

1 ORIGINAL ARTICLE

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3 **Jump Squat Momentum: An Alternative Method to Prescribe Jump Squat Loads**
4 **for Elite Rugby Union Players**

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6 *Running-head: Jump squat momentum in rugby players*

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ABSTRACT

Rugby union is a team-sport in which collisions and impact forces play a decisive role. In this regard, momentum-based measurements (the product of mass and velocity of a body in a given movement) are frequently used by practitioners. Generally, sprint momentum (SM; the product of sprinting speed and athlete's body mass) is the most commonly considered momentum-based measure by coaches and sport scientists, either to differentiate playing positions or to examine player performance. However, recently, jump squat momentum (JSM) has been suggested as a complementary momentum-based measure, due to its strong relationship with SM. In this study, we compared the body-mass, half-squat one-repetition maximum (HS 1RM), in both absolute and relative terms (i.e., relative strength [RS]), sprinting speed and momentum, and JSM of 21 rugby backs and forwards using an independent t-test. As expected, forwards are significantly heavier and stronger and exhibit higher SM and JSM than backs ($P \leq 0.02$). In contrast, backs are faster in linear sprints over both 10- and 30-m ($P < 0.001$) and exhibit higher values of RS ($P < 0.05$). Furthermore, irrespective of playing position, RS was significantly different between the "low" and "high" RS groups ($P < 0.001$). Despite these marked differences, all players achieved their greatest magnitudes of JSM at an average of 40% HS 1RM. Strength and conditioning coaches interested in increasing JSM and its related metrics (e.g., SM) in rugby players could utilize this specific loading range to prescribe JS loads during their strength-power training sessions.

Keywords: team sports; resistance training; muscle strength; athletic performance; athletes.

INTRODUCTION

Rugby union is a collision sport, in which contacts and one-to-one combats (e.g., scrums, rucks, tackles, and lineouts) occur regularly throughout games and training sessions (39, 41, 57). During rugby matches, players are frequently exposed to high impact forces; thus, substantial amounts of body mass (BM) and whole-muscle mass are essential, not only for generating, but also for resisting greater impacts and avoiding injuries during these high-intensity sport-specific situations (3, 41). Notably, the rate of injuries in rugby tends to increase as the playing level and playing intensity increase (15, 16). Another central component of the impact forces in collision sports is sprinting speed, which, when multiplied by an individual's BM, generates a crucial game variable termed as sprint momentum (SM) (1, 13). An official rugby team comprises various positional roles (e.g., hookers, locks, flankers, scrum-half, wingers, full-backs), each with distinct anthropometric traits, physical qualities, and training backgrounds (3, 47). Although a list of functions and specific roles can be enumerated and detailed, for objective reasons and physical training purposes, these positions are usually grouped into two main categories: backs and forwards (49).

In general, backs are faster, jump higher, and demonstrate higher levels of relative strength (RS) compared to forwards, whereas forwards are usually heavier and exhibit greater levels of maximal (absolute) strength (3, 58). During sport-specific training and competitions, backs typically cover greater distances at higher speeds than forwards, due to their positional tasks and technical-tactical demands (e.g., finishing attacks by scoring tries, breaking the defensive line and creating space, organizing and directing attacks, etc.) (17, 25, 49). In contrast, forwards play a crucial role in contact actions and high-intensity efforts, such as scrummaging, rucking, and mauling, as well as in defensive actions (e.g., making tackles and preventing opponents from advancing) (17, 25, 47).

Therefore, these critical differences between playing positions (i.e., backs vs. forwards) and their technical and tactical functions justify the marked differences in their physical qualities and anthropometric characteristics (8, 53). Nevertheless, it needs to be remembered that, regardless of their positions and primary demands, rugby union players are always at risk of being involved in high impact tackles and collisions (14, 46). This makes momentum-based measurements, such as SM, crucial indicators of their performance (1).

In this context, another simple and practical measure that can be calculated using standardized values collected with the use of force plates is the jump squat momentum (JSM) (18, 37, 39). Accordingly, McMahon et al. (38) revealed that academy rugby players with a jump momentum of $213 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}$ would be classified as “poor” compared to forwards and “below average” compared to backs, based on reference data and objective benchmarks established in a normative study involving professional rugby players (39). Given the “nearly perfect positive relationship” between jump take-off momentum and SM ($r = 0.920$, $P < .001$), as well as the importance of SM for rugby players, measuring - or even training with a focus on JSM - may be an effective strategy for indirectly monitoring and potentially enhancing SM in elite rugby players (18, 37). For McMahon et al. (39), this strong correlation could also be a key factor for coaches working with academy rugby players who aim to enhance the SM of these young athletes as they transition to the senior level of competition. Additionally, it is reasonable to consider that in collision sports, athletes who can generate greater impact forces and momentum in either vertical (e.g., JSM) or horizontal (e.g. SM) directions may gain an advantage over their opponents, allowing them to perform technical and tactical actions more effectively (1, 18, 19, 37).

As a rule, JSM is calculated as the product of the take-off velocity (TOV) during a jump squat (JS) and the mass of the system (18). More recently, Harry et al. (18) proposed that the computation of JSM could help coaches and sport scientists to identify appropriate training loads for JS training. The rationale behind this load-prescription method is based on the concept of the “cumulative effort” required during ballistic lifts. Essentially, a higher JSM at take-off indicates that a more demanding task was performed, leading to greater effort from the athlete. Thus, identifying this specific loading zone and establishing whether this range varies between backs and forwards may be an important step in prescribing effective JS loads and resistance training programs for elite rugby players (18). Moreover, comparing the magnitude of JSM produced at a wide range of loads by rugby players could help practitioners determine if certain relative loads (percentages of one-repetition maximum [% 1RM]) are more efficient (i.e., able to generate greater JSM) for specific playing positions, and whether this measure can also be used to discriminate between backs and forwards. As mentioned earlier, this ability to differentiate between distinct positional roles in rugby has already been observed in other metrics and physical qualities, such as SM and sprinting speed (3, 17, 25, 49, 58).

Therefore, the current study aimed to investigate whether the JSM produced across a comprehensive loading range (from 20% to 80% of half-squat [HS] 1RM) can be used to distinguish between rugby players from different playing positions (i.e., backs and forwards) and if a specific loading intensity (% 1RM) is more sensitive at detecting any existing differences. Additionally, we examined the % 1RM at which each group achieved their maximum values of JSM, in order to assist coaches wishing to utilize momentum-based prescriptions in their daily training practices. Since forwards typically exhibit higher maximum strength values and are heavier than backs (3, 58), we hypothesized that the magnitude of JSM and the load (% 1RM) that maximizes this metric

would be greater in these players (compared to backs). Lastly, to confirm previous findings (3, 17, 25, 49, 58) and better elaborate our discussion, we also compared the sprinting speed and SM of backs and forwards.

METHODS

Experimental Approach to the Problem

This cross-sectional study was designed to test the differences in JSM between backs and forwards and to determine the load that maximizes JSM in rugby union players. Measurements were performed over two consecutive days, starting promptly at 9:30 a.m. on both days (day 1 and day 2), as follows: On the first day, the 1RM in the HS exercise was determined. On the second day, a 30-m linear sprint speed test and a progressive loading test in the JS exercise were conducted, using exactly the same percentages of 1RM (i.e., from 20% to 80% of the HS 1RM) that players typically use during their JS training and testing routines (27). Due to the constant training and assessments in our facilities, all athletes were familiar with the testing procedures. Prior to the measurements, players performed a standardized warm-up protocol that included general exercises (i.e., running at a moderate self-selected pace for 10 minutes followed by 3 minutes of lower-limb dynamic stretching and mobility exercises) and 2-3 submaximal attempts of each test (e.g., submaximal sprints and barbell JS without extra loads).

Subjects

Twenty-one male rugby union players from the Brazilian National Team (backs: $n = 11$; age: 24.3 ± 2.1 years; height: 1.77 ± 0.09 m; forwards: $n = 10$; age: 25.3 ± 2.3 years; height: 1.82 ± 0.07 m) participated in this study. The rugby players were evaluated during the first half of the competitive season and were all free of injuries or any other

limitations that could affect testing performance. The study was approved by the local Ethics Committee (approval number: 4.355.629) and all athletes signed an informed consent form prior to participation.

Procedures

One-Repetition Maximum in the Half-Squat Exercise

Maximum strength was assessed using the HS 1RM test performed on a Smith Machine, as previously described (4, 32). Players were instructed to perform the HS with their knees flexed at a 90° angle, always starting the movement from the same position relative to their feet placement on the ground (32, 33). All testing sessions (for both HS and JS) were supervised and visually monitored by two highly experienced researchers and the professional strength and conditioning coach of the Brazilian National Team. Before the test, athletes performed a specific warm-up set, which consisted of 5 repetitions ranging from 40% to 60% of the estimated 1RM (4). Three minutes after the warm-up, rugby players were allowed up to 5 trials at approximately 70%, 80%, 90%, and > 95% of the estimated 1RM to accurately determine the 1RM value (4, 32). In essence, these subsequent lifts involved single repetitions of progressively heavier loads until failure, as defined and standardized by Brown and Weir (4). It is important to emphasize that all players from the Brazilian National Team had extensive experience with 1RM tests, enabling them to provide very precise estimations of their actual HS 1RM values and corresponding percentages, thereby facilitating and simplifying the maximum strength measurements (4, 32). A 3-minute rest interval was given between the sequential and incremental attempts (4, 32). Athletes were required to move the barbell as fast as possible during the concentric phase of the lift in all trials.

Subsequent lifts are single repetitions of progressively heavier weights until failure.

Progressive Loading Test in the Jump Squat exercises

The JS exercise was performed on a Smith Machine positioned over a ground-fixed, validated force plate (AccuPower, AMTI, MA, USA) sampling at a rate of 1,000 Hz. The test was conducted under standardized conditions, using only the 20 kg barbell without additional loads, and with incremental loads corresponding to 20%, 40%, 60%, and 80% of the HS 1RM (7, 26, 27, 30, 51). Players were required to execute a concentric-only JS with their knees flexed at a 90° angle, maintaining this position for approximately 2 s before jumping (43). The lift was initiated from the same position relative to their feet placement on the force plate, and the TOV was recorded for all attempts. TOV is the instantaneous velocity at takeoff, identified as the first summed Fz data point below 53.4 N in the jumping cycle (26, 27, 51). AccuPower calculates the center of mass velocity using the impulse-momentum relationship (i.e., $F\Delta t/BM = \Delta V$; where: F is net force, Δt is the change in time, BM is the body mass, and ΔV is the change in velocity) (11, 20, 51). An Excel (Microsoft Inc., Redmond, WA, USA) spreadsheet was utilized to determine the relative loads (1RM) for each rugby player during their individual trials. The force-time data were kept unfiltered to preserve and ensure the complete integrity of the raw data collected during the measurements, as no significant noise was detected at any phase of data collection (26, 27, 28, 51). This approach aligns with protocols used in several previous studies, which also utilized unfiltered data collection methods when using the AccuPower system to record force-time data (26, 27, 28). Two attempts were performed for each load, with a 3-minute rest interval provided between all loading conditions, and the best trial was used for further analysis (7, 34). JSM was calculated as

the product of the change in velocity (i.e., TOV minus 0) and the sum of the athlete's BM and the respective load lifted (i.e., system mass) (18).

Sprinting Speed

Three pairs of single-beamed photocells (Elite Speed[®], S2 Sports, São Paulo, Brazil) were positioned above the players' hip height, at the starting line, and at the distances of 10- and 30-m. Players completed two sprints from a standing position, using the forward-step standing start technique (i.e., feet parallel, stepping forward with the preferred foot) (24), positioned 0.5 meters behind the starting line. The sprint tests were conducted on an indoor running track with an artificial grass surface. Sprint speed was calculated by dividing the distance travelled (i.e., 10-m and 30-m) by the corresponding time interval measured at each respective distance. A 5-minute rest interval was allowed between the two attempts, and the fastest time was used for the analyses and calculations. SM was obtained by multiplying the athlete's BM by the velocities achieved during the linear sprint tests.

Statistical Analyses

Data are presented as mean $\pm$ standard deviation. The normality of the data was checked using the Shapiro-Wilk test. A median split analysis was employed to divide rugby players into two groups based on their RS: "low" and "high" RS levels. The independent samples *t*-test was used to test for differences between backs and forwards groups in the variables analyzed. Differences in TOV and JSM between the different loading conditions were assessed through an analysis of variance with repeated measures (2 groups x 5 loads), followed by Bonferroni post hoc pairwise comparisons. The significance level for all analyses was set as $P < 0.05$. To determine the magnitude of the

differences in the tested variables when comparing backs and forwards, Hedge's g (23) effect sizes (ES) were calculated and interpreted using the thresholds proposed by Rhea (48) for highly-trained subjects, as follows: <0.25 , $0.25-0.50$, $0.50-1.00$, and >1.00 for trivial, small, moderate, and large, respectively. Reliability data were obtained from the distinct attempts of each test using the intraclass correlation coefficient (ICC) and the coefficient of variation (CV).

RESULTS

All measurements used in this study showed high levels of relative reliability (ICC > 0.90 ; 95% confidence interval [CI]: $0.91-0.97$) and absolute reliability (CV $< 10\%$; 95% CI: $4.6-6.6$). The BM and absolute HS 1RM were significantly higher for forwards (113.5 ± 6.8 kg; 235.2 ± 15.3 kg, respectively) than backs (88.5 ± 8.0 kg; 212.6 ± 23.9 kg, respectively; ES = 3.22 , $P < .001$; ES = 1.07 , $P = 0.02$, respectively). Table 1 presents the comparisons of sprint speed and SM between backs and forwards. Backs exhibited higher sprint speed and lower SM than forwards ($P < 0.05$).

INSERT TABLE 1 HERE

Table 2 presents individual and group values for RS, JSM and the changes in JSM across different loads, as well as the comparisons of RS and JSM between backs and forwards. The RS (i.e., HS 1RM normalized to BM) was significantly higher for backs compared to forwards (2.40 ± 0.19 vs. 2.08 ± 0.21 , respectively; ES = 1.54 , $P = 0.002$). Forwards showed higher JSM than backs in all loading conditions (ES ranging from 1.07 to 2.24 ; $P < 0.05$). On average, the highest increase in JSM was detected

between 20% and 40% HS 1RM, with the average loading intensity that maximized JSM being $61.8 \pm 18.9\%$ HS 1RM for backs and $50.0 \pm 17.0\%$ HS 1RM for forwards.

*****INSERT TABLE 2 HERE*****

Table 3 presents individual and group values for RS, JSM and the changes in JSM across different loads, as well as comparisons of RS and JSM between the low- and high-RS groups. RS was significantly different between the low- and high-RS groups (2.05 ± 0.18 vs. and 2.43 ± 0.16 , respectively; $ES = 2.28$, $P < .001$). No significant differences were observed between groups in JSM across all loading conditions (ES ranging from 0.56 to 0.87 ; $P > 0.05$). The average loading intensity that maximized JSM was $54.0 \pm 21.2\%$ HS 1RM for the low-RS group and $54.5 \pm 15.7\%$ HS 1RM for the high-RS group.

*****INSERT TABLE 3 HERE*****

Table 4 presents the individual and group values for TOV, the decreases in TOV at distinct loading conditions, and the comparisons of TOV between backs and forwards. No significant differences were observed when comparing TOV between backs and forwards (ES ranging from 0.01 to 0.19 ; $P > 0.05$). Considering the mean values of each position, the smallest decrease in TOV was detected at between 20% and 40% HS 1RM.

*****INSERT TABLE 4 HERE*****

DISCUSSION

In the current study, we examined and compared the magnitude of the load that maximizes JSM between backs and forwards. As expected, due to their higher levels of maximum strength and specific anthropometric traits (i.e., being heavier athletes), forwards exhibited a greater magnitude of JSM compared to backs across all loading conditions (i.e., from 20% to 80% 1RM), as well when using only the barbell without additional weight plates. Despite these significant differences, it is noteworthy that, consistent with other studies on this topic (18), the loading intensity for maximizing JSM in both playing positions was, on average, $\approx 40\%$ 1RM (Table 2), although this loading range tends to vary according to the playing position and RS. Finally, in line with findings from similar investigations, sprinting speed at 10- and 30-m was faster in backs, whereas SM at these same distances was higher in forwards (13, 45, 50, 58) (Table 1).

As expected, the magnitude of JSM was significantly greater in forwards compared to backs across all loaded conditions (i.e., $\geq 20\%$ Table 2). Somewhat surprisingly, although backs are characterized by their faster speeds, lighter BM, and greater explosiveness, there were no significant differences in the TOV between the two playing positions throughout the entire range of loads (from 20% to 80% 1RM) (Table 4). Therefore, the substantial differences in JSM favoring the forwards may be explained by their heavier BM, which, associated with their higher levels of maximum strength (i.e., $> 1\text{RM}$ values), indicate that the athlete-load system plays a key role in determining the magnitude of JSM (18). On the other hand, this partially aligns with the strong and consistent load-velocity relationships commonly observed across a wide range of relative loads (i.e., distinct % 1RM) and barbell velocities ($R^2 > 0.90$, $CV \leq 5\%$, $ICC \geq 0.90$, and 95% CI: 0.79-0.75, 0.57-0.60, 0.42-0.44; for HS performed at 40%, 60%, and 80% 1RM, respectively) in studies examining non-ballistic variations of squat exercises (35, 44). Importantly, this phenomenon was also detected in a specific study on JS exercise

conducted with rugby players, which, across a wide range of loads (from $\approx 25\%$ to 95% 1RM), reported CVs $< 10\%$ for the association between relative loads and barbell velocities (30). In that study, as well as in another study on reference data in the JS executed at different relative loads (29), elite rugby players, grouped together without division by playing positions, exhibited CVs $< 7\%$ and $< 11\%$, for peak velocity and JS height, respectively. This reveals that these jump metrics show small variations under certain relative loaded conditions, irrespective of positional roles (i.e., backs or forwards). Given that the success of a vertical jump primarily depends on the TOV (9, 56), which in turn, relies on the precedent impulse (56), it is plausible to infer that comparable velocities at take-off will result in narrow variations in vertical jump height, as confirmed by previous studies (28-30).

Interestingly, despite the significant differences in maximum strength (i.e., higher 1RM values for forwards), on average, the loading range that maximizes JSM is the same for both backs and forwards (i.e., 40% 1RM) (Table 2). This loading intensity closely aligns with the findings of Harry et al. (18), who reported that JSM reaches its peak value (i.e., peak momentum) at 30% of back squat 1RM. It is worth noting that Harry et al. (18) used different loading intensities (i.e., 15% , 30% , 45% , 60% of 1RM), while we tested our athletes using 20% , 40% , 60% , and 80% of 1RM, suggesting that this similarity might be even more pronounced under the same loading conditions. Another crucial point to consider is that, similar to our study, Harry et al. (18) also revealed that after the ideal training load, JSM progressively decreases as the load increases; however, this decrease occurs to different extents, potentially due to the significant differences in RS observed between the two positional roles.

For example, at the heaviest loading intensity (i.e., 60% 1RM for Harry et al. (18) and 80% 1RM in our study), the decrements in the magnitude of JSM were 10% and 8.5%

(relative to peak momentum) for resistance-trained subjects and forwards, respectively. In contrast, using the same load as forwards (i.e., 80% 1RM), backs exhibited a decrease of only $\approx 3\%$ in peak momentum (Table 2). This is clearly associated with the greater RS values detected in backs (also reported in Table 2), who showed a 20% higher RS in the HS exercise compared to forwards (2.40 vs. 2.08, respectively). Furthermore, higher RS values (as well as higher relative power values) have consistently been related to superior levels of various speed- and jump-related qualities (3, 29, 58), partially accounting for the positive differences observed in favor of backs when comparing their sprint speeds to those of forwards over 10- and 30-m distances (Table 1). As a consequence, the ability of backs to apply force and maintain more stable levels of JSM and mean concentric velocity across a range of loads is generally less affected by increases in load (12). In fact, for both playing positions and RS levels (Table 3), the magnitude of JSM seems to be optimized under light-to-moderate loading conditions (i.e., from 40% to 60% of HS 1RM). Nevertheless, the higher values of RS identified in backs may allow this group to utilize heavier loads (e.g., 80% HS 1RM) during their JS training sessions, as this group exhibit only a minimal decrease in JSM (-0.9% compared to -4.4% in forwards) relative to the previous loading range (i.e., 40%-60% HS 1RM). Moreover, when observing the same group of players (i.e., either backs or forwards; Table 2) a considerable variation in the load that maximizes JSM is noted, which might also be correlated with differing levels of RS within each group (12). Hence, while the current study provides general ranges of loading intensities for momentum-based prescriptions, coaches are encouraged, when possible, to individually test their athletes to prescribe more accurate training loads.

Notably, power-based training prescriptions also appear to be more effective at light-to-moderate loading intensities, where mechanical power, especially for the lower limbs, is usually maximized (i.e., “optimum power load”; [OPL]) (6, 10, 31). Specifically

in the JS exercise, the OPL typically occurs at $\approx 1\text{m}\cdot\text{s}^{-1}$ (for mean and mean propulsive velocities), which represents $\approx 40\text{-}45\%$ HS 1RM (6, 30, 31, 54). Connecting with the current study, the OPL in the JS demonstrates a narrow range of loads at which muscle power is maximized, and this is independent of strength level, sport discipline, and training background (31, 54). Despite this, since power is calculated as the instantaneous product of force output and movement velocity (6, 10, 35), and bar-velocity (particularly in zones far from the 1RM) tends to vary substantially over a training period (i.e., within a week), the use of OPL strategies - similar to velocity-based training (VBT) - enables coaches to regularly monitor bar-velocity using a linear position or linear velocity transducer. This approach facilitates the adjustment and individualization of JS training loads to meet the specific needs and requirements of each athlete (6). Another interesting study on the effectiveness of JS showed that this ballistic exercise gradually loses its “ballistic advantages” (e.g., higher power and force production, and faster velocities) compared to the HS exercise with increasing loads (i.e., from 20% to 80% 1RM) (27). Therefore, regardless of the rationale or objectives behind the strength-power training prescription (e.g., momentum-based, power-based, or exclusively to preserve the mechanical advantages of ballistic lifts), there seems to be no reason to utilize JS (or other types of loaded jumps) with loads exceeding 40-50% of 1RM. Lastly, it is relevant to note that a previous study comparing stronger and weaker subjects indicated that those with higher levels of maximum strength achieved peak power in jumping tasks at higher levels of relative intensity (% 1RM) (52), which, in this context, can be expressed in terms of RS. Practitioners should take this into account and also consider that rugby union involves actions occurring across a wide range of loads and velocities (21, 59, 60) when selecting the most appropriate training loads for their athletes, regardless of their positional roles.

We acknowledge that the cross-sectional nature of this investigation may limit our findings, their potential applications, and perspectives, and that substantial variation exists in the loading ranges that maximize JSM, even within the same playing positions and RS levels (i.e., low- or high-RS groups). Nonetheless, it is essential to emphasize that there are several indications suggesting that ballistic lifts are more effective when performed under light-to-moderate loading conditions and at velocities similar to those encountered in sport-specific activities, which aligns with the light-to-moderate range of loads reported here (i.e., from 40% to 60% 1RM) (5, 22, 34, 36, 55). Additionally, we opted not to discuss the inherent differences in BM, sprinting speed, and SM between backs and forwards, as these findings have already been extensively discussed in the literature (2, 8, 40, 42). As a result, our main purpose was to provide coaches and sport scientists with a novel and consistent approach to prescribing and monitoring JS loads during their regular training programs. Further studies are needed to establish and confirm the efficacy of JS momentum-based training schemes when compared to more traditional resistance training approaches (e.g., training based on power-load and velocity-load relationships).

PRACTICAL APPLICATIONS

Rugby union is a collision sport in which both inertial and impact forces are of fundamental importance. Thus, practitioners frequently assess and seek effective ways to increase momentum-based measures, such as SM. In the current study, we draw attention to the potential utility of JSM, a simple measurement that can be computed by multiplying the TOV collected during a barbell JS (with or without extra loads) by the athlete's BM. JSM may be used for different purposes, either to distinguish players from different positions (i.e., backs vs. forwards) or for training-related issues. In this context, while SM

at 10- and 30-m shows differences $\leq 19\%$ in favor of the forwards, JSM can show differences of up to $\approx 30\%$ for these same players (JSM at 20% 1RM; Table 2). Regarding training prescription, similar to other mechanical outputs (e.g., OPL; the load that maximizes power production), JSM appears to be enhanced at a certain range of loads ($\approx 40\%$ 1RM). Therefore, this relative load may serve as a basis to increase JSM, as this metric is closely related to SM (37, 39), a key component for rugby players in various playing positions (2). Although we recognize that it remains uncertain whether this range of loads is truly superior for increasing JSM (and consequently SM), there are reasons to believe that the load magnitude associated with the greatest overall increase in JSM may be effective for improving this momentum-based metric (18). As a final note, since this loading zone tends to vary even within the same positional roles and across different levels of RS (i.e., low- and high-RS groups), coaches are encouraged to assess their athletes individually whenever possible to optimize the potential benefits of this alternative resistance training strategy.

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Table 1. Comparisons of the sprint speed and momentum (SM) between backs and forwards.

	Backs	Forwards	% Difference	<i>P</i>	Effect Size (95% CI)
Speed 10-m (m·s⁻¹)	5.66 ± 0.19	5.27 ± 0.29	7.3	<.001	1.54 – <i>large</i> (0.49; 2.60)
Speed 30-m (m·s⁻¹)	7.21 ± 0.26	6.66 ± 0.25	8.2	<.001	2.07 – <i>large</i> (0.92; 3.22)
SM 10-m (N·m·s⁻¹)	501.9 ± 54.9	597.6 ± 30.1	19.1	<.001	2.05 – <i>large</i> (0.90; 3.19)
SM 30-m (N·m·s⁻¹)	638.9 ± 67.7	755.3 ± 41.0	18.2	<.001	1.97 – <i>large</i> (0.84; 3.11)

CI: confidence interval.

Table 2. Individual and group values for the relative strength (RS), jump-squat momentum (JSM) and for the changes in JSM across the range of loads[#].

Athlete	RS	Jump Squat Momentum (kg·m·s ⁻¹)					Changes in Momentum (%)			
		BL	20%	40%	60%	80%	BL vs. 20	20 vs. 40	40 vs. 60	60 vs. 80
Backs										
1	2.74	229.2	259.6	285.1	310.9	310.6	13.2	9.8	9.0	-0.1
2	2.29	274.3	256.6	304.8	286.1	212.2	-6.5	18.8	-6.1	-25.8
3	2.17	202.4	256.9	248.1	252.4	287.6	26.9	-3.4	1.7	13.9
4	2.41	267.7	277.9	305.2	293.7	282.9	3.8	9.8	-3.8	-3.7
5	2.34	236.8	251.7	280.9	298.9	306.9	6.3	11.6	6.4	2.7
6	2.24	217.2	248.1	277.7	254.2	289.3	14.2	11.9	-8.5	13.8
7	2.63	275.7	290.9	394.3	318.4	313.3	5.5	35.5	-19.2	-1.6
8	2.36	238.8	236.1	247.3	256.6	299.7	-1.1	4.7	3.8	16.8
9	2.43	272.5	329.9	374.6	356.5	359.1	21.0	13.6	-4.8	0.7
10	2.65	253.9	253.9	284.5	308.6	208.9	0.0	12.1	8.5	-32.3
11	2.17	318.1	332.2	375.6	377.4	398.7	4.4	13.1	0.5	5.7
Mean	2.40	253.3	272.2*	307.1**	301.2**	297.2*	8.0	12.4	-1.1	-0.9
SD	0.19	32.7	32.5	51.4	40.2	54.8	10.0	9.5	8.5	15.6
Forwards										
1	2.28	285.5	337.3	387.1	400.3	390.1	18.2	14.8	3.4	-2.5
2	2.08	368.3	439.2	457.0	415.6	325.6	19.2	4.1	-9.1	-21.6
3	2.13	321.0	411.1	381.0	473.3	340.6	28.1	-7.3	24.2	-28.0
4	1.85	327.6	337.8	431.3	373.2	467.4	3.1	27.7	-13.5	25.2
5	2.33	291.6	329.5	393.3	307.5	340.8	13.0	19.4	-21.8	10.8
6	2.30	321.9	370.9	372.8	380.1	364.1	15.2	0.5	2.0	-4.2
7	2.03	314.4	321.1	391.0	407.7	328.2	2.1	21.8	4.3	-19.5
8	2.08	309.3	305.2	404.5	369.3	384.4	-1.3	32.6	-8.7	4.1
9	2.08	321.6	311.2	366.8	342.3	328.4	-3.3	17.9	-6.7	-4.1
10	1.65	335.7	360.7	306.7	300.5	287.0	7.4	-15.0	-2.0	-4.5
Mean	2.08	319.7	352.4*	389.1**	377.0*	355.7 ^S	10.2	11.7	-2.8	-4.4
SD	0.21	23.0	43.8	39.8	51.9	49.6	10.2	15.5	12.5	15.9
%Dif.	15.4 [‡]	26.2 [‡]	29.5 [‡]	26.7 [‡]	25.1 [‡]	19.7 [‡]				

BL: Barbell Load - a 20 kg barbell without extra loads; SD: standard deviation; [#]Relative to half-squat one-repetition maximum; **P* < 0.05 in comparison to the BL condition; ⁺*P* < 0.05 in comparison to 20%; [§]*P* < 0.05 in comparison to 40%; [‡]*P* < 0.05 when comparing backs and forwards.

Table 3. Individual and group values for relative strength (RS), jump-squat momentum (JSM), and changes in JSM across the range of loads[#].

Athlete	RS	Jump Squat Momentum (kg·m·s ⁻¹)					Changes in Momentum (%)			
		BL	20%	40%	60%	80%	BL vs. 20	20 vs. 40	40 vs. 60	60 vs. 80
Low-RS Group										
1	1.65	335.7	360.7	306.7	300.5	287.0	7.4	-15.0	-2.0	-4.5
2	1.85	327.6	337.8	431.3	373.3	467.4	3.1	27.7	-13.5	25.2
3	2.03	314.4	321.1	391.0	407.7	328.2	2.1	21.8	4.3	-19.5
4	2.08	309.3	305.2	404.5	369.3	384.4	-1.3	32.6	-8.7	4.1
5	2.08	321.6	311.2	366.8	342.3	328.4	-3.3	17.9	-6.7	-4.1
6	2.08	368.3	439.2	457.0	415.6	325.7	19.2	4.1	-9.1	-21.6
7	2.13	321.0	411.1	381.0	473.3	340.6	28.1	-7.3	24.2	-28.0
8	2.17	202.4	256.9	248.1	252.4	287.6	26.9	-3.4	1.7	13.9
9	2.17	318.1	332.2	375.6	377.4	398.7	4.4	13.1	0.5	5.7
10	2.24	217.2	248.1	277.7	254.2	289.3	14.2	11.9	-8.5	13.8
Mean	2.05	303.6	332.3	364.0*	356.6*	343.7	10.1	10.3	-1.8	-1.5
SD	0.18	52.2	60.1	66.8	70.9	57.9	11.4	15.5	10.7	17.4
High-RS Group										
1	2.28	285.5	337.4	387.1	400.3	390.1	18.2	14.8	3.4	-2.5
2	2.29	274.4	256.6	304.8	286.1	212.2	-6.5	18.8	-6.1	-25.8
3	2.30	321.9	370.9	372.8	380.1	364.1	15.2	0.5	2.0	-4.2
4	2.33	291.6	329.5	393.3	307.5	340.8	13.0	19.4	-21.8	10.8
5	2.34	236.8	251.7	280.9	298.9	306.9	6.3	11.6	6.4	2.7
6	2.36	238.8	236.1	247.3	256.6	299.7	-1.1	4.7	3.8	16.8
7	2.41	267.7	277.9	305.3	293.7	282.9	3.8	9.8	-3.8	-3.7
8	2.43	272.5	329.9	374.6	356.5	359.1	21.0	13.6	-4.8	0.7
9	2.63	275.7	290.9	394.3	318.4	313.3	5.5	35.5	-19.2	-1.6
10	2.65	253.9	253.9	284.5	308.6	208.9	0.0	12.1	8.5	-32.3
11	2.74	229.2	259.6	285.1	310.9	310.6	13.2	9.8	9.0	-0.1
Mean	2.43	268.0	290.4	330.0*	319.8*	308.1	8.1	13.7	-2.1	-3.6
SD	0.16	27.2	44.5	54.6	42.5	57.7	8.7	9.1	10.5	14.2
%Dif.	18.7 [‡]	13.3	14.4	10.3	11.5	11.6				

BL: Barbell Load - a 20 kg barbell without extra loads; SD: standard deviation; [#]Relative to half-squat one-repetition maximum; * $P < 0.05$ compared to the BL condition; [‡] $P < 0.05$ when comparing low-RS and high-RS groups.