SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

The Journal of Sport and Exercise Science, Vol. 7, Issue 2, 29-37 (2023)

www.jses.net

JSES

ISSN: 2703-240X

Kinematic determinants of acceleration sprint performance in male academy Rugby Union players: Developing a technique model

Jessica A. Calderbank[1,2*], Paul A. Jones[1], Thomas Dos'Santos[3], Andrew Jibson[2], Robert A. Simpson[2]

[1]*Department of Sport, Exercise and Physiotherapy, University of Salford, England*
[2]*Sale Shark Rugby Club, England*
[3]*Department of Sport and Exercise Science, Manchester Metropolitan University, England*

ARTICLE INFO

Received: 28.06.2021
Accepted: 30.03.2023
Online: 25.10.2023

Keywords:
Step length
Step frequency
Step velocity
Ground contact time
Step duration
Take-off

ABSTRACT

The aim of this study was to identify which kinematic variables are associated with Rugby Union (RU) acceleration sprint performance (step velocity during the first three steps of a 40 m sprint) to create a technical model for RU acceleration sprinting. Nineteen semi-professional male academy RU players were split into fast (top quickest 40 m sprinters; n = 9, 5 backs and 4 forwards; age = 18.0 ± 0.5 years, height = 1.86 ± 0.07 m, mass = 88.9 ± 8.55 kg) and slow groups (bottom slowest 40m sprinters; n = 10, 2 forwards and 8 backs; age = 18.0 ± 0.5 years, height = 1.81 ± 0.07 m, mass = 91.6 ± 11.5 kg). Subjects completed 3 trials of a maximum effort 40 m sprint test. Step length, step duration, ground contact time, flight time, step frequency, step velocity, trunk angle at take-off, hip flexion angle at take-off, leg extension angle at take-off, shoulder extension angle at take-off, and touchdown distance were collected during the sprint via video analysis. After normality was inspected, intraclass correlation coefficients (ICC) and coefficients of variation (CV) were calculated to quantify movement variability and reliability. A series of Pearson's and Spearman's correlation analyses were conducted to identify which variables best correlated with step velocity. To explore differences between fast and slow groups, independent t-tests were performed with Hedges' g effect sizes calculated. ICCs and CVs for the combined groups displayed varied reliability and variability for all step characteristics (ICC = 0.511 to 0.920, moderate to excellent; CV = 4.50% to 20.8%). Correlations ranged from trivial to high where step length (r = 0.505, p = 0.028), trunk angle at take-off (r = -0.489, p = 0.034) step duration (r = -0.388, p = 0.100), step frequency (r = -0.344, p = 0.150), were the top four highest correlating variables to step velocity. Results of the current study suggest that these variables may predict successful RU sprint performance.

1. Introduction

Rugby Union (RU) is a fast paced, high contact team sport (Baker, 1981) with two established groups of positions: forwards (*n* = 8; loose head prop, hooker, tighthead prop, 2 locks, blind side flanker, open side flanker, number 8) and backs (*n* = 7; scrum half, fly half, left wing, right wing, inside centre, outside centre, full back). Typically, forwards are bigger and heavier anthropometrically compared to backs, thus take a greater responsibility in the force and collision-based actions during the game. Contrastingly, backs hold a more athletic stature and are more responsible for the high-speed actions (Deutsch et al., 2007). However, whilst this is true, all RU positions still complete contact-based actions including rucks, mauls, and tackles, though due to differences mentioned, forwards exhibit a greater number of contacts compared to backs.

*Corresponding Author: Jessica A. Calderbank, Department of Sport, Exercise and Physiotherapy, University of Salford, UK, jessicacalderbank@gmail.com

Roberts et al. (2008) found forwards completed 35 ± 8 rucks compared to 11 ± 6 rucks in backs. In mauls, authors found forwards completed 25 ± 8 mauls vs 4 ± 4 in backs and for tackles, authors found forwards completed 14 ± 4 vs 10 ± 4 in backs. During match-play, RU players cover distances of approximately 8.5 km – 9.9 km (Cross et al., 2015; Lockie et al., 2013b) and also complete many dynamic actions across this distance of play, such as: set pieces, rucking, mauling, and change of direction but one of the most frequently performed actions in the game is sprinting (Deutsch et al., 2007). Players will usually sprint in bursts between 0 m – 40 m (Sayers, 2000) and have adopted a running technique, allowing them to reach speeds in excess of 90% of their maximum within this distance (Duthie et al., 2006), which is much earlier than track and field athletes, who typically reach speeds in excess of 90% of their maximum around 70 m – 80 m (Mackala & Mero, 2013).

Trunk angle at take-off, leg extension angle at take-off, step velocity (SV), step frequency (SF), ground contact time (GCT), flight time (FT), and step length (SL) are just some of the key components for acceleration in line with the deterministic model (Bezodis et al., 2019; Fletcher, 2009). These variables have been considered to be key due to the formula: Running speed = SF x SL (Bezodis, 2012). The deterministic model states that, a development in some of the key variables listed above can further improve components of this equation (Fletcher, 2009; Lockie et al., 2013b).

Biomechanically, acceleration is characterised by a 15° – 45° trunk lean with full triple extension of the rear leg (Bezodis et al., 2019; Kale & Acikada, 2016). This is desired in order to promote increased horizontal propulsive force and minimise braking, as increased trunk angles have been previously linked with larger propulsion forces (Kugler & Janshen, 2010). However, this may not be applicable for RU, due to differences in ecological constraints between track and field compared to RU. Within track and field, the use of a rubber track, starting blocks, and spiked running shoes, differs highly to that in RU. RU players complete sprints on grass/synthetic field-turfs and also have very different somatotypes (Wild et al., 2018).

In comparison to track and field, RU players have also been found to adopt a closed/hunched over running style with significant forward lean (Gambetta, 1996, 1997; Sheppard & Young, 2006). However, due to the constant visual scanning that occurs during RU, RU players' frequently change from a forward leant posture to a more upright running posture during gameplay in order to make correct decisions and respond appropriately to opponents. Therefore, whilst this adaptation may not be deemed the ideal way to accelerate according to track and field, RU players adapted running style has assisted them to suit the demands of the game and should not be discouraged (Gambetta, 1996, 1997). Nevertheless, it is still common for RU players to be coached in line with recommendations for track and field. Coaching RU players in this way is not tailored for the intercepting dynamic actions involved in RU, different running surfaces, different running postures, and also does not cater for the two different positional groups (Bradshaw et al., 2007; Ryan & Harrison, 2003).

As sprint acceleration is complex, and involves the rate of change in velocity, it places high physical demand on the performer and requires high levels of coordination to perform at superior standards (Young, 2007). The action is made up of an optimal combination of SF and SL. SF is defined as the rate at which footsteps can be repeated and SL is defined as the distance between alternating foot contacts (Hunter et al., 2004). Other factors involved in acceleration include GCT, which is the duration of the contact between the support leg and the ground, and FT, which is the period when the subject is airborne during the sprint step (Lockie et al., 2013a). Research has found that in order to improve SV and thus running speed, there must be an increase in one or both of SL or SF (Vittori, 1996) due to Running speed = SL × SF (Ryan & Harrison, 2003). However, research has paid particular attention to the importance of a higher SF for faster acceleration in team sports (Murphy et al., 2003; Sayers, 2000). Murphy et al. (2003) found that the players who could accelerate faster had a significantly higher horizontal hip velocity compared to the slower group which was due to the faster group having a 9% higher SF. The differences in SF were directly caused by the differences in GCT between the two groups (where faster players displayed shorter GCTs). Sayers (2000) also found similar, which could suggest shorter steps and thus shorter FTs could be beneficial for team sport sprint acceleration. Interestingly, some research has observed opposing findings, and shown SL to be the major contributor to acceleration (Bezodis et al., 2011; Lockie et al., 2013b; Nagahara et al., 2018) emphasising the complexity of the sprinting action. Lockie et al. (2013b) carried out a stepwise regression analysis and found large correlations between SV and SL between 0 m – 10 m ($r = 0.535$, $p = 0.016$). When GCT was added to the stepwise regression analysis for 0 – 10 m, the relationship was further strengthened ($r = 0.685$, $p = 0.006$). Similarly, Brughelli et al. (2011) found similar results, showing strong correlations between SV and stride length ($r = 0.66$, $p < 0.05$) in team sport players. Authors displayed a coefficient of variation (CV) of 9.6% for variables across the steps tested, showing findings to be reliable. However, Lockie et al. (2013b) failed to present CVs and also carried out testing procedures on an indoor basketball court whereas Brughelli et al. (2011) tested on a non-motorised treadmill. Therefore, whilst these findings are insightful, they are not ecologically valid as they eliminate the application for RU players who accelerate on grass and synthetic field-turfs. Despite this, Nagahara et al. (2018) supported that longer SLs correlate to higher sprinting speeds and found strong correlations between SL and sprinting speed across initial acceleration. But, whilst Nagahara et al's. (2018) correlations were low for SF, SF began to correlate stronger as the sprint progressed, suggesting that the variable SL may be more important for sprint acceleration, but SF may be an important factor for top end speed. However, whilst such findings are evident, it is clear much of the research has been conducted on mixed team sport samples and not solely RU. This is likely to cause a lack of transference to RU, implying further research is needed.

Unique to any other research, Wild et al. (2018) investigated step mechanics in RU players versus track and field athletes. Wild et al. (2018) found toe-off distance to be highest correlating variable to average normalised external sprint power where having a stance further behind the centre of mass at toe-off resulted in superior acceleration. Backs exhibited higher SVs displaying a more posterior touchdown distance compared to slower forwards. Morin et al. (2012) found smaller touchdown distances were related to a more forward orientated ground reaction force vector and thus smaller touchdown distances have been identified as a key determinant of acceleration. Wild et al. (2018) also found that touchdown distance for forwards relative to centre of mass was further forward compared to the fastest of all-time athletes, track, and field athletes, displaying a very large effect size (sprinters vs forwards). Differences in body masses between RU and track and field athletes are largely different. RU players are much heavier than track and field athletes, thus must produce larger external net forces in order to overcome their inertia which could suggest trunk angles may differ between RU and track and field athletes, also suggesting reason for differing TDs. However, further research is needed to prove this.

Previous research has identified an optimal sprint technique for the most efficient acceleration and maximal speed; however, applying such recommendations does not cater for the intercepting demands involved in RU, leaving players exposed to potential injury. Therefore, the aim of this study is to identify which kinematic variables are associated with RU acceleration sprint performance (SV during the first three steps of a 40 m sprint) to in turn create a technical model for initial acceleration in RU. In addition, differences between faster and slower players will be explored. It was hypothesised that: (a) the faster group would display significantly faster SVs compared to the slow group, where the fast group would have a combination of both a higher SL and SF compared to the slow group; (b) ≥ large correlation would be exhibited between SVs and SF where the faster group would exhibit a significantly faster SFs than the slow group; and (c) SV and FT would display a ≥ large correlation where the fast group would also display shorter FTs compared to the slow group.

2. Methods

2.1. Participants

Based on previously published methods (Calderbank et al., 2021), nineteen semi-professional elite male academy RU players were recruited to partake in the study. Subjects were split into fast and slow groups where the top nine quickest 40 m sprinters (time to completion) were deemed to be in the fast group (n = 9, 5 backs and 4 forwards; age = 18.0 ± 0.5 years, height = 1.86 ± 0.07 m, mass = 88.9 ± 8.55 kg) and the bottom ten slowest 40 m sprinters (time to completion) were deemed to be in the slow group (n = 10, 2 forwards and 8 backs; age = 18.0 ± 0.5 years, height = 1.81 ± 0.07 m, mass = 91.6 ± 11.5 kg). Using a power of 0.8, and type 1 error or alpha level of 0.05, a minimum of 14 (n = 7 each group) subjects was determined from an *a priori* power analysis using G*Power (Version 3.1.9.2, University of Dusseldorf, Germany) based upon a previously established Cohen's d effect size of 1.69 for contact time during the first three steps (steps 1 – 3) (Wild et al., 2018; Dos'Santos et al., 2020). For the testing procedures, all subjects were highly familiar with testing and training procedures for sprinting and strength & conditioning. Subjects wore studded rugby boots for sprinting trials and were also injury free. Ethical approval was obtained from the University of Salford ethics board. Written informed consent along with a physical activity readiness questionnaire were provided to all participants for completion prior to data collection to check eligibility for study participation. Previous research into time-motion during field-based team sports, has shown that during competition, 40 m is the maximum distance likely to be sprinted in one burst by RU players, although on average sprints tend to range between 0 – 20 m therefore step mechanics will be taken during the 0 – 20 m portion of the sprint (during the first three steps of the sprint) (Spencer et al., 2005).

2.2. Apparatus and task

In line with Calderbank et al. (2021) testing was carried out in one testing session. The 40 m sprint test was selected as 40 m is the maximum distance likely to be covered through a sprint burst during a RU game (Sayers, 2000). Additionally, as the RU players in this study complete 40 m sprints regularly as part of their training, it also allowed for training consistency to be held. The test has also been shown to be highly reliable (Darrall-Jones et al., 2016). Three maximal effort trials were completed by each subject on a synthetic 3G AstroTurf surface. Similar to previous research, a video camera was placed between the 0 – 10 m portion of the track in order to evaluate step mechanics (Wild et al., 2018; Calderbank et al., 2021). Video acquisition of kinematics can be seen in Table 1. Intraclass correlation coefficients (ICCs) with 95% confidence intervals (CI) and CVs were calculated for the fast and slow groups combined, for the fast group independently, and for the slow group independently. Group comparisons were made for all step mechanic variables and Hedges' g effect sizes calculated.

Table 1: Acquisition/definition of step mechanic variables (Hunter et al., 2004; Seagrave et al., 2009).

Step Mechanics	**Process of Acquisition/Definition**
Step length (m)	Toe to toe horizontal distance between consecutive foot contacts.
Step duration (s)	Number of frames from take-off to take-off of consecutive steps × 1/100
Ground contact time (s)	Number of frames from touchdown to take-off of one-foot contact × 1/100
Flight time (s)	Number of frames from take-off to touchdown, during one step × 1/100
Step frequency (Hz)	1/ step duration
Step velocity (m/s)	Step length × step frequency
Trunk angle at take-off (°)	Angle of trunk relative to the vertical at take-off. Where a lower trunk angle would be a more upright and vertical posture.
Leg extension angle at take-off (°)	Angle of rear leg (ankle to hip) at full extension relative to vertical at take-off (A lower angle would indicate less leg extension at take-off).
Hip flexion angle at take-off (°)	Angle of thigh of forward leg (centre of knee to hip) relative to horizontal at take-off. A lower hip flexion angle would have greater knee lift.
Shoulder extension angle at take-off (°)	Angle formed between upper arm and trunk at take-off. Where a greater shoulder extension angle would result in a greater backward arm drive.
Touchdown distance (m)	Horizontal distance of toe to hip at touchdown. A foot landing further forwards relative to the hip would result in a greater touchdown distance.

2.3. Procedure

The data collection used an experimental quantitative approach (between subjects, cross sectional design). The study assessed the variables listed and defined in Table 1 during the first three steps of the 40 m sprint. The study used similar methods to Calderbank et al. (2021) and are summarized here.

Subjects undertook a standardized warm up in line with previous successful research (Dos'Santos et al., 2017). The 40 m track was marked out on the testing surface. The camera set up can be seen in Figure 1. Placed on a rigid tripod 0.98 m off the floor, the Panasonic Lumix DMC - FZ200 camera (Panasonic corporation, Kadoma, OSA, JP) sampled at 100 Hz with a resolution of 1280 x 720p was set on a manual focus. The camera set up permitted evaluation of the first three steps of each trial. As positioned in Figure 1, one pair of Draper flood lights (WL28, Draper, UT, USA) (1500 watts) were set on a 3 m tall tripod. Although the camera field of view was 7 m, measurements were only taken in the central 5 m to reduce parallax error. Prior to data collection, in the centre of the track, a 1.22 m calibration frame was taken directly in front of the camera frame.

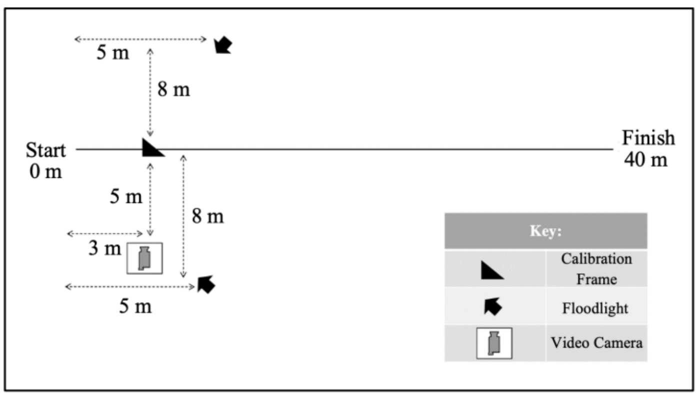

Figure 1: Diagram of 40 m sprint test set up.

Upon starting each trial, subjects were informed to start 0.5 m behind the start line in a 2-point athletic start before then completing three maximal 40 m sprint efforts each with a 3- to 4-minute rest period between (Wild et al., 2018). Subjects started each effort with the synchronization of the camera recording for each trial and were instructed to *run as fast as possible and to not decelerate until they passed the finish line* and were given encouragement throughout (Woolford et al., 2013). A step was defined as one consecutive movement of right foot contact to left foot contact (Wild et al., 2018; Calderbank et al., 2021). The point of touchdown was identified as the first frame the foot was visibly in contact with the ground and toe-off was identified as the first frame the foot had visibly left the ground (Wild et al., 2018; Calderbank et al., 2021).

Videos were imported and calibrated using into the computer system and analysed using Quintic Biomechanics software (Version 31, Solihull, UK). Through this software the 'angle drawing', 'shapes', and 'marker' functions were utilised to determine all step mechanic variables (Table 1) during the first three steps (these values were then averaged across steps then reported). The data was then separated into groups: groups combined, fast group, and slow group.

2.4. Statistical approach

Using ICC (ICC 3,1) with 95% CI (Shrout & Fleiss, 1979; Wild et al., 2018), test-retest intra-rater reliability of manual digitization for all step mechanics was determined. Similar to Wild et al. (2018) and Calderbank et al. (2021), the data of 10 subjects, was selected at random from the sample and digitized on two separate occasions (2 weeks apart). Using SPSS for Mac (Version 27; SPSS Inc., Chicago, IL, USA) ICCs, CVs, and CIs were calculated. ICCs with 95% CI were determined to test rank order consistency between trials (two-way mixed effects, average measures absolute agreement) for the groups when combined, and separately. Using the Koo and Li (2016) scale, ICCs were interpreted as poor reliability (< 0.5), moderate reliability (0.5 – 0.75), good reliability (0.76 – 0.9), and excellent reliability (> 0.9), where ICC ≥ 0.7 was deemed acceptable (Baumgartner & Chung, 2001). Intra-rater reliability with 95% CI was calculated (two-way random effects, average measures, absolute agreement). For each variable, using the formula: standard deviation divided by the mean multiplied by 100, percentage within subject CV was calculated to determine the variability across the three trials. Ninety-five percent CIs for CVs were calculated and reported. An acceptable CV was < 15% (Baumgartner & Chung, 2001). Using a Shapiro-Wilks test normality was inspected. Normality ($p > 0.05$) was established for all variables highlighted in Table 1. To explore differences between fast vs slow groups for variables established as normal a parametric independent samples t-test was used. A Levene's test was used to test the assumption of equality of variances, with degrees of freedom adjusted for 'variances not assumed' for violations of this assumption. Step duration and FT and SV were not normally distributed ($p < 0.05$). In order to explore differences between fast and slow groups for variables not normally distributed, a Mann-Whitney U test was used. To explore the relationship between step mechanics and SV a series of parametric Pearson's correlations were conducted with significance set to $p \leq 0.0045$, Bonferroni adjusted to allow for multiple correlations. However, as step duration and FT were not normally distributed, a series of non-parametric Spearman's rank correlations were conducted for these variables. In agreement with Hopkins (2002) correlation values were interpreted as less than trivial (≤ 0.1), small (0.11 – 0.3), moderate (0.31 – 0.5), large (0.51 – 0.7), very large (0.71 – 0.9), and almost perfect (0.91 – 1.0). The data was split into fast and slow groups where the top nine subjects with the fastest SV were deemed 'fast' and the bottom ten subjects with the slowest SV were deemed 'slow'. Effect sizes were determined and corrected using Hedges' *g* due to uneven sample sizes, with values interpreted as follows: trivial (≤ 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), very large (2.0 – 4.0), and extremely large (≥ 4.0) (Hopkins, 2002).

3. Results

Excellent intra-rater reliability (between first and second digitization) was found for all step characteristics (ICC = 0.993 to 1.00, 95% CI = 0.972 to 1.00). Mixed reliability and variability (ICC = 0.511 to 0.920, moderate-excellent; CV = 4.50% to 20.8%) was found for all step characteristics in grouped data (Figure 2).

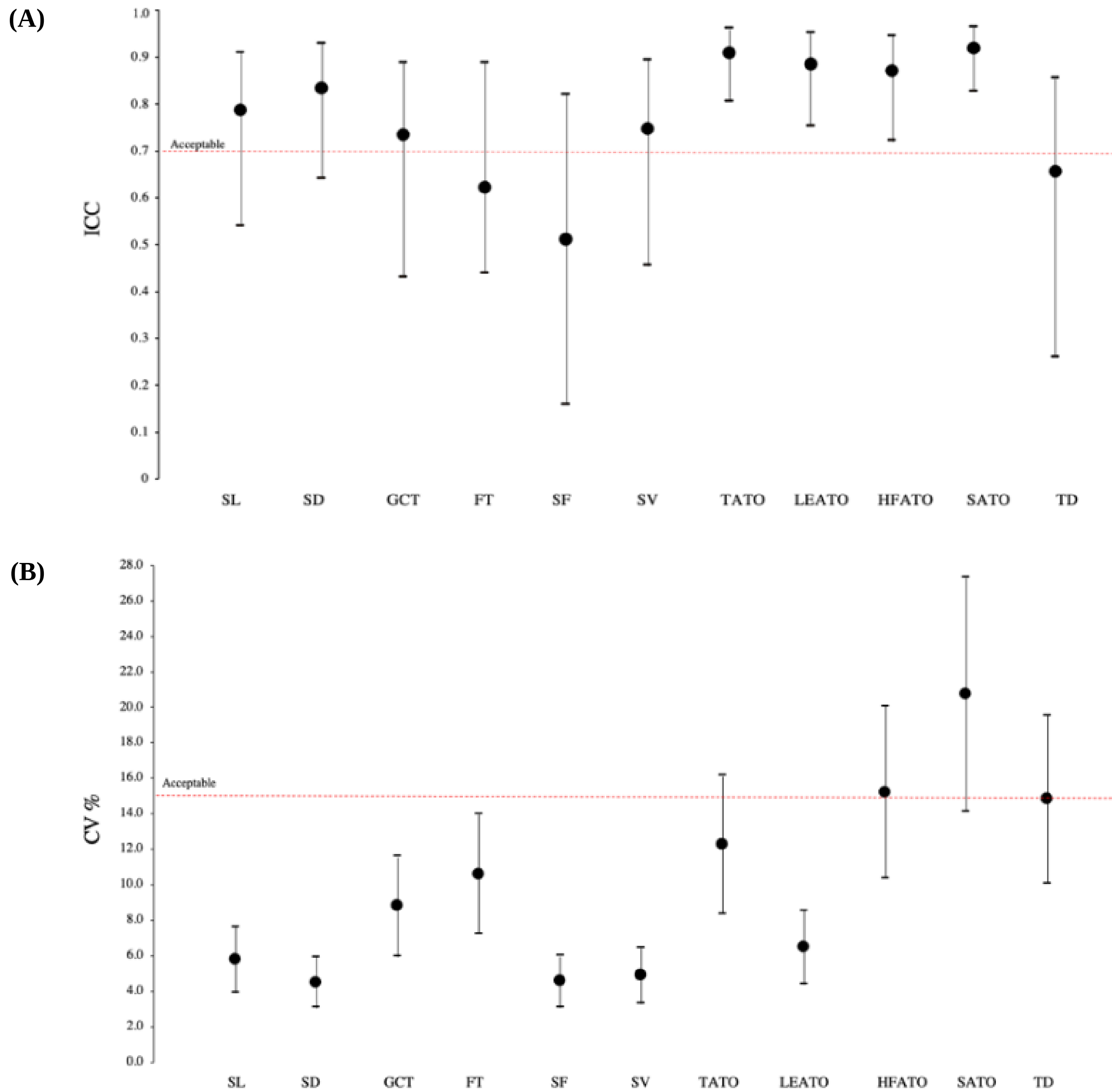

Figure 2: (A) Reliability (ICC) and (B) variability (CV) measures for step mechanics variables (groups combined). Error bars represent upper and lower 95% confidence intervals.

For fast and slow groups, step mechanics demonstrated varied results (fast ICC = 0.519 to 0.955; slow ICC = 0.202 to 0.832; fast CV = 2.57% to 15.57%; slow CV = 0.97% to 16.09%). Effect sizes ranged from trivial to large (g = 0.00 to -1.456) and correlations ranged between trivial to high (r = -0.009 to 0.505) (Table 2 and Figure 3).

4. Discussion

The study aimed to identify which kinematic variables were associated with RU sprint performance (SV during the first three steps) and to explore differences between faster and slower players to in turn create a technical model for initial acceleration in RU. The faster group displayed significantly faster SVs, with both higher SF and SL compared to the slow group, accepting the hypothesis. SV- SF displayed a moderate correlation (r = -0.344, p = 0.150) and SV- SL displayed a high correlation, (r = 0.505, p = 0.028), thus partially accepting the hypothesis. The fast group displayed identical FTs compared to the slow group, where SV-FT displayed only a small correlation (r = -0.191, p = 0.434), rejecting the hypothesis.

SL results from the current study displayed highest correlations with SV in a positive direction. SV is the product of SL and SF (SV = SL x SF) where, step duration is also directly influenced by the combination of SL and SF and thus SV. In the current study, step duration and SF displayed a moderate correlation and moderate effect size. Whereas, although SL displayed the highest correlation in the current study, SL displayed only a small effect size. Therefore, suggesting both fast and slow RU players can produce similar SLs meaning the discrepancy between fast and slow SVs is likely due to SF. Findings by Murphey et al. (2003) agreed with findings of the current study.

Table 2: Descriptive statistics and effect sizes of step mechanics variables and correlation coefficients of step mechanics variables with step velocity.

	Groups Combined			Fast Group	Slow Group		
Step Characteristics	**Mean ± SD**	***r***	***p***	**Mean ± SD**	**Mean ± SD**	***g***	***p* (2-tailed)**
Step length (m)	1.27 ± 0.13	0.505[a]	0.028	1.27 ± 0.07	1.25 ± 0.06	0.286[c]	0.116
Step duration (s)	0.24 ± 0.01	-0.388[b]	0.100#	0.23 ± 0.01	0.24 ± 0.01	-0.952[b]	0.094†
Ground contact time (s)	0.14 ± 0.01	-0.180[c]	0.460	0.14 ± 0.11	0.15 ± 0.12	-0.082[d]	0.224
Flight time (s)	0.09 ± 0.01	-0.191[c]	0.434#	0.09 ± 0.01	0.09 ± 0.01	0.00[d]	0.632†
Step frequency (Hz)	4.25 ± 0.20	-0.344[b]	0.150	4.30 ± 0.17	4.21 ± 0.17	1.008[b]	0.059
Step velocity (m/s)	5.36 ± 0.26			5.48 ± 0.23	5.25 ± 0.13	1.173[b]	< 0.001†
Trunk angle at take-off (°)	34 ± 4.00	-0.489[b]	0.034	32 ± 1.00	36 ± 4.00	-1.456[a]	0.107
Leg extension angle at take-off (°)	43 ± 3.00	0.320[b]	0.182	44 ± 2.00	43 ± 3.00	0.584[c]	0.691
Hip flexion angle at take-off (°)	29 ± 5.00	-0.321[b]	0.180	28 ± 4.00	30 ± 5.00	-0.368[c]	0.370
Shoulder extension angle at take-off (°)	49 ± 10.0	-0.009[d]	0.969	48 ± 6.00	50 ± 13.0	-0.124[d]	0.543
Touch down distance (m)	0.26 ± 0.04	-0.013[d]	0.956	0.25 ± 0.32	0.26 ± 0.03	-0.042[d]	0.639

Note: Interpretations for *r* and *g* values: [a]high/large; [b]moderate; [c]small; [d]trivial. SD = standard deviation; *g* = Hedges' *g*; #Spearman's correlation; †Mann-Whitney U.

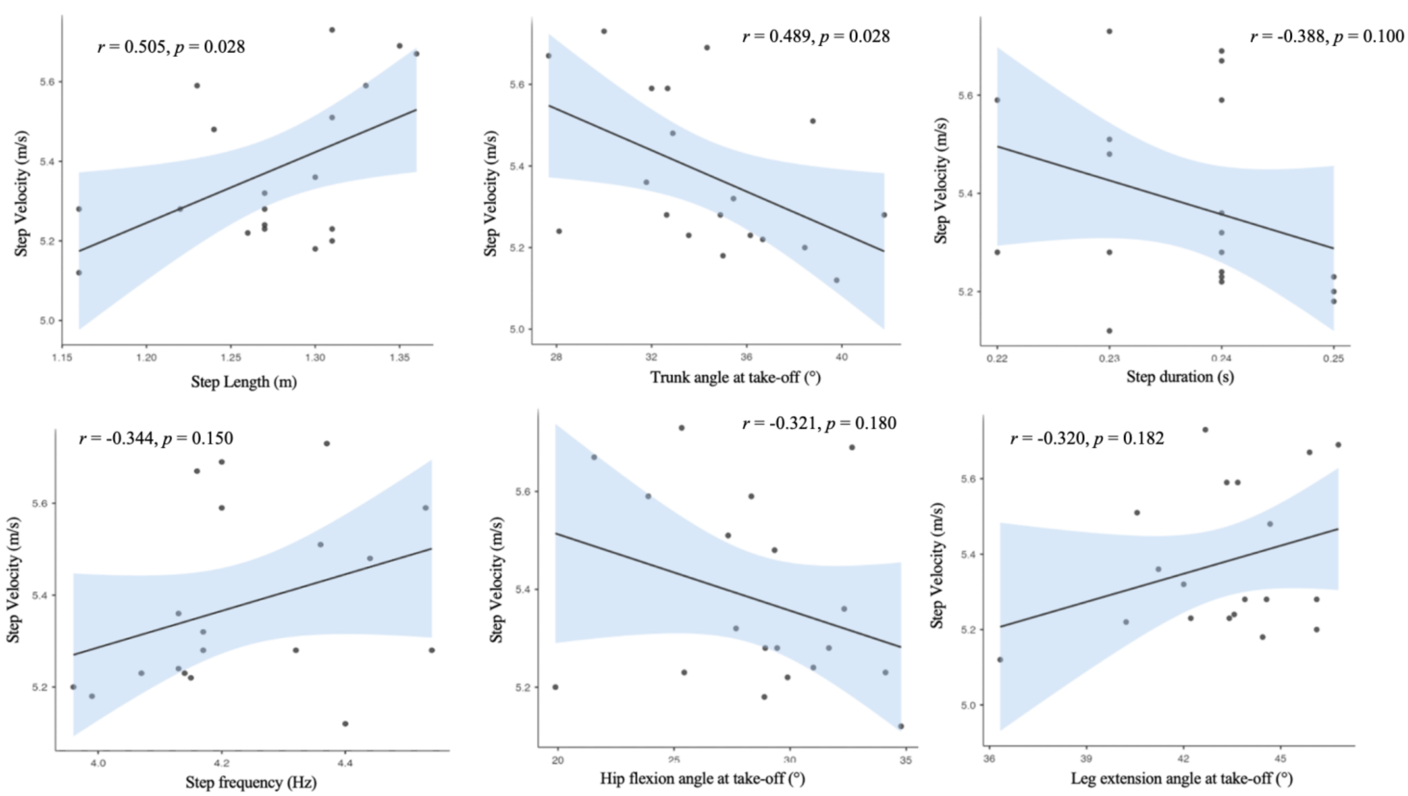

Figure 3: Scatter Plots and 95% confidence intervals displaying relationship between step velocity and the six highest correlating step mechanics; step length, trunk angle at take-off, step duration, step frequency, hip flexion angle at take-off, and leg extension angle at take-off.

Murphey et al. (2003) found that subjects with a higher acceleration had a 9% higher SF compared to the slower group. They concluded that the reason their athletes were able to generate higher SVs over short distances was due to reduced GCT, contrasting results from the current study. GCT results from the current study displayed both a small correlation and small effect size. Both fast and slow groups in the current study failed to produce differences, which may be due to the relatively similar body masses between the two groups explained by impulse-momentum relationship ($F_{mean} \times \Delta t \propto p = mv - mv_0$; F_{mean} = mean force, Δt = change in time, p = momentum, m = mass, v = final velocity, v_0 = initial velocity). In the current study, two thirds of sample were forwards who had a larger body mass compared to that of lighter backs. Therefore, heavier forwards are more likely to have larger GCTs, as they aim to maximize force production, resulting in longer force application (longer GCTs), thus making them more SL dependent and less SF dependent. Which could imply, RU sprinting success relies on the ability for one to reach the highest possible SF (whilst maintaining the longest possible SL).

Trunk angle at take-off displayed a moderate correlation with SV, exhibiting a large effect size. Whilst players presented some forward lean, trunk angle at take-off results suggest that a more upright torso angle (smaller torso angle) is advantageous (similar to trunk angle at take-off in the maximal speed phase of the technical model) (Ryan & Harrison, 2003), where large differences were displayed between the fast and slow groups (*g* = -1.456).

It is likely that RU players in the current study adopted an upright position due to players being accustomed to the constant visual scanning that occurs during RU match-play (Meir, 2005) commonly practiced during many RU training drills (Sayers, 2000). It is important for RU players to sprint with an upright position in order to assess the game and make correct decisions for successful performance. In contrast La Monica et al. (2016) and Sayers (2000) found that adopting an upright posture during certain game-time scenarios, could potentially leave players exposed to injury as this may leave players in a more open unprotected position. Thus, more vulnerable to contact collisions. Though this is clear, the 40 m sprint test used in the current study does not show a true representation of actual RU match-time sprint performance. The 40 m sprint test does not include intercepting contact collisions between sprint bursts that occur during live match-play. Practitioners should consider analyzing sprint mechanics live during match-play to gain an even better understanding of their athlete's sprint performance.

Hewit et al. (2013) used similar methods to the current study although found opposite. Hewit et al. (2013) found significant differences between fast and slow groups where faster players exhibited a larger trunk angle at take-off. The differences exhibited between the current study and findings found by Hewit et al. (2013) may also be due to anthropometrics. Although researchers used a team sport subject sample, players were not RU based were of a similar body mass to the average body mass of track and field athletes. Therefore, direct between study comparisons cannot be made. In the current study, correlations between hip flexion angle at take-off and SV, and Leg extension angle at take-off and SV displayed moderate correlations. Results suggest that a higher knee lift combined with that of a greater leg extension angle is beneficial for RU sprint performance. These findings agree with the current technical model (Ryan & Harrison, 2003). Wild et al. (2018) found faster backs had a more posterior touchdown and toe-off position, thus displaying greater Leg extension angle at take-off. This enabled backs to maximize propulsion and limit braking compared to that of slower forwards, suggesting this is likely the case in the current study.

Shoulder extension angle at take-off and touchdown distance in the current study presents trivial findings. Previous studies suggest that a bigger arm drive enables players to exhibit enhanced sprint performance combined with that of a shorter touchdown distance (Macadam et al., 2018). Though this agrees with results of the current study, results were trivial. Previous research found that not only does the arm action counterbalance the rotary momentum of the legs during sprinting, but a larger arm drive also plays an important role during early acceleration by contributing to up to 10% of the total vertical propulsive force the body can apply to the ground (Macadam et al., 2018). However, though this is true, results from the current study suggest that shoulder extension angle at take-off and touchdown distance do not determine sprint performance.

In conclusion, Figure 4 displays the new technical model for RU sprint acceleration performance. Results of the current study suggest that the driver for superior sprint performance is due to one's ability to maximize SF (minimize step duration) whilst maintaining the longest possible SL with a more upright torso. To further enhance results, a more extended leg at take-off with combined greater knee lift should be adhered to. Therefore, it can be seen in Figure 4, if the variables shaded in turquoise and yellow are improved, more successful RU sprint performance may be exhibited. Results suggest that, in order to fine tune performance, a quicker GCT, shorter FT, a greater shoulder extension angle at take-off and shorter touchdown distance should be adhered to in order to maximize propulsion, limit braking and thus exhibit faster sprint times.

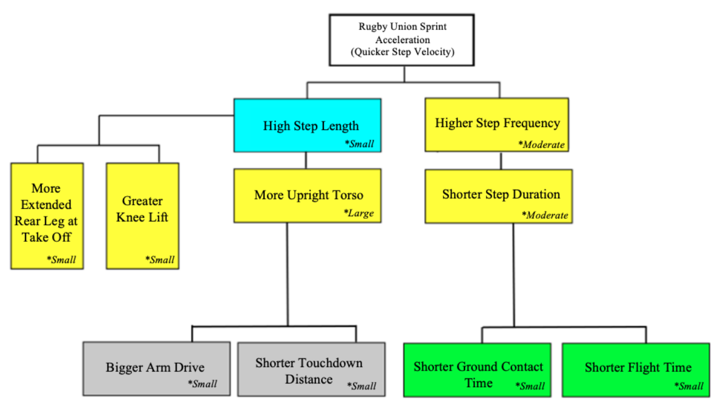

Figure 4: Rugby Union Sprinting Technical Model for Acceleration. Turquoise represents strongest correlating variables to acceleration performance followed by yellow, green, and then grey. *Hedges' *g* effect size.

Conflict of Interest

The authors declare no conflict of interests.

Acknowledgment

Authors would like to thank Sale shark RFU U18 academy players for taking part in the study. No funding was received to support this study.

References

Baker, W. (1981). William Webb Ellis and the origins of Rugby Football : The life and death of a victorian myth. *The North American Conference with British Studies Studies*, *13*(2), 117–130.

Baumgartner, T. A., & Chung, H. (2001). Confidence limits for intraclass reliability coefficients. *Measurement in Physical Education and Exercise Science*, *5*(3), 179–188.

Bezodis, I. (2012). Investigations of the step length-step frequency relationship in sprinting: Applied implications for performance. In *ISBS-Conference Proceedings Archive*.

Bezodis, I. N., Irwin, G., Kuntze, G., & Kerwin, D. G. (2011). Changes in step characteristics between the maximum velocity and deceleration phases of the 100 metre sprint run. *Portuguese Journal of Sport Sciences*, *11*(2), 455–458.

Bezodis, N. E., Willwacher, S., & Salo, A. I. T. (2019). The biomechanics of the track and field sprint start: A narrative review. *Sports Medicine*, *49*(9), 1345–1364.

Bradshaw, E. J., Maulder, P. S., & Keogh, J. W. L. (2007). Biological movement variability during the sprint start: Performance enhancement or hindrance? *Sports Biomechanics*, *6*(3), 246–260. https://doi.org/10.1080/14763140701489660

Brughelli, M., Cronin, J., & Chaouachi, A. (2011). Effects of running velocity on running kinetics and kinematics. *Journal of Strength and Conditioning Research*, *25*(4), 933–939.

Calderbank, J. A., Jones, P. A., Dos'Santos, T., Jibson, A., Simpson, R. A., & Burns, J. E. (2021) Reliability and variability of step mechanics in Rugby Union: A comparison between forwards and backs. *The Journal of Sport and Exercise Science, Journal*, *5*(3), 212–220.

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

Darrall-Jones, J. D., Jones, B., Roe, G., & Till, K. (2016). Reliability and usefulness of linear sprint testing in adolescent Rugby Union and League players. *Journal of Strength and Conditioning Research*, *30*(5), 1359–1364.

Deutsch, M. U., Kearney, G. A., & Rehrer, N. J. (2007). Time-motion analysis of professional rugby union players during match-play. *Journal of Sports Sciences*, *25*(4), 461–472. https://doi.org/10.1080/02640410600631298

Dos'Santos, T., McBurnie, A., Thomas, C., Comfort, P., & Jones, P. A. (2020). Biomechanical determinants of the modified and traditional 505 change of direction speed test. *Journal of Strength and Conditioning Research*, *34*(5), 1285–1296. https://doi.org/10.1519/jsc.0000000000003439

Duthie, G. M., Pyne, D. B., Marsh, D. J., & Hooper, S. L. (2006). Sprint patterns in Rugby Union players during competition. *Journal of Strength and Conditioning Research*, *20*(1), 208–214. https://doi.org/10.1519/R-16784.1

Fletcher, I. (2009). Biomechanical aspects of sprint running. *UK Strength and Conditioning Association*, *16*(16), 20–23.

Gambetta, V. (1996). In a blur: How to develop sport-specific speed. *Sports Coach*, *19*, 22–24.

Gambetta, V. (1997). How to develop sport-specific speed-part 2. *Sports Coach*, *19*, 26–28.

Hewit, J. K., Cronin, J. B., & Hume, P. A. (2013). Kinematic factors affecting fast and slow straight and change-of-direction acceleration times. *The Journal of Strength & Conditioning Research*, *27*(1), 69–75.

Hopkins, W. G. (2002). A scale of magnitudes for effect statistics. *A New View of Statistics*, *502*(1), 411.

Hunter, J. P., Marshall, R. N., & McNair, P. J. (2004). Interaction of step length and step rate during sprint running. *Medicine and Science in Sports and Exercise*, *36*(2), 261–271. https://doi.org/10.1249/01.MSS.0000113664.15777.53

Kale, M., & Acikada, C. (2016). Effects of stride length and frequency training on acceleration kinematic, and jumping performances. *Sport Science Review*, *25*(3–4), 243–260. https://doi.org/10.1515/ssr-2016-0013

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163.

Kugler, F., & Janshen, L. (2010). Body position determines propulsive forces in accelerated running. *Journal of Biomechanics*, *43*(2), 343–348.

La Monica, M. B., Fukuda, D. H., Miramonti, A. A., Beyer, K. S., Hoffman, M. W., Boone, C. H., & Hoffman, J. R. (2016). Physical differences between forwards and backs in American collegiate rugby players. *Journal of Strength and Conditioning Research*, *30*(9), 2382–2391.

Lockie, R. G., Murphy, A. J., Jeffriess, M. D., & Callaghan, S. J. (2013a). Step kinematic predictors of short sprint performance in field sport athletes. *Journal of Sports Sciences*, *7*(2), 71–77.

Lockie, R. G., Murphy, A. J., Schultz, A. B., Jeffriess, M. D., & Callaghan, S. J. (2013b). Influence of sprint acceleration stance kinetics on velocity and step kinematics in field sport athletes. *The Journal of Strength & Conditioning Research*, *27*(9), 2494–2503.

Macadam, P., Cronin, J. B., Uthoff, A. M., Johnston, M., & Knicker, A. J. (2018). Role of arm mechanics during sprint running: A review of the literature and practical applications. *Strength and Conditioning Journal*, *40*(5), 14–23. https://doi.org/10.1519/SSC.0000000000000391

Mackala, K., & Mero, A. (2013). A kinematics analysis of three best 100 m performances ever. *Journal of Human Kinetics*, *36*(1), 149–160. https://doi.org/10.2478/hukin-2013-0015

Meir, R. (2005). Conditioning the visual system: A practical perspective on visual conditioning in Rugby Football. *Strength and Conditioning Journal*, *27*(4), 86–92. https://doi.org/10.1519/1533-4295(2005)27[86:CTVSAP]2.0.CO;2

Morin, J., 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

Murphy, A. J., Lockie, R. G., & Coutts, A. J. (2003). Kinematic determinants of early acceleration in field sport athletes.

Journal of Sports Science and Medicine, *2*(4), 144–150.

Nagahara, R., Takai, Y., Kanehisa, H., & Fukunaga, T. (2018). Vertical impulse as a determinant of combination of step length and frequency during sprinting. *International Journal of Sports Medicine*, *39*(4), 282–290. https://doi.org/10.1055/s-0043-122739

Roberts, S. P., Trewartha, G., Higgitt, R. J., El-Abd, J., & Stokes, K. A. (2008). The physical demands of elite English Rugby Union. *Journal of Sports Sciences*, *26*(8), 825–833.

Ryan, G. J., & Harrison, A. J. (2003). Technical adaptations of competitive sprinters induced by bend running. *New Studies in Athletics*, *18*(4), 57–70.

Sayers, M. (2000). Running techniques for field sport players. *Sports Coach*, *23*(1), 26–27.

Seagrave, L. (1996). Introduction to sprinting. In *New Studies in Athletics*, 11(1), 93–113.

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: Classifications, training and testing. *Journal of Sports Sciences*, *24*(9), 919–932.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin*, *86*(2), 420–428.

Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities. *Sports Medicine*, *35*(12), 1025–1044.

Vittori, C. (1996). The European schoool in sprint training: The experiences in Italy. *New Studies in Athletics*, *11*(2–3), 85–92.

Wild, J. J., Bezodis, I. N., North, J. S., & Bezodis, N. E. (2018). Differences in step characteristics and linear kinematics between rugby players and sprinters during initial sprint acceleration. *European Journal of Sport Science*, *18*(10), 1327–1337. https://doi.org/10.1080/17461391.2018.1490459

Woolford, S., Polgaze, T., Rowsell, G., & Spencer, M. (2013). Field testing principles and protocols. In R. Tanner, & C. Gore (Eds.), *Physiological tests for elite athletes.* (2nd Ed., pp. 231–248). Human Kinetics.

Young, M. (2007). Maximal Velocity Sprint Mechanics. *Track Coach*, *179(1)*, 5723–5730.