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Does Entry Velocity Matter? Static-Start and Pick-Up Acceleration Sprinting in Female Rugby Union Players

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Abstract

Background and Objectives: Most rugby sprints begin in motion, yet standardized testing uses static starts. This study compared static-start and pick-up acceleration at entry velocities of 1.5 and 3.0 $m \cdot s^{-1}$ in female rugby union players, examining positional differences and countermovement jump (CMJ) associations. **Methods**: Thirty-eight senior female rugby union players completed CMJ testing, static-start sprints, and LED-paced pick-up sprints. Linear mixed models compared sprint conditions and playing positions, while correlation and multivariable analyses examined CMJ associations. **Results**: Pick-up sprint variables showed excellent intra-session reliability (coefficient of variation = 0.63–4.29%; intraclass correlation coefficient = 0.90–1.00). Higher entry velocities reduced split times, mean acceleration and distance to maximal velocity, but not maximal velocity. Backs outperformed forwards across all static-start sprint outcomes, but some early positional differences (5 and 10 m times and 0–5 m acceleration) were non-significant in pick-up trials, despite broadly similar small-to-moderate effect sizes. CMJ-derived variables correlated with all sprint outcomes across conditions ($p \leq 0.046$; r/rho = 0.33–0.85) and jointly explained additional variance (ΔR^2 = 0.055–0.547; $p \leq 0.027$), but none showed significant independent associations ($p \geq 0.140$). **Conclusions**: Pick-up acceleration shortened split times and distance to maximal velocity, with backs generally outperforming forwards. CMJ variables correlated with sprint performance but showed no significant independent associations.

Keywords: rugby; acceleration; athletic performance; running; female

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1. Introduction

As a field-based contact sport, rugby union is characterized by an intermittent activity profile, where players must repeatedly perform short bursts of high-intensity actions (e.g., sprinting, tackling, and rapid changes of direction) alternating with low-intensity activities [1]. Given that rugby union involves contact situations in which speed and power can make players outmatch their opponents (e.g., break tackles or gain the defensive line), it requires developing physical qualities such as linear sprinting ability and vertical jump

performance [2–4]. Specifically, when assessing these capabilities (i.e., linear sprint and vertical jump) in women's rugby union, a recent study showed a strong positive association between countermovement jump (CMJ) height and maximum sprint velocity (Vmax) [1]. Similar relationships have also been reported in international female rugby league players, where CMJ height was significantly associated with 30 and 40 m sprint times [5]. Regarding the assessment of Vmax, the literature has traditionally evaluated sprint capabilities using tests initiated from a static, standing position [1,3,6]. Since most sprints in matches begin while players are already in motion, typically from a walking or jogging pace, the recent literature proposes assessing sprints from non-static positions (i.e., with a prior entry velocity) [7–10].

Specifically, analyzing rugby union competition, Lacome et al. [11] reported that approximately 85% of all sprints in elite male players occur while players are already in motion, with 53.4 ± 5.5% beginning from a walking pace (0–1.9 $m \cdot s^{-1}$) and 31.8 ± 5% from a jogging start (>1.9 $m \cdot s^{-1}$). Although these findings support the relevance of assessing non-static sprint actions in rugby union, their direct applicability to female players remains uncertain. In this context, assessing non-static sprint actions has historically posed a methodological challenge, primarily because entry velocity must be standardized [7–10]. To overcome this, Pryer et al. [7–10] proposed an innovative assessment protocol utilizing LED pacing systems to standardize entry velocities at 1.5 $m \cdot s^{-1}$ and 3.0 $m \cdot s^{-1}$, representing walking and jogging speeds, respectively, from which sprints commonly begin during rugby union match play [11]. By successfully controlling the entry velocity (i.e., low and moderate), this methodology enables the evaluation of a maximal linear sprint initiated from a non-static start, a capability defined as 'pick-up acceleration' [7–10]. Crucially, this specific action (i.e., pick-up acceleration) has been shown to produce distinct mechanical profiles compared to traditional static sprints, including differences in step kinematics (e.g., step length and step frequency), trunk positioning, as well as horizontal and vertical braking and propulsive impulses during the transition and initial pick-up steps [7–10]. To quantify these profiles, this procedure allows for the measurement of determinant sprint metrics, such as Vmax, split times (e.g., 5 m sprint time [T5] and 10 m sprint time [T10]) and the distance required to reach Vmax (Distance-to-Vmax) subsequent to the entry phase [1,6,7,9].

In rugby union, shorter sprint times and higher Vmax may provide an advantage when players need to move into open space in attack or close down opponents in defense [1,4]. Distance-to-Vmax, meanwhile, can help practitioners select appropriate sprint testing and training distances according to whether the objective is to assess acceleration or ensure that players attain Vmax [1]. Despite these potential applications, both the methodological development and empirical evaluation of pick-up acceleration have been conducted predominantly by the same research group, with the available evidence derived from small, heterogeneous samples of male team-sport athletes [7–10]. Pick-up acceleration therefore remains unstudied in a sport- and sex-specific sample of female rugby union players. This lack of evidence is particularly relevant because sprint performance differs according to playing position in female rugby union players [1,12]. For example, senior backs have shown higher Vmax (7.31 ± 0.46 vs. 6.90 ± 0.33 $m \cdot s^{-1}$) and greater Distance-to-Vmax (23.99 ± 3.57 vs. 20.78 ± 2.85 m) than their forward counterparts [1]. Therefore, analyzing the reliability of the pick-up acceleration test and its performance in female rugby union players, considering their playing positions (i.e., backs and forwards), could help practitioners and coaches monitor this capability and design specialized training programs.

Lower-limb power is recognized as a determining factor in rugby union, where greater vertical jump capacity significantly correlates with enhanced execution of tasks such as scrums [13], collisions [2], and sprints [14]. In line with these findings, a recent study in

female rugby union players [1] revealed that CMJ height correlates with various static-start sprint variables, demonstrating a stronger association with the Vmax phase (i.e., Vmax and 30, 40, and 50 m split times) than with the initial acceleration phase (i.e., 5, 10, and 20 m split times). This may be supported by the force vector theory, as attaining Vmax requires substantial vertical force application, like the mechanics of a vertical jump [1,15]. In addition, recent biomechanical analyses by Pryer et al. [8] highlight the importance of vertical force application, suggesting that a substantial increase in vertical propulsive impulse plays a key role in optimizing step length and flight time during the transition step (i.e., the step marking the shift from entry velocity to sprinting), facilitated by a reduction in braking forces. While this relationship is well-documented for static-start sprints, the association between CMJ-derived performance variables and pick-up acceleration has not yet been investigated in team sports. Accordingly, CMJ-derived performance variables such as CMJ height, Peak power/BM, and RSI-mod may characterize different but related aspects of CMJ performance. More specifically, CMJ height reflects vertical jump performance, Peak power/BM reflects power production relative to body mass, whereas RSI-mod combines jump height and time to take-off, reflecting CMJ performance relative to the time required to produce the jump [16]. Examining these variables simultaneously may therefore clarify their combined association with pick-up acceleration and whether each provides information independent of the others.

To the best of our knowledge, no studies to date have comprehensively investigated the pick-up acceleration profile and its relationship with CMJ-derived performance variables in female rugby union players. Therefore, the present study aimed to compare sprint performance across static-start and pick-up acceleration conditions at 1.5 and 3.0 $m \cdot s^{-1}$ in female rugby union players, considering playing-position differences and associations between CMJ-derived performance variables and sprint performance, including their combined and independent contributions. The intra-session reliability of the radar-derived sprint variables was also assessed as part of the methodological evaluation of the testing protocol. In line with this aim, the following hypotheses were proposed: (i) an increase in entry velocity (static-start < 1.5 $m \cdot s^{-1}$ < 3.0 $m \cdot s^{-1}$) would result in reduced split times, Distance-to-Vmax, and interval-based acceleration, while Vmax would remain similar across sprint conditions [7]; and (ii) backs would generally outperform forwards, although the magnitude of positional differences may vary according to sprint condition and sprint outcome [1,9]; and (iii) higher CMJ height, RSI-mod, and Peak power/BM would be associated with better pick-up acceleration performance [1,9,10].

2. Materials and Methods

2.1. Design of the Study

A descriptive, cross-sectional, and correlational design was adopted to compare pick-up acceleration and static-start sprint performance in female rugby union players, while also examining playing-position differences and associations with CMJ-derived performance variables. The intra-session reliability of the radar-derived sprint variables was also assessed. Primary testing was conducted in-season during a single session in May, taking place outdoors on an artificial turf rugby field, with players wearing sports attire and footwear appropriate to each test.

Seven days prior to testing, players completed a 60 min familiarization session that primarily focused on the pacing technology (LED Rabbit, BV Systems, LLC, Shawnee, KS, USA), while also including the measurement technology and the overall protocol [10]. The evaluation sequence was as follows: duplicate anthropometric measurements (i.e., body mass [BM] and height), a standardized general warm-up, three CMJ trials, two static sprints, and two pick-up accelerations at each entry velocity (i.e., 1.5 and 3.0 $m \cdot s^{-1}$).

2.2. Participants

Thirty-eight high-level amateur senior female rugby union players (age: 23.11 ± 5.11 years; body mass: 70.33 ± 10.68 kg; height: 1.63 ± 0.05 m) from a leading club in Spain volunteered to participate in this study. Although the players were classified as amateur, the team competed at national level. According to the Participant Classification Framework proposed by McKay et al. [17], the sample was classified as Tier 3 (Highly Trained/National Level), as all players were competing at the national level at the time of testing. Three players had previous national team experience. In accordance with the Spanish Rugby Federation regulations, the Senior category is defined as athletes aged 18 years or older during the competitive season (September–May). Based on their primary on-field roles, the players were categorized into forwards (n = 23; age: 23.64 ± 5.64 years; body mass: 75.69 ± 10.46 kg; height: 1.64 ± 0.05 m) and backs (n = 15; age: 22.38 ± 4.35 years; body mass: 62.96 ± 5.30 kg; height: 1.61 ± 0.05 m). To be eligible for inclusion, players were required to: (i) have a minimum of two years of competitive rugby experience; (ii) be actively participating in regional or national-level leagues during the assessment period; and (iii) be free from any musculoskeletal injuries for at least 3 months prior to testing. To estimate the required sample size, an a priori power analysis was conducted using G*Power software (version 3.1.9.7; Heinrich Heine University Düsseldorf, Düsseldorf, Germany) for a repeated-measures ANOVA within–between interaction. The analysis assumed a medium effect size (f = 0.25), an α level of 0.05, statistical power of 0.95, two groups (i.e., backs and forwards), and three repeated conditions (i.e., static sprint, 1.5 $m \cdot s^{-1}$ pick-up acceleration, and 3.0 $m \cdot s^{-1}$ pick-up acceleration), with a nonsphericity correction of ε = 1.0 and a correlation among repeated measures of 0.70. The analysis indicated that a minimum total sample size of 28 participants was required to detect the specified position × sprint-condition interaction, with an actual power of 0.962. This repeated-measures ANOVA framework was used for the a priori calculation to represent the planned 2 (position) × 3 (sprint condition) repeated-measures design, targeting the position × sprint-condition interaction, which was subsequently examined using linear mixed-effects models. All participants were informed about the aims, protocols, and potential risks of the assessments and provided written informed consent before enrolment. The present investigation was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Pablo de Olavide University (protocol code: 25/1-2).

2.3. Pre-Test Procedures and Warm-Up

Participants were required to avoid strenuous physical activity for the preceding 24 h and to have their last meal at least 3 h before testing. They were also asked to avoid caffeine-containing products, including coffee and energy drinks, during this period. Water was allowed ad libitum before, during, and after testing. Height was determined using a portable stadiometer (SECA 213, Hamburg, Germany), while BM was recorded via dual force platforms (ForceDecks; VALD Performance, Brisbane, Australia).

The general warm-up consisted of 5 min of light jogging at a rating of perceived exertion (RPE) of 3–4 on the Borg CR10 scale [18], followed by mobility exercises (ankle dorsiflexion mobilizations and hip circles; 1 set of 8 repetitions per leg) and dynamic stretching exercises (forward–backward and lateral leg swings; 1 set of 10 repetitions per leg, and walking lunges; 1 set of 5 repetitions per leg). Before CMJ testing, a specific warm-up was performed, consisting of 5 min of joint mobility exercises, followed by 2 sets of 5 submaximal jumps and 2 min of recovery. Preceding the sprint assessments, participants completed a specific warm-up involving 5 min of incremental accelerations and directional changes, followed by 5 to 40 m sprints to guarantee peak readiness without inducing fatigue [3]. At least 5 min of passive rest separated the different tests to prevent fatigue interference [19].

2.4. Countermovement Jump (CMJ)

Vertical jump performance was quantified using dual portable force platforms sampling at 1000 Hz (ForceDecks, VALD Performance, Brisbane, Australia). Participants executed three maximal CMJs with 20 s of rest between trials [20]. The force plates were placed on a solid concrete base, and the players jumped wearing athletic training shoes, consistent with the footwear and surface conditions used in previous CMJ testing of female rugby union players [1]. During each attempt, players positioned their feet shoulder-width apart and were instructed to keep hands on hips and legs extended during the flight phase. Following the cue 'when you are ready,' participants were instructed to jump as high as possible using a countermovement to a self-selected depth. Strong verbal encouragement was provided throughout the test to ensure maximal effort. Raw force–time data were processed using the manufacturer's software (ForceDecks v.2.0). Jump height was calculated from flight time to facilitate comparisons with previous studies in female rugby players using the same method [1,5]. The RSI-mod was calculated as flight-time-derived jump height divided by contraction time, defined as the time from the start of movement to take-off. The start of movement was detected using the default 20-N ForceDecks threshold. Peak power was defined as the maximum power attained during the propulsive phase and was normalized to body mass.

2.5. Sprint Test

The testing comprised two protocols, performed in a fixed order: static-start sprints, where players performed two trials on a standard 30 m track, followed by pick-up accelerations, involving four trials performed in randomized order (two each at 1.5 and 3.0 $m \cdot s^{-1}$ entry velocities) on a 50 m setup consisting of a 20 m paced entry zone followed by a 30 m pick-up zone [9]. All sprint trials were performed wearing rugby boots on the artificial turf field. Velocity–time data were captured using a Doppler radar gun sampling at 46.875 Hz (Stalker ATS II, Stalker Sport, Richardson, TX, USA) [21], mounted on a tripod at a height of 1 m, positioned 5 m behind the respective starting line, and aligned with the longitudinal axis of the running lane for each protocol (i.e., static-start and pick-up sprints). The radar has a manufacturer-specified speed measurement range of 0.45–357.6 $m \cdot s^{-1}$ and an accuracy of ± 0.045 $m \cdot s^{-1}$ [22]. The Stalker ATS II has also been used as a reference system for assessing linear sprint velocity in previous validation studies [23].

For all attempts, players adopted a split stance with their preferred foot placed forward. In the static-start protocol, players began from a dead stop without any prior rocking motion. During the pick-up accelerations, entry velocities were regulated by the LED pacing system positioned parallel to the track. The LED system was programmed to provide a gradual acceleration over the first 7 m, reaching the prescribed constant velocity (i.e., 1.5 or 3.0 $m \cdot s^{-1}$) for the remaining 13 m of the paced entry zone. Participants matched this pace and, upon reaching the 20 m mark, accelerated maximally through the 30 m pick-up zone. The pick-up acceleration testing setup is illustrated in Figure 1. Actual entry velocity was calculated from the radar-derived velocity and distance data as the average speed over the final 5 m of the paced zone [7]; trials differing by >10% from the prescribed target velocity (i.e., 1.5 and 3.0 $m \cdot s^{-1}$) were considered invalid. If any trial failed to meet this criterion, the participant repeated the complete sprint protocol 48 h later under the same testing procedures, and only data from the repeat session were retained for analysis. This procedure was required for only one participant, whose trial in the 3.0 $m \cdot s^{-1}$ pick-up condition exceeded the predefined tolerance. Accordingly, 37 participants completed six maximal sprint trials, whereas one participant completed 12 trials across two sessions. The mean achieved entry velocities across all valid trials were 1.54 ± 0.04 $m \cdot s^{-1}$ and 3.08 ± 0.08 $m \cdot s^{-1}$ for the 1.5 and 3.0 $m \cdot s^{-1}$ pick-up protocols, respectively.

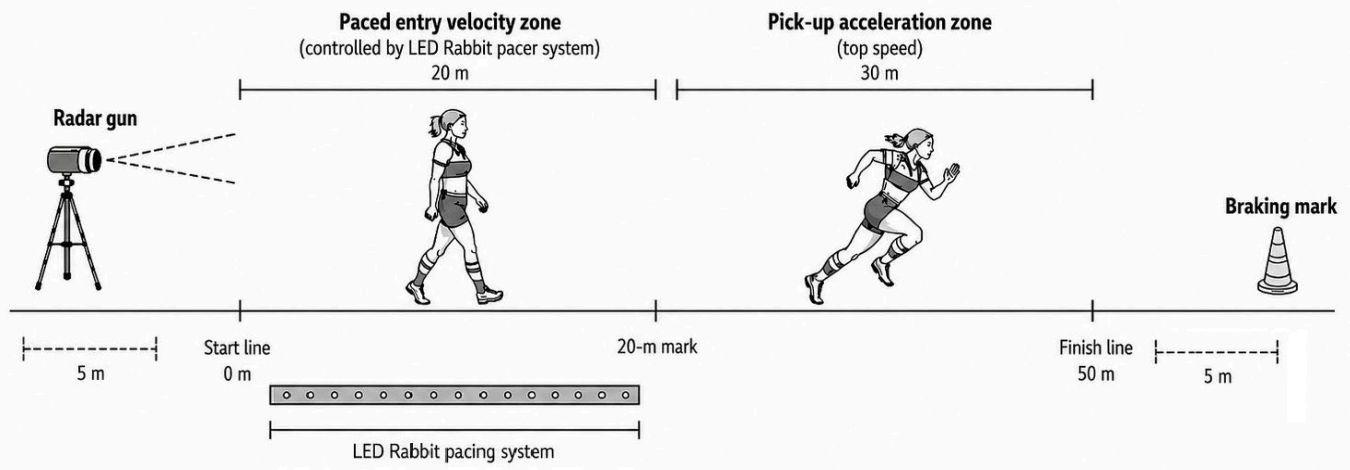


Figure 1. Schematic representation of the pick-up acceleration testing protocol. Overview of the 50 m sprint setup, comprising a 20 m paced entry zone regulated by a parallel LED pacing system, followed immediately by a 30 m pick-up zone for maximal acceleration. A radar gun was positioned 5 m behind the starting line to capture continuous velocity–time data, and an additional braking mark was placed 5 m beyond the finish line. LED: light-emitting diode.

To prevent premature deceleration across all trials, an additional set of cones was placed 5 m beyond the finish line, and players were instructed to sprint maximally through these markers. All attempts were separated by at least 5 min of passive recovery. Continuous verbal encouragement was provided to elicit maximal exertion throughout the trial. Environmental conditions were monitored at the start, middle, and end of testing using a digital anemometer (HoldPeak HP-866B-APP, HoldPeak, Zhuhai, China) and remained within the predefined criteria (>10 °C, <52% humidity, lateral wind at ~90°), with mean session values of 25.4 ± 0.7 °C for ambient temperature, 0.43 ± 0.11 $m \cdot s^{-1}$ for wind speed, and 39.8 ± 2.2% for relative humidity.

For both the static and pick-up sprint protocols, the primary kinematic variables extracted for analysis included Vmax, Distance-to-Vmax, intermediate split times (T5, T10, 20 m sprint time [T20], and 30 m sprint time [T30]) and mean acceleration across 0–5 and 0–10 m intervals (Accel0–5 and Accel0–10).

2.6. Data Analysis

Velocity–time data recorded by the radar were first processed in Stalker Stats II software (v.5.0.3.0; Applied Concepts, Dallas, TX, USA) using the manufacturer's Digital Heavy low-pass, zero-lag filter, before being exported and further processed using a custom script in R software (version 4.5.3, R Foundation for Statistical Computing, Vienna, Austria). For pick-up acceleration trials, the filtered velocity–time trace was then cropped to retain only the pick-up acceleration phase following the LED-paced entry phase. The first retained sample (i.e., radar data point) was identified using a standardized velocity–departure criterion. Specifically, the 10-point window starting at this sample was required to show: (i) a mean speed at least 0.05 $m \cdot s^{-1}$ higher than the mean speed over the final 5 m of the LED-paced entry phase; and (ii) a final speed at least 0.10 $m \cdot s^{-1}$ higher than the initial speed of the same window. This criterion was used to identify the onset of the pick-up acceleration phase while avoiding the selection of isolated radar fluctuations. The mean speed over the final 5 m of the LED-paced entry phase served as the reference for both the velocity–departure criterion and the verification of actual entry velocity, as described in the sprint-test procedures. For static-start trials, given the absence of a paced entry phase, the first retained sample simply corresponded to the onset of detectable movement from the initial dead-stop position. Across all sprint conditions, the onset of the analyzed phase

was normalized by setting the time and distance values of the first retained data point to zero (t = 0; d = 0), with subsequent time and distance values expressed relative to this point using the radar-exported values.

Kinematic variables were extracted from the processed radar data. No additional filtering or smoothing was applied in R. Vmax was defined as the highest velocity attained in the filtered trace, and Distance-to-Vmax as the relative distance corresponding to that velocity. To determine kinematic values at predefined distance markers (5, 10, 20, and 30 m), time and velocity were estimated using linear interpolation of the distance–time and distance–velocity data. Additionally, mean acceleration over the 0–5 m and 0–10 m intervals was calculated using the following equation:

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

where v_1 and v_2 represent the velocities at the beginning and end of the respective interval, and t_1 and t_2 represent the corresponding time points. For both intervals, t_1 was set to 0 at the onset of the analyzed sprint phase. For the performance analyses, the best value recorded for each variable was retained.

2.7. Statistical Analysis

All statistical analyses were performed in R (version 4.5.3; R Foundation for Statistical Computing, Vienna, Austria) using RStudio (v.2025.05.1 + 513; Posit Software, PBC, Boston, MA, USA). The R packages used for the inferential analyses were lme4, lmerTest, emmeans, car, nortest, clubSandwich, and performance. Data are presented as mean ± standard deviation (SD). Intra-session reliability was assessed using the coefficient of variation (CV) and intraclass correlation coefficients (ICC). CV was calculated by expressing the standard error of measurement, derived from the error mean square of the two repeated measurements, relative to their grand mean and as a percentage. For interpretation, CV values were classified as excellent (<5%), good (5–10%), moderate (10–15%), or poor (>15%) [24], whereas ICC was interpreted as excellent (≥0.90), good (0.75–0.89), moderate (0.50–0.74), or poor (<0.50) [25]. Overall reliability was classified by combining both indicators, with excellent reliability defined as ICC ≥ 0.90 and CV < 5%, good reliability as ICC ≥ 0.75 and CV < 10% when the criteria for excellent reliability were not met, moderate reliability when only one of these two criteria (ICC ≥ 0.75 and CV < 10%) was not met, and poor reliability when both criteria were not met (ICC < 0.75 and CV ≥ 10%) [26].

For the sprint and jump-performance analyses, model assumptions were assessed using the Anderson–Darling test for residual normality and Levene's test for homogeneity of residual variances. A separate linear mixed-effects model was fitted for each sprint-related outcome (Vmax, Distance-to-Vmax, T5, T10, T20, T30, Accel0–5, and Accel0–10). Sprint condition (static start, 1.5 $m \cdot s^{-1}$ pick-up, and 3.0 $m \cdot s^{-1}$ pick-up), playing position (backs and forwards), and their interaction were included as fixed effects, while player identity was modeled as a random intercept to account for the dependency arising from repeated measurements within players. When either residual normality or homogeneity of variance assumptions were not met, inference was based on cluster-robust CR2 standard errors clustered by player. Post hoc comparisons using estimated marginal means examined differences between sprint conditions in the whole sample and positional differences within each sprint condition. For each sprint outcome, the three pairwise comparisons between sprint conditions were adjusted as one family using the Benjamini–Hochberg procedure, whereas the three positional comparisons across sprint conditions were adjusted as a separate family, controlling the false discovery rate at q = 0.05.

Jump performance variables (CMJ, Peak power/BM, and RSI-mod) were compared between positions using Student's *t*-tests when residual normality and homogeneity of variance assumptions were met, and permutation-based independent-samples tests when residual normality was violated despite homogeneous variances. For these permutation tests, 9999 random reassignments of playing-position labels were performed, with two-sided *p*-values calculated from the resulting distribution of Student's t statistics. Effect sizes (ES) for within-player comparisons between sprint conditions were calculated as Cohen's d, using the mean of the paired differences divided by their standard deviation. For between-position comparisons, Cohen's d was calculated using the pooled standard deviation. The resulting ES were reported with 95% confidence intervals and interpreted as trivial (<0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), or very large (≥2.00) [27]. For correlation analyses, normality was assessed separately for the raw values of each variable within each sprint–jump pair, with Pearson's correlations used when both variables were normally distributed and Spearman's rank correlations used when at least one variable deviated from normality. *p*-values across all 72 sprint–jump correlations (8 sprint variables × 3 sprint conditions × 3 jump variables) were adjusted together as a single family using the Benjamini–Hochberg procedure to control the false discovery rate at q = 0.05. Correlations were interpreted as trivial (<0.10), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), or nearly perfect (≥0.90) [28]. To examine the collective and independent associations of the CMJ-derived variables with sprint performance, additional mixed-effects models were fitted for each sprint outcome, including sprint condition, playing position, and their interaction as fixed effects and player identity as a random intercept, before simultaneously adding CMJ height, Peak power/BM, and RSI-mod. The collective contribution of the CMJ-derived variables was quantified as the change in marginal R^2 (ΔR^2), whereas their independent associations were expressed as standardized regression coefficients (β) with 95% confidence intervals. The significance of the CMJ block was assessed using likelihood-ratio tests comparing the base and full models. When residual assumptions were violated, cluster-robust joint Wald tests (CR2; HTZ) were used instead. Multicollinearity was assessed using variance inflation factors (VIF), with values ≥5 considered indicative of elevated multicollinearity and ≥10 of severe multicollinearity. The same residual assumption checks and CR2 procedure described above were applied, and *p*-values were Benjamini–Hochberg-adjusted separately across the eight CMJ-block tests and 24 individual predictor tests. The level of statistical significance was set at $\alpha = 0.05$.

3. Results

3.1. Assumptions and Reliability

For the sprint linear mixed-effects models, residual normality and homogeneity of variance were met for most outcomes (i.e., T5, T10, T20, T30, Accel0–5, and Accel0–10; $p > 0.050$). Vmax did not meet the assumption of residual normality ($p = 0.044$), nor did Distance-to-Vmax for homogeneity of variance ($p = 0.023$); therefore, both were analyzed using cluster-robust CR2 standard errors. For jump-performance comparisons, assumptions were met for Peak power/BM and RSI-mod ($p > 0.050$), whereas the residuals for CMJ did not meet the assumption of normality ($p = 0.033$); therefore, CMJ was analyzed using a permutation-based independent-samples test. For the correlation analyses, normality was assessed on the raw values for each sprint–jump pair. CMJ, Peak power/BM, and all sprint variables in each sprint condition were normally distributed, except for Accel0–5 in the 3.0 $m \cdot s^{-1}$ pick-up condition, which failed to meet the assumption of normality ($p = 0.014$), as did RSI-mod ($p = 0.015$). Reliability statistics are detailed in Table 1. Excellent overall reliability (i.e., ICC ≥ 0.90 and CV < 5%) [26] was observed for all sprint variables (i.e., Vmax, Distance-to-Vmax, T5, T10, T20, T30, Accel0–5, and Accel0–10) across the

static-start, pick-up 1.5 m·s^{-1}, and pick-up 3.0 m·s^{-1} conditions (CV = 0.56 to 4.29%; ICC = 0.90 to 1.00). Furthermore, CMJ-derived performance variables also demonstrated excellent overall reliability, specifically for CMJ height (CV = 1.40%; ICC = 1.00), Peak power/BM (CV = 2.71%; ICC = 0.98), and RSI-mod (CV = 4.95%; ICC = 0.98).

Table 1. Reliability of sprint variables across static-start and pick-up acceleration conditions.

Variable	Static-Start		Pick-Up 1.5 m·s^{-1}		Pick-Up 3.0 m·s^{-1}		Reliability Rating
	CV (%)	ICC (95% CI)	CV (%)	ICC (95% CI)	CV (%)	ICC (95% CI)	
Vmax (m·s^{-1})	0.86	0.99 (0.99–1.00)	0.63	1.00 (0.99–1.00)	1.20	0.99 (0.98–0.99)	Excellent
Distance-to-Vmax (m)	2.32	0.99 (0.98–0.99)	2.79	0.98 (0.97–0.99)	4.22	0.96 (0.93–0.98)	Excellent
T5 (s)	1.30	0.98 (0.97–0.99)	2.53	0.93 (0.87–0.96)	1.76	0.90 (0.81–0.95)	Excellent
T10 (s)	0.89	0.99 (0.98–1.00)	1.77	0.96 (0.93–0.98)	1.20	0.96 (0.93–0.98)	Excellent
T20 (s)	0.59	1.00 (0.99–1.00)	1.15	0.98 (0.97–0.99)	0.85	0.99 (0.98–0.99)	Excellent
T30 (s)	0.56	1.00 (0.99–1.00)	0.90	0.99 (0.98–1.00)	0.71	0.99 (0.99–1.00)	Excellent
Accel0–5 (m·s^{-2})	2.42	0.98 (0.97–0.99)	3.84	0.97 (0.94–0.98)	4.29	0.96 (0.93–0.98)	Excellent
Accel0–10 (m·s^{-2})	1.65	0.99 (0.98–1.00)	2.53	0.98 (0.97–0.99)	3.66	0.97 (0.94–0.98)	Excellent

Note. Data are presented as coefficient of variation (CV) and intraclass correlation coefficient (ICC) with 95% confidence intervals (95% CI). Overall reliability rating indicates the classification achieved by each variable in each of the three sprint conditions, based on the combined ICC and CV criteria. Vmax: maximal velocity; Distance-to-Vmax: distance at which maximal velocity is reached; T5, T10, T20 and T30: time to reach 5, 10, 20 and 30 m, respectively; Accel0–5 and Accel0–10: average acceleration over the 0–5 m and 0–10 m intervals, respectively. Static start: sprint initiated from a stationary position; Pick-up 1.5 m·s^{-1} and Pick-up 3.0 m·s^{-1}: sprint initiated after reaching an entry velocity of 1.5 and 3.0 m·s^{-1}, respectively.

3.2. Effects of Starting Condition

Global linear mixed-effects model results showed a significant main effect of sprint condition for Distance-to-Vmax, T5, T10, T20, T30, Accel0–5, and Accel0–10 (all $p < 0.001$), but not for Vmax ($p = 0.214$). A significant main effect of playing position was observed for all sprint outcomes (Vmax: $p = 0.003$; Distance-to-Vmax: $p = 0.003$; T5: $p = 0.021$; T10: $p = 0.005$; T20: $p = 0.002$; T30: $p = 0.002$; Accel0–5: $p = 0.011$; Accel0–10: $p = 0.003$). The sprint condition × playing position interaction was significant only for Accel0–10 ($p = 0.009$), while no significant interactions were observed for Vmax, Distance-to-Vmax, T5, T10, T20, T30, or Accel0–5 ($p = 0.083$–0.373).

Table 2 presents the descriptive statistics and pairwise comparisons for sprint metrics across the three starting conditions. Specifically, Distance-to-Vmax and all split times were significantly shorter during both pick-up sprints compared to the static start, reaching their lowest values at 3.0 m·s^{-1} ($p \leq 0.042$; ES: small to very large). Additionally, Accel0–5 and Accel0–10 were significantly higher during the static start and decreased as entry velocities increased ($p < 0.001$; ES: large to very large). Finally, no significant differences were found for Vmax among the starting conditions ($p \geq 0.230$; ES: trivial to small).

Table 2. Descriptive statistics and pairwise comparisons of sprint variables across static-start and pick-up accelerations.

Variable	Static-Start (*n* = 38)	Pick-Up 1.5 m·s^{-1} (*n* = 38)	Pick-Up 3.0 m·s^{-1} (*n* = 38)	Static-Start vs. Pick-Up 1.5 m·s^{-1}	Static-start vs. Pick-Up 3.0 m·s^{-1}	Pick-Up 1.5 m·s^{-1} vs. Pick-Up 3.0 m·s^{-1}
Vmax (m·s^{-1})	6.94 ± 0.56	6.95 ± 0.56	6.92 ± 0.56	$p = 0.845$; ES = −0.03 (−0.38 to 0.27)	$p = 0.285$; ES = 0.22 (−0.11 to 0.51)	$p = 0.230$; ES = 0.29 (−0.03 to 0.68)
Distance-to-Vmax (m)	22.70 ± 3.66	18.67 ± 2.91	15.74 ± 2.58	**$p < 0.001$; ES = 2.31 (1.91 to 2.98)**	**$p < 0.001$; ES = 2.78 (2.32 to 3.63)**	**$p < 0.001$; ES = 1.45 (1.16 to 1.93)**
T5 (s)	1.52 ± 0.11	1.46 ± 0.10	1.15 ± 0.05	**$p < 0.001$; ES = 0.58 (0.28 to 0.95)**	**$p < 0.001$; ES = 3.49 (2.91 to 4.68)**	**$p < 0.001$; ES = 3.68 (3.11 to 4.64)**

Table 2. *Cont.*

Variable	Static-Start (n = 38)	Pick-Up 1.5 m·s^{-1} (n = 38)	Pick-Up 3.0 m·s^{-1} (n = 38)	Static-Start vs. Pick-Up 1.5 m·s^{-1}	Static-start vs. Pick-Up 3.0 m·s^{-1}	Pick-Up 1.5 m·s^{-1} vs. Pick-Up 3.0 m·s^{-1}
T10 (s)	2.39 ± 0.16	2.36 ± 0.15	2.02 ± 0.09	**p = 0.042; ES = 0.33 (0.03 to 0.68)**	**p < 0.001; ES = 3.00 (2.48 to 3.95)**	**p < 0.001; ES = 3.41 (2.85 to 4.34)**
T20 (s)	3.94 ± 0.26	3.90 ± 0.25	3.55 ± 0.19	**p = 0.021; ES = 0.37 (0.06 to 0.71)**	**p < 0.001; ES = 3.01 (2.47 to 4.05)**	**p < 0.001; ES = 3.18 (2.69 to 4.03)**
T30 (s)	5.43 ± 0.37	5.38 ± 0.37	5.06 ± 0.31	**p = 0.018; ES = 0.38 (0.08 to 0.71)**	**p < 0.001; ES = 2.79 (2.31 to 3.71)**	**p < 0.001; ES = 2.69 (2.27 to 3.39)**
Accel0–5 (m·s^{-2})	3.49 ± 0.47	2.43 ± 0.38	2.00 ± 0.31	**p < 0.001; ES = 3.31 (2.71 to 4.49)**	**p < 0.001; ES = 3.99 (3.32 to 5.19)**	**p < 0.001; ES = 1.62 (1.30 to 2.13)**
Accel0–10 (m·s^{-2})	2.58 ± 0.34	1.94 ± 0.28	1.57 ± 0.23	**p < 0.001; ES = 4.00 (3.45 to 5.02)**	**p < 0.001; ES = 5.14 (4.22 to 6.99)**	**p < 0.001; ES = 2.83 (2.37 to 3.59)**

Note. Data are presented as mean ± standard deviation for the whole sample. Pairwise comparisons between sprint conditions were performed using the whole sample and are presented as p-values adjusted using the Benjamini–Hochberg procedure and effect sizes (ES) with 95% confidence intervals. Significant differences are highlighted in bold. Vmax: maximal velocity; Distance-to-Vmax: distance at which maximal velocity is reached; T5, T10, T20 and T30: time recorded at 5, 10, 20 and 30 m, respectively; Accel0–5 and Accel0–10: average acceleration over the 0–5 m and 0–10 m intervals, respectively. Static start: sprint initiated from a stationary position; Pick-up 1.5 m·s^{-1} and Pick-up 3.0 m·s^{-1}: sprint initiated after reaching entry velocities of 1.5 and 3.0 m·s^{-1}, respectively.

3.3. Positional Differences

Table 3 presents the comparisons between playing positions for the sprint variables. Specifically, across all starting conditions, backs recorded significantly higher Vmax, Distance-to-Vmax, and Accel0–10, alongside lower T20 and T30 values compared to forwards (p < 0.05; ES: moderate). During the static start, backs exhibited significantly lower T5 and greater Accel0–5 compared to forwards (p < 0.05; ES: moderate). Additionally, T10 was significantly lower for backs across both the static and the 1.5 m·s^{-1} pick-up conditions (p < 0.01; ES: moderate). Regarding the vertical jump comparisons (Figure 2), backs demonstrated significantly greater CMJ height, Peak power/BM, and RSI-mod compared to forwards (p < 0.05; ES: moderate).

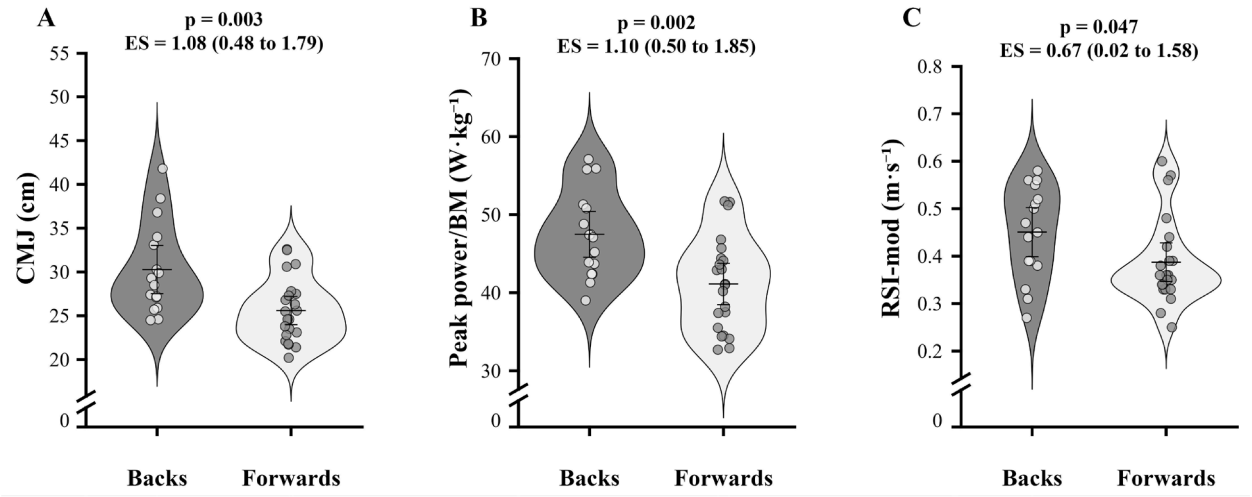


Figure 2. Comparison of jump variables between backs and forwards. (**A**) CMJ height; (**B**) Peak power/BM; and (**C**) RSI-mod. Violin plots illustrate the data density distribution, with internal box plots representing the median and interquartile range, alongside individual data points. Exact p-values and effect sizes (ES) with 95% confidence intervals are shown above each plot. Significance was set at p < 0.05. CMJ: countermovement jump height; Peak power/BM: relative peak power; RSI-mod: reactive strength index-modified; B: backs; F: forwards.

Table 3. Positional differences in sprint variables across static-start and pick-up acceleration conditions.

Variable	Static-Start			Pick-Up 1.5 m·s^{-1}			Pick-Up 3.0 m·s^{-1}		
	B (*n* = 15)	**F (*n* = 23)**	**Comparison**	**B (*n* = 15)**	**F (*n* = 23)**	**Comparison**	**B (*n* = 15)**	**F (*n* = 23)**	**Comparison**
Vmax (m·s^{-1})	7.23 ± 0.40	6.74 ± 0.58	**p = 0.002 ES = 0.96 (0.37 to 1.73)**	7.25 ± 0.38	6.72 ± 0.57	**p = 0.002 ES = 1.05 (0.48 to 1.86)**	7.21 ± 0.42	6.71 ± 0.57	**p = 0.002 ES = 0.97 (0.38 to 1.78)**
Distance-to-Vmax (m)	24.30 ± 2.31	21.54 ± 4.06	**p = 0.012 ES = 0.80 (0.24 to 1.44)**	20.40 ± 1.77	17.41 ± 2.95	**p < 0.001 ES = 1.18 (0.63 to 1.92)**	16.67 ± 2.12	15.07 ± 2.72	**p = 0.042 ES = 0.64 (0.04 to 1.37)**
T5 (s)	1.48 ± 0.12	1.55 ± 0.10	**p = 0.042 ES = −0.68 (−1.61 to −0.00)**	1.43 ± 0.10	1.49 ± 0.09	p = 0.089 ES = −0.55 (−1.37 to 0.07)	1.13 ± 0.04	1.16 ± 0.04	p = 0.329 ES = −0.63 (−1.40 to 0.00)
T10 (s)	2.31 ± 0.16	2.45 ± 0.14	**p = 0.006 ES = −0.92 (−1.84 to −0.25)**	2.29 ± 0.14	2.40 ± 0.15	**p = 0.016 ES = −0.77 (−1.54 to −0.17)**	1.98 ± 0.08	2.05 ± 0.09	p = 0.102 ES = −0.84 (−1.61 to −0.25)
T20 (s)	3.80 ± 0.22	4.04 ± 0.24	**p = 0.003 ES = −1.03 (−1.85 to −0.40)**	3.77 ± 0.20	3.99 ± 0.25	**p = 0.004 ES = −0.97 (−1.75 to −0.39)**	3.45 ± 0.14	3.62 ± 0.19	**p = 0.018 ES = −1.00 (−1.76 to −0.43)**
T30 (s)	5.23 ± 0.28	5.58 ± 0.37	**p = 0.003 ES = −1.03 (−1.78 to −0.43)**	5.18 ± 0.26	5.53 ± 0.38	**p = 0.003 ES = −1.03 (−1.81 to −0.48)**	4.89 ± 0.23	5.17 ± 0.31	**p = 0.010 ES = −1.00 (−1.77 to −0.44)**
Accel0–5 (m·s^{-2})	3.73 ± 0.48	3.32 ± 0.39	**p = 0.004 ES = 0.94 (0.26 to 1.83)**	2.57 ± 0.37	2.33 ± 0.36	p = 0.073 ES = 0.67 (0.06 to 1.40)	2.11 ± 0.28	1.93 ± 0.32	p = 0.139 ES = 0.60 (0.00 to 1.38)
Accel0–10 (m·s^{-2})	2.77 ± 0.31	2.44 ± 0.30	**p < 0.001 ES = 1.11 (0.48 to 1.91)**	2.08 ± 0.25	1.85 ± 0.26	**p = 0.013 ES = 0.92 (0.31 to 1.73)**	1.67 ± 0.18	1.49 ± 0.24	**p = 0.046 ES = 0.80 (0.19 to 1.59)**

Note. Data are presented as mean ± standard deviation. Comparisons between Backs and Forwards are presented as Benjamini–Hochberg-adjusted p-values and effect sizes (ES) with 95% confidence intervals. Significant between-position differences are highlighted in bold. ES represents Cohen's d for independent-group comparisons. B: Backs; F: Forwards; Vmax: maximal velocity; Distance-to-Vmax: distance at which maximal velocity is reached; T5, T10, T20 and T30: time recorded at 5, 10, 20 and 30 m, respectively; Accel0–5 and Accel0–10: average acceleration over the 0–5 m and 0–10 m intervals, respectively. Static start: sprint initiated from a stationary position; Pick-up 1.5 m·s^{-1} and Pick-up 3.0 m·s^{-1}: sprint initiated after reaching entry velocities of 1.5 and 3.0 m·s^{-1}, respectively.

3.4. Sprint–Jump Associations

Correlation coefficients between sprint variables and CMJ-derived performance variables across all starting conditions are detailed in Table 4. Specifically, all jump metrics (i.e., CMJ, Peak power/BM, and RSI-mod) demonstrated significant, moderate to very large positive correlations with Vmax, Distance-to-Vmax, Accel0–5, and Accel0–10 regardless of the starting protocol ($p \leq 0.007$; r/rho = 0.44 to 0.85). Conversely, the jump metrics (i.e., CMJ, Peak power/BM, and RSI-mod) exhibited significant, moderate to very large negative associations with all split times (i.e., T5, T10, T20, and T30) across the static and pick-up acceleration conditions ($p \leq 0.046$; r/rho = −0.33 to −0.84).

Table 4. Correlations between sprint variables and jump performance variables across static-start and pick-up acceleration conditions.

Sprint Variable	CMJ			Peak Power/BM			RSI-mod		
	Static-Start	**Pick-Up 1.5 m·s^{-1}**	**Pick-Up 3.0 m·s^{-1}**	**Static-Start**	**Pick-Up 1.5 m·s^{-1}**	**Pick-Up 3.0 m·s^{-1}**	**Static-Start**	**Pick-Up 1.5 m·s^{-1}**	**Pick-Up 3.0 m·s^{-1}**
Vmax	**r = 0.84** $p < 0.001$	**r = 0.84** $p < 0.001$	**r = 0.84** $p < 0.001$	**r = 0.84** $p < 0.001$	**r = 0.85** $p < 0.001$	**r = 0.84** $p < 0.001$	**rho = 0.81** $p < 0.001$	**rho = 0.78** $p < 0.001$	**rho = 0.74** $p < 0.001$
Distance-to-Vmax	**r = 0.61** $p < 0.001$	**r = 0.60** $p < 0.001$	**r = 0.62** $p < 0.001$	**r = 0.61** $p < 0.001$	**r = 0.60** $p < 0.001$	**r = 0.61** $p < 0.001$	**rho = 0.60** $p < 0.001$	**rho = 0.50** $p = 0.001$	**rho = 0.59** $p < 0.001$
T5	**r = −0.67** $p < 0.001$	**r = −0.58** $p < 0.001$	**r = −0.44** $p = 0.006$	**r = −0.61** $p < 0.001$	**r = −0.55** $p < 0.001$	**r = −0.46** $p = 0.005$	**rho = −0.59** $p < 0.001$	**rho = −0.55** $p < 0.001$	**rho = −0.33** $p = 0.046$
T10	**r = −0.76** $p < 0.001$	**r = −0.72** $p < 0.001$	**r = −0.69** $p < 0.001$	**r = −0.71** $p < 0.001$	**r = −0.70** $p < 0.001$	**r = −0.70** $p < 0.001$	**rho = −0.66** $p < 0.001$	**rho = −0.66** $p < 0.001$	**rho = −0.56** $p < 0.001$
T20	**r = −0.80** $p < 0.001$	**r = −0.80** $p < 0.001$	**r = −0.81** $p < 0.001$	**r = −0.79** $p < 0.001$	**r = −0.80** $p < 0.001$	**r = −0.83** $p < 0.001$	**rho = −0.72** $p < 0.001$	**rho = −0.75** $p < 0.001$	**rho = −0.72** $p < 0.001$
T30	**r = −0.82** $p < 0.001$	**r = −0.82** $p < 0.001$	**r = −0.82** $p < 0.001$	**r = −0.81** $p < 0.001$	**r = −0.82** $p < 0.001$	**r = −0.84** $p < 0.001$	**rho = −0.75** $p < 0.001$	**rho = −0.77** $p < 0.001$	**rho = −0.74** $p < 0.001$
Accel0–5	**r = 0.78** $p < 0.001$	**r = 0.77** $p < 0.001$	**rho = 0.65** $p < 0.001$	**r = 0.73** $p < 0.001$	**r = 0.72** $p < 0.001$	**rho = 0.60** $p < 0.001$	**rho = 0.65** $p < 0.001$	**rho = 0.66** $p < 0.001$	**rho = 0.44** $p = 0.007$
Accel0–10	**r = 0.83** $p < 0.001$	**r = 0.82** $p < 0.001$	**r = 0.79** $p < 0.001$	**r = 0.79** $p < 0.001$	**r = 0.81** $p < 0.001$	**r = 0.79** $p < 0.001$	**rho = 0.72** $p < 0.001$	**rho = 0.75** $p < 0.001$	**rho = 0.68** $p < 0.001$

Note. Data are presented as correlation coefficients and Benjamini–Hochberg-adjusted *p*-values. Statistically significant correlations ($p < 0.05$) are indicated in bold. Pearson's r was used when normality assumptions were met, and Spearman's Rho when normality assumptions were not met. CMJ: countermovement jump height; Peak power/BM: peak power normalized to body mass; RSI-mod: modified reactive strength index; Vmax: maximal velocity; Distance-to-Vmax: distance at which maximal velocity is reached; Accel0–5 and Accel0–10: average acceleration over the 0–5 m and 0–10 m intervals, respectively. Static start: sprint initiated from a stationary position; Pick-up 1.5 m·s^{-1} and Pick-up 3.0 m·s^{-1}: sprint initiated after reaching entry velocities of 1.5 and 3.0 m·s^{-1}, respectively.

In the multivariable analysis, the CMJ block accounted for significant additional variance across all sprint outcomes ($\Delta R^2 = 0.055$–0.547; $p \leq 0.027$; Table 5). However, none of the individual CMJ-derived variables retained a significant independent association with sprint performance after Benjamini–Hochberg adjustment ($p \geq 0.140$). VIF values ranged from 4.48 to 8.84, with two of the three predictors exceeding the threshold of 5, indicating considerable shared variance among the CMJ-derived predictors.

Table 5. Multivariable associations between CMJ-derived performance variables and sprint outcomes.

Sprint Outcome	CMJ Block	CMJ Height	Peak Power/BM	RSI-Mod
Vmax	ΔR^2 = 0.547; ***p* < 0.001**	β = 0.34 [−0.06 to 0.73]; *p* = 0.290	β = 0.36 [−0.04 to 0.75]; *p* = 0.290	β = 0.18 [−0.20 to 0.57]; *p* = 0.598
Distance-to-Vmax	ΔR^2 = 0.135; ***p* = 0.027**	β = 0.15 [−0.22 to 0.52]; *p* = 0.606	β = 0.04 [−0.48 to 0.56]; *p* = 0.912	β = 0.24 [−0.10 to 0.58]; *p* = 0.394
T5	ΔR^2 = 0.055; ***p* < 0.001**	β = −0.25 [−0.48 to −0.02]; *p* = 0.216	β = 0.01 [−0.24 to 0.27]; *p* = 0.925	β = −0.04 [−0.22 to 0.14]; *p* = 0.786
T10	ΔR^2 = 0.144; ***p* < 0.001**	β = −0.31 [−0.60 to −0.02]; *p* = 0.216	β = −0.09 [−0.41 to 0.22]; *p* = 0.701	β = −0.04 [−0.27 to 0.18]; *p* = 0.786
T20	ΔR^2 = 0.294; ***p* < 0.001**	β = −0.31 [−0.66 to 0.04]; *p* = 0.290	β = −0.24 [−0.63 to 0.15]; *p* = 0.470	β = −0.10 [−0.37 to 0.18]; *p* = 0.679
T30	ΔR^2 = 0.402; ***p* < 0.001**	β = −0.30 [−0.70 to 0.10]; *p* = 0.394	β = −0.31 [−0.75 to 0.13]; *p* = 0.394	β = −0.14 [−0.46 to 0.17]; *p* = 0.606
Accel0–5	ΔR^2 = 0.110; ***p* < 0.001**	β = 0.34 [0.10 to 0.58]; *p* = 0.140	β = 0.10 [−0.16 to 0.36]; *p* = 0.677	β = −0.05 [−0.24 to 0.13]; *p* = 0.701
Accel0–10	ΔR^2 = 0.149; ***p* < 0.001**	β = 0.29 [0.05 to 0.53]; *p* = 0.216	β = 0.14 [−0.13 to 0.40]; *p* = 0.598	β = 0.03 [−0.15 to 0.22]; *p* = 0.786

Note. The CMJ block comprised CMJ height, Peak power/BM, and RSI-mod. ΔR^2 represents the change in marginal R^2 after adding the CMJ block to the base model accounting for sprint condition and playing position. β = standardized regression coefficient; values in brackets are unadjusted 95% confidence intervals. All *p*-values are Benjamini–Hochberg-adjusted, with statistically significant values shown in bold. CMJ: countermovement jump; Peak power/BM: peak power normalized to body mass; RSI-mod: modified reactive strength index; Vmax: maximal velocity; Distance-to-Vmax: distance at which maximal velocity is reached; T5, T10, T20, and T30: split times over 5, 10, 20, and 30 m, respectively; Accel0–5 and Accel0–10: average acceleration over the 0–5 m and 0–10 m intervals, respectively.

4. Discussion

The present study compared sprint performance across static-start and pick-up acceleration conditions at 1.5 and 3.0 $m \cdot s^{-1}$ in female rugby union players, considering playing-position differences and associations between CMJ-derived performance variables and sprint performance, including their combined and independent contributions. Intra-session reliability of the radar-derived sprint variables was also assessed as part of the methodological evaluation of the protocol. The main findings were the following: first, the pick-up acceleration protocol demonstrated excellent intra-session reliability across all sprint variables and entry conditions (Table 1); second, increasing entry velocity produced a clear main effect on split times, Distance-to-Vmax, and interval-based acceleration, while Vmax remained unchanged (Table 2); third, playing position showed a main effect across sprint outcomes, with backs generally outperforming forwards (Table 3); and fourth, the sprint condition × position interaction was significant only for Accel0–10, indicating a condition-dependent positional difference for this outcome. Finally, CMJ-derived performance variables (i.e., CMJ, Peak power/BM, and RSI-mod) showed significant moderate to very large bivariate correlations with all sprint metrics within each sprint condition (Table 4). However, when these variables were considered simultaneously, the CMJ block (i.e., CMJ height, Peak power/BM, and RSI-mod taken together) explained significant additional variance across all sprint outcomes, whereas no individual variable retained a significant independent association after Benjamini–Hochberg adjustment (Table 5).

Intra-session reliability was excellent for all radar-derived sprint variables across the static-start, 1.5 $m \cdot s^{-1}$ and 3.0 $m \cdot s^{-1}$ pick-up acceleration conditions (Table 1). Due to the methodological challenge of standardizing entry velocity, few studies have directly examined pick-up acceleration, and available evidence has been derived from male cohorts using different pacing and measurement approaches. This includes local position measurement with an auditory-paced runner in junior soccer players [29] and a motorized linear position

encoder with LED-paced entry velocities in heterogeneous team-sport athletes [7,9]. Previous reliability evidence is also limited: Sonderegger et al. [29] reported one-week test–retest CVs only for maximal acceleration (amax) across standing, trotting, jogging and running starts (target entry velocities: 0, ~1.7, ~3.0 and ~4.2 $m \cdot s^{-1}$; CV = 5.4–10.9%), whereas Pryer et al. [7] reported between-session CVs for amax, Vmax, T5, T10 and T20 using LED-paced relative entry velocities (20%, 40% and 60% of Vmax; mean entry velocities: 1.87, 4.43 and 6.71 $m \cdot s^{-1}$), with all performance-variable CVs $\leq$ 4.75%. However, between-session reliability has not yet been established for the specific radar-based protocol used in the present study. Therefore, although the present findings support its within-session repeatability, its suitability for longitudinal monitoring remains to be established. Nevertheless, the present findings provide important initial evidence of the intra-session reliability of a radar gun combined with LED-paced entry velocities for assessing pick-up acceleration performance in a sport- and sex-specific sample of female rugby union players. Accordingly, these findings should be interpreted as evidence of intra-session reliability rather than protocol validity. Importantly, this study also showed excellent reliability for Distance-to-Vmax and mean acceleration over the 0–5 m and 0–10 m intervals, variables not previously examined in this context. Unlike amax, which represents the highest acceleration value reached at a single point of the sprint, mean acceleration over a defined distance interval reflects the change in velocity achieved over that entire section. This approach has previously been used to characterize short-distance acceleration capacity in team-sport athletes [30].

With respect to the comparison between sprint types (i.e., static-start, 1.5 $m \cdot s^{-1}$ and 3.0 $m \cdot s^{-1}$ pick-up acceleration), increasing entry velocity significantly and progressively reduced split times (i.e., T5, T10, T20 and T30) and Distance-to-Vmax, with the shortest values observed in the 3.0 $m \cdot s^{-1}$ condition (Table 2). Similarly, Accel0–5 and Accel0–10 were significantly greater during the static-start sprint and decreased as entry velocity increased, whereas Vmax remained unchanged across sprint types. Taken together, these results suggest that entry velocity mainly modifies the acceleration demands during the pick-up acceleration phase, rather than the maximal velocity ultimately attained. From a mechanical perspective, this response is consistent with the linear force–velocity relationship of sprinting, whereby the capacity to produce net horizontal force decreases as running velocity increases [31]. Thus, when athletes initiate the maximal acceleration phase from a higher entry velocity, less capacity remains to further increase running speed, which may explain the lower Accel0–5 and Accel0–10 values despite the shorter split times and Distance-to-Vmax. This interpretation is consistent with previous work showing that acceleration capacity decreases as entry velocity increases during pick-up acceleration [7,29]. Notably, these interval-based acceleration variables have, to our knowledge, not previously been examined in this context. Importantly, shorter split times in the pick-up conditions should be interpreted in the context of higher entry velocities, rather than as evidence of greater maximal-speed capacity. In practical terms, pick-up sprint protocols may allow practitioners to assess acceleration from entry velocities representative of rugby match play.

Beyond these changes in acceleration demand, the present results support the notion that pick-up acceleration should not be interpreted as a simple extension of static-start acceleration, but rather as a distinct sprinting condition in which athletes must generate further acceleration from an already moving state [7,9]. This distinction is reinforced by previous evidence showing that static-start amax had only a moderate association with 1.5 $m \cdot s^{-1}$ pick-up amax ($p < 0.001$; r = 0.63) and a low, non-significant association with 3.0 $m \cdot s^{-1}$ pick-up amax ($p = 0.06$; r = 0.34) [9]. The novel inclusion of Distance-to-Vmax in the present study provides a practical expression of these sprint-type differences, as values decreased from 22.70 $\pm$ 3.66 m in the static-start sprint to 18.67 $\pm$ 2.91 m and 15.74 $\pm$ 2.58 m in the 1.5 $m \cdot s^{-1}$ and 3.0 $m \cdot s^{-1}$ pick-up conditions, respectively (Table 2). Consequently,

evaluation and training distances may need to be adjusted according to the sprint condition, with drills initiated at higher entry velocities generally requiring shorter distances to reach Vmax than those initiated at lower velocities or from a static start.

Although superior sprint performance in backs compared with forwards has been widely reported in rugby, particularly for Vmax and longer sprint distances [1,5,12,32], the present findings indicate that backs generally maintained superior sprint performance across conditions. In the static-start sprint, backs outperformed forwards across all sprint variables analyzed (Table 3). During pick-up acceleration, however, some of the between-position comparisons for the earliest sprint outcomes (i.e., T5, T10, and Accel0–5) did not reach statistical significance after Benjamini–Hochberg adjustment. Specifically, T5 and Accel0–5 were not significantly different between positions at 1.5 $m \cdot s^{-1}$, while T5, T10, and Accel0–5 were not significantly different at 3.0 $m \cdot s^{-1}$. Significant positional differences were still observed for Vmax, Distance-to-Vmax, T20, T30, and Accel0–10 in both pick-up conditions (Table 3). Importantly, the ES for T5 ranged from small to moderate, whereas those for T10 remained moderate across conditions, with little variation in magnitude (Table 3). Therefore, the absence of statistical significance in some pick-up comparisons should not be interpreted as evidence that backs and forwards performed similarly.

However, the sprint condition × position interaction was not significant for T5 or T10 and reached significance only for Accel0–10. Thus, the strongest statistical evidence for a condition-dependent change in the positional difference was observed for Accel0–10. One possible explanation is that starting from walking or jogging speeds may leave less scope for additional acceleration over the first 5–10 m, potentially influencing how positional differences are expressed [7,29]. Additionally, the unequal group sizes (backs, n = 15; forwards, n = 23) may have reduced the sensitivity of the post hoc comparisons to detect positional differences in these short splits. These findings are particularly relevant because rugby acceleration demands are rarely limited to static-start actions [7,11]. Indeed, elite rugby data indicate that 53.4 ± 5.5% of accelerations begin from low-velocity movement (0–1.9 $m \cdot s^{-1}$), with a further 31.8 ± 5.0% initiated from jogging velocities (>1.9 $m \cdot s^{-1}$) [7,11]. Consequently, static-start and pick-up acceleration tests may provide complementary information when profiling positional sprint performance in rugby. From an applied perspective, these results suggest that training programs should not focus exclusively on static-start acceleration but should also include pick-up acceleration drills initiated from walking and jogging velocities. This may help practitioners develop sprint qualities that are more specific to common rugby movement scenarios while addressing the positional demands of both backs and forwards.

Regarding jump performance, our results indicated that backs exhibited significantly higher CMJ, Peak power/BM, and RSI-mod values compared to forwards ($p \leq 0.047$; ES = 0.67 to 1.10) (Figure 2), which aligns with previous findings in both elite female rugby union [33] and rugby league [5] players. These positional differences may partly reflect the distinct anthropometric characteristics of each playing position, as backs generally exhibit lower body mass, whereas the greater body mass typically observed in forwards may increase the mechanical demands of vertical jumping and contribute to lower relative lower-limb power performance [12,33]. Furthermore, our findings revealed that regardless of the starting condition (i.e., static or pick-up), all CMJ-derived performance variables demonstrated significant, moderate to very large bivariate correlations with all sprint performance metrics ($p \leq 0.046$; r/rho = 0.33 to 0.85) (Table 4). This generalized association agrees with recent evidence in female rugby union players showing significant relationships between CMJ height and Vmax in both backs and forwards ($p < 0.001$; r = 0.72 and 0.77, respectively) [1]. In this context, the positive associations with Distance-to-Vmax should be interpreted cautiously, as a greater Distance-to-Vmax is not necessarily

favorable and may partly reflect the higher Vmax attained by more powerful players. Therefore, Distance-to-Vmax should be interpreted alongside Vmax rather than as an isolated performance indicator.

Mechanically, although sprint acceleration is highly dependent on the ability to apply force horizontally, continuing to accelerate from an already moving state may also require high levels of vertical impulse [8], closely mirroring the vertical force application of the CMJ. Similarly, the need to apply high mass-specific forces during these transitions [10] may partly explain the associations between Peak power/BM and pick-up acceleration performance (Table 4). RSI-mod combines jump height and time to take-off and therefore reflects the ability to achieve greater CMJ performance relative to the time required to complete the movement [16]. Given that pick-up acceleration requires athletes to rapidly increase propulsive output while already moving at a pre-existing velocity [8], a higher RSI-mod may reflect a greater capacity to express lower-limb performance within a limited time window. This interpretation is consistent with the observed associations between RSI-mod and pick-up acceleration performance.

The multivariable analysis, however, provides an important qualification to these correlational findings. When CMJ height, Peak power/BM, and RSI-mod were considered simultaneously, the CMJ block explained significant additional variance across all sprint outcomes (ΔR^2 = 0.055–0.547), but none of the individual variables retained a significant independent association after Benjamini–Hochberg adjustment (Table 5). Together with VIF values ranging from 4.48 to 8.84, this suggests that a substantial proportion of the sprint-related information captured by these CMJ-derived variables is shared rather than unique to any one metric. At this degree of multicollinearity, the precision of individual coefficient estimates is reduced, limiting the statistical power to detect independent associations even when such associations may exist. Therefore, the strong bivariate correlations should not be interpreted as evidence that each variable provides distinct information about sprint performance. From an applied perspective, these findings do not support prioritizing one CMJ-derived metric as a uniquely informative marker of sprint performance across the tested conditions. Instead, the choice of CMJ metric should be guided by the neuromuscular characteristic of interest, while recognizing that their associations with sprint performance may substantially overlap.

4.1. Practical Applications

The present findings suggest that practitioners can use LED-paced entry velocities of 1.5 and 3.0 m·s^{-1} to assess and prescribe pick-up acceleration from walking and jogging speeds in female rugby union players. Based on the observed Distance-to-Vmax values, post-pick-up distances of approximately 25 m at 1.5 m·s^{-1} and 20 m at 3.0 m·s^{-1} may serve as practical guidelines for assessing acceleration up to Vmax in senior female rugby union players. However, these distances should be considered indicative, as Distance-to-Vmax may vary across populations (e.g., according to sport and competitive level) [1]. Practitioners are therefore encouraged to assess Distance-to-Vmax within their teams to establish a common testing distance that allows the velocity–time profile up to Vmax to be captured across players. Coaches should also complement static-start sprint testing with pick-up acceleration tasks, particularly when profiling short accelerations initiated from non-static-start conditions. However, because reliability was assessed within a single session, longitudinal monitoring with this protocol should be interpreted cautiously until its between-session reliability is established. Accordingly, CMJ-derived performance variables may provide useful supporting information when interpreting sprint performance across static-start and pick-up conditions, although the present findings do not support selecting one metric over another as a better indicator of sprint performance.

4.2. Limitations

The current study presents several limitations that should be acknowledged. First, although the players belonged to a high-level amateur environment, the findings should be interpreted as population-specific and may not be directly extrapolated to professional, youth, or male rugby union players. Additionally, all participants were recruited from a single team, and testing was conducted during a single session in May, at the end of the competitive season. Therefore, potential between-team and seasonal variation in pick-up acceleration performance could not be examined. Second, menstrual-cycle phase and hormonal contraceptive use were not controlled, which should be considered when interpreting neuromuscular performance outcomes. Third, the evaluation of neuromuscular performance was confined to bilateral vertical jumps (i.e., CMJ). The integration of unilateral or horizontally oriented assessments (e.g., broad jump) could provide additional information on the horizontal force production required during pick-up acceleration. Fourth, the associations between CMJ-derived performance variables and sprint performance were examined cross-sectionally within a single testing session. Therefore, these findings cannot establish whether improvements in CMJ, Peak power/BM or RSI-mod lead to improvements in pick-up acceleration performance. Longitudinal or intervention studies are needed to examine this relationship. Fifth, radar measurements during the first steps of a static-start sprint may be affected by rapid postural changes, because lower-trunk motion may not closely reflect whole-body center-of-mass displacement during this phase [34]. Although the Stalker ATS II has shown close agreement with timing gates and high-speed video during conventional linear sprint testing [23,35], these studies used static-start protocols rather than moving-entry sprints. Accordingly, the criterion validity of radar-derived measurements during pick-up acceleration has not yet been established. Future research should determine whether sprint force–velocity profiling [31] can be adapted and validated for pick-up acceleration initiated from non-zero entry velocities, allowing the mechanical determinants of performance under these conditions to be examined more directly. A further limitation is that static-start sprints always preceded pick-up accelerations, meaning that potential order effects cannot be entirely ruled out despite prior familiarization and recovery periods between trials. Finally, the pick-up acceleration protocol utilized absolute entry velocities of 1.5 and 3.0 $m \cdot s^{-1}$. While this approach replicates typical match-play locomotion, it inherently creates different relative mechanical and physiological demands among athletes.

5. Conclusions

In conclusion, increasing entry velocity reduced split times, Accel0–5, Accel0–10 and Distance-to-Vmax, while Vmax remained unchanged, indicating that pick-up acceleration mainly modifies the acceleration phase. Backs outperformed forwards across all sprint outcomes in the static-start condition. During pick-up acceleration, positional differences remained significant for Vmax, Distance-to-Vmax, T20, T30, and Accel0–10, whereas T5 and Accel0–5 were not significantly different between positions at either entry velocity, and T10 was also non-significant at 3.0 $m \cdot s^{-1}$. Despite this, the ES for T5 ranged from small to moderate, whereas those for T10 remained moderate across conditions; only Accel0–10 showed a significant sprint condition $\times$ position interaction. Therefore, the non-significant early comparisons should not be interpreted as indicating an absence of positional differences during pick-up acceleration. Additionally, CMJ height, Peak power/BM, and RSI-mod were associated with sprint outcomes across both static-start and pick-up acceleration conditions. When considered simultaneously, these variables collectively explained additional variance across sprint outcomes, although none of the three metrics retained a significant independent association. For coaches and practitioners, incorporating CMJ

assessments alongside pick-up sprint testing may provide complementary information when evaluating players' lower-limb neuromuscular and acceleration capabilities. From a methodological perspective, a radar gun combined with LED-paced entry velocities demonstrated excellent intra-session reliability for assessing static-start and pick-up acceleration performance in female rugby union players.

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Abbreviations

The following abbreviations are used in this manuscript:

Accel0–5	Average acceleration over the 0–5 m interval
Accel0–10	Average acceleration over the 0–10 m interval
amax	Maximal acceleration
BM	Body mass
CI	Confidence interval
CMJ	Countermovement jump height
CV	Coefficient of variation
Distance-to-Vmax	Distance at which maximal velocity is reached
ES	Effect size
ICC	Intraclass correlation coefficient
LED	Light-emitting diode
Peak power/BM	Peak power normalized to body mass
RSI-mod	Modified reactive strength index
SD	Standard deviation
T5, T10, T20, T30	Time to reach 5, 10, 20 and 30 m, respectively
Vmax	Maximal velocity

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