Journal of Sports Physiology and Performance*, *14*(4), 478–485.

Jovanovic, M., Sporis, G., Omrcen, D., & Fiorentini, F. (2011). Effects of speed, agility, quickness training method on power performance in elite soccer players. *Journal of Strength and Conditioning Research*, *25*(5), 1285–1292. https://doi.org/10.1519/JSC.0b013e3181d67c65

Markovic, G., Dizdar, D., & Jaric, S. (2006). Evaluation of tests of maximum kicking performance. *The Journal of Sports Medicine and Physical Fitness*, *46*(2), 215–220.

Mendez-Villanueva, A., Buchheit, M., Simpson, B., & Bourdon, P. (2012). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine*, *34*(02), 101–110. https://doi.org/10.1055/s-0032-1306323

Morin, J. B., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P., & Lacour, J. R. (2012). Mechanical determinants of 100-m sprint running performance. *European Journal of Applied Physiology*, *112*(11), 3921–3930. https://doi.org/10.1007/s00421-012-2379-8

Morin, J. B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and Science in Sports and Exercise*, *43*(9), 1680–1688.

Morin, J. B., & Samozino, P. (2016). Interpreting power-force-velocity profiles for individualized and specific training. In *International Journal of Sports Physiology and Performance* (Vol. 11, Issue 2, pp. 267–272). Human Kinetics Publishers Inc. https://doi.org/10.1123/ijspp.2015-0638

Nygaard Falch, H., Guldteig Rædergård, H., & van den Tillaar, R. (2019). Effect of different physical training forms on change of direction ability: a systematic review and meta-analysis. *Sports Medicine - Open*, *5*(1), 53. https://doi.org/10.1186/s40798-019-0223-y

Orloff, H., Sumida, B., Chow, J., Habibi, L., Fujino, A., & Kramer, B. (2008). Ground reaction forces and kinematics of plant leg position during instep kicking in male and female collegiate soccer players. *Sports Biomechanics*, *7*(2), 238–247. https://doi.org/10.1080/14763140701841704

Romero-Franco, N., Jiménez-Reyes, P., Castaño-Zambudio, A., Capelo-Ramírez, F., Rodríguez-Juan, J. J., González-Hernández, J., Toscano-Bendala, F. J., Cuadrado-Peñafiel, V., & Balsalobre-Fernández, C. (2017). Sprint performance and mechanical outputs computed with an iPhone app: Comparison with existing reference methods. *European Journal of Sport Science*, *17*(4), 386–392. https://doi.org/10.1080/17461391.2016.1249031

Salaj, S., & Markovic, G. (2011). Specificity of jumping, sprinting, and quick change-of-direction motor abilities. *Journal of Strength and Conditioning Research*, *25*(5), 1249–1255. https://doi.org/10.1519/JSC.0b013e3181da77df

Samozino, P., Rabita, G., Dorel, S., Slawinski, J., Peyrot, N., Saez de Villarreal, E., & Morin, J. B. (2016). A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scandinavian Journal of Medicine and Science in Sports*, *26*(6), 648–658. https://doi.org/10.1111/sms.12490

Sigward, S. M., Cesar, G. M., & Havens, K. L. (2015). Predictors of frontal plane knee moments during side-step cutting to 45° and 110° men and women: Implications for ACL injury. *Clinical Journal of Sport Medicine*, *25*(6), 529–534. https://doi.org/10.1097/JSM.0000000000000155

Sporis, G., Jukic, I., Milanovic, L., & Vucetic, V. (2010). Reliability and factorial validity of agility tests for soccer players. *Journal of Strength and Conditioning Research*, *24*(3), 679–686. https://doi.org/10.1519/JSC.0b013e3181c4d324

Verheijen, R. (1997). *Handbuch für Fussballkondition*. BPF Versand.

Zhang, Q., Dellal, A., Chamari, K., Igonin, P.-H., Martin, C., & Hautier, C. (2022). The influence of short sprint performance, acceleration, and deceleration mechanical properties on change of direction ability in soccer players—A cross-sectional study. *Frontiers in Physiology*, *13*, 1027811. https://doi.org/10.3389/fphys.2022.1027811

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