Original Investigation

Maximum strength, relative strength, and strength deficit: relationships with performance and differences between elite sprinters and professional rugby union players

Running head: Strength deficit in elite athletes

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Abstract

Purpose: To test the relationships between maximum and relative strength (MS and RS), absolute and relative peak force (PF and RPF), and strength deficit (SDef), with sprint and jump performance, and to compare these mechanical variables between elite sprinters and professional rugby union players. **Methods:** Thirty-five male rugby union players and thirty male sprinters performed vertical jumps, 30-m sprint, and the half-squat one-repetition maximum (1RM) assessment, where these force-related parameters were collected. Pearson correlation coefficient was used to test the relationships among the variables. An independent t-test and magnitude-based inferences compared the mechanical variables between sprinters and rugby players. **Results:** Almost certain significant differences were observed for jump and sprint performance between the groups ($P < 0.0001$). Rugby union players demonstrated a likely significant higher MS ($P = 0.03$), but a very likely lower RS ($P = 0.007$) than sprinters. No significant differences were observed for PF between them. Sprinters exhibited an almost certain significant higher RPF than rugby players ($P < 0.0001$). Furthermore, rugby players demonstrated almost certain to likely significant higher SDef from 40 to 70% 1RM ($P < 0.05$) compared to sprinters. Overall, all strength-derived parameters were significantly related to functional performance. **Conclusions:** Elite sprinters present higher levels of RS and RPF, lower levels of SDef, and superior sprint and jump performance than professional rugby players. Relative strength-derived values (RS and RPF) and SDef are significantly associated with speed-power measures and may be used as effective and practical indicators of athletic performance.

Key Words: dynamic strength; elite athletes; track and field; team-sport; Olympians.

Introduction

Maximum strength (MS) is a basic capacity that underpins several physical and technical skills, being generally described as "the greatest force possible under specified conditions".[1, 2] MS is usually assessed by the one-repetition maximum (1RM) test and has been shown to be closely related to a series of performance measures, in a wide variety of individual and team sports.[3, 4] These correlations tend to increase substantially when the 1RM values are normalized with respect to individual body-mass (BM) (i.e., $1RM{\cdot}BM^{-1}$), a methodological procedure capable of producing a weight-adjusted physical fitness score, scientifically termed as "relative strength" (RS).[3, 5-7] Therefore, from an applied perspective, RS may be defined as the heaviest load that can be lifted one time in relation to BM.[8]

Besides its strong associations with performance, RS seems to be a very sensitive discriminator of sexes, age-categories, and competitive status. For example, male college athletes who exhibited an RS level ~45% higher than their female peers also achieved superior performances in both vertical jump and sprint tests (~45% and ~20% higher, respectively, compared to female college athletes).[6] Accordingly, Kelly et al.[9] found significant differences in lower- and upper-body RS scores between senior and junior Australian football players of different chronological ages and athletic levels. Overall, when comparing the outcomes, the authors detected a substantial deficit in RS in the junior athletes (in relation to the senior category), a result that was also observed in other functional measurements (e.g., explosive jumping and throwing tests).[9] Kirkpatrick and Comfort[10] reinforced these findings in a study with elite under-20 rugby league players, demonstrating that, irrespective of playing position (i.e., backs or forwards), the RS level was able to differentiate between higher and lower sprint and jump performance. Hence, regardless of sport and training background, RS capacity appears to be a good indicator of athletic potential.[4, 8]

In addition to the RS ratio, the strength deficit (SDef) is another variable that may influence sport performance.[8, 11] The SDef represents the difference between the force produced when the resistance is the maximum that can be lifted (i.e., 1RM), and any other force value achieved against lighter relative loads.[8, 11, 12] For Suchomel et al.[8], a large SDef indicates that a subject may not be capable of exploiting his/her strength capacity, and thus, translate it into performance improvements. In this context, González-Badillo et al.[11] advocated that subjects with lower SDefs are likely able to more effectively use their MS potential during strength tasks performed against submaximal loads (i.e., distinct %1RM). From a mechanical standpoint, a reduction in the SDef means that an athlete can apply more force to the same percentage of 1RM (i.e., %1RM) and, as a consequence, move this relative load at a higher velocity.[11] This is especially important in sport activities where athletes have to produce substantial amounts of force against ("only") their own BM in order to achieve superior and more consistent levels of performance (e.g., sprinting and jumping actions).[13]

Despite the relevance of these absolute (MS) and relative measures (RS and SDef), to date, no studies have simultaneously investigated their relationships with functional performance or compared these mechanical variables between athletes from different sport disciplines. Research in this regard is essential to understand more deeply the influence of MS and its derived parameters on athletic performance and training status. Therefore, the objectives of this study were twofold: (1) to examine the correlations between MS, RS, SDef, and other derived force outputs (peak force [PF] and relative peak force [RPF]) and sprint and jump performance, and (2) to compare these aforementioned variables between elite sprinters and professional rugby players. Since elite sprinters are usually faster and relatively more powerful (i.e., jump higher), than team-sport athletes,[14] we hypothesized that they would display higher levels of RS and lower levels of SDef. Furthermore, based on previous research,[4, 8, 11] we expected that MS and RS would be positively, and SDef negatively correlated with sprint velocity and jump height.

Methods

Subjects

Sixty-five male athletes from two sport disciplines (rugby union players: n = 35; 25.4 ± 4.2 years; 185.4 ± 5.4 cm; 92.5 ± 13.9 kg; and sprinters: n = 30; 24.6 ± 4.1 years; 178.4 ± 3.6 cm 76.0 ± 8.9 kg) took part in this study. Rugby players were members of the Brazilian National Team. Sprinters regularly participated in National and International competitions, comprising two athletes who participated in the last Olympic Games edition (Rio-2016) and two athletes already classified for the next Olympic Games. Before participating in this study, all subjects gave written informed consent in accordance with the Declaration of Helsinki. The study protocol was approved by the local research ethics committee.

Study Design

This cross-sectional study aimed to examine the correlations between MS, RS, SDef, PF, and RPF and vertical jump and 30-m sprint performance and compare these respective variables between elite sprinters and professional rugby players. The assessments were performed during the competitive phase of the season and all athletes were well familiarized with the testing procedures due to their constant and regular training routines in our high-performance training center. Subjects were required to be in a fasting state for at least 2 h, avoiding caffeine and alcohol consumption for 24 h before the procedures. Prior to the test, athletes performed a standardized warm-up protocol including general (i.e., running at a moderate pace for 10-min followed by dynamic lower limb stretching for 3-min) and specific exercises (i.e., submaximal attempts of each test). The tests were performed on the same day for athletes of the same sport discipline, always in the following order: 1) squat and countermovement jumps (SJ and CMJ); 2) 30-m sprint; and 3) progressive loading test in half-squat (HS) exercise. Between each test, a 10-min interval was provided to explain the procedures, allow adequate recovery, and adjust the equipment.

Methodology

Vertical Jumping Tests

Vertical jump height was assessed using the SJ and CMJ. In the SJ, athletes were required to remain in a static position with a 90° knee flexion angle for ~2-s before jumping, without any preparatory movement. In the CMJ, athletes were instructed to execute a downward movement followed by complete extension of the legs and were free to determine the countermovement amplitude in order to avoid changes in jumping coordination. All jumps were performed with the hands on the hips and the athletes were instructed to jump as high as possible. The jumps were executed on a contact platform (Elite Jump®, S2 Sports, São Paulo, Brazil). A total of five attempts were allowed for each jump, interspersed by 15-s intervals. The best attempts for the SJ and CMJ were used for subsequent analyses.

Sprinting speed

Two pairs of photocells (Smart Speed, Fusion Sport, Brisbane, Australia) were positioned at the starting line and at a distance of 30-m. Athletes sprinted twice, starting from a standing position 0.3-m behind the starting line. The sprint tests were performed on an indoor running track. Sprint velocity (VEL) was calculated as the distance travelled over a measured time interval. A 5-min rest interval was allowed between the two attempts and the fastest time was considered for subsequent analyses.

Progressive loading test in the half-squat exercise

Maximum dynamic strength was assessed using the HS 1RM test as described previously.[15] Prior to the test, the subjects executed a warm-up set, which consisted of 5 repetitions between 40 and 60% of the estimated 1RM. Three minutes after the warm-up, athletes were allowed up to 5 attempts at ~70, 80, 90, and > 95% of the estimated 1RM to obtain the actual 1RM value.[7, 15] A 3-min rest interval was provided between all repetitions.[15] The test was performed on a Smith-machine device (Hammer-Strength Equipment, Rosemont, IL, USA). Athletes were instructed to move the barbell as fast as possible during the concentric phase of movement in all attempts. The PF was continuously assessed during all attempts at a sample frequency of 1000 Hz by a linear velocity transducer (T-Force Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) attached to the Smith-machine barbell. In addition to 1RM and PF, the SDef was calculated as the percentage differences between PF at distinct relative intensities (i.e., % 1RM) and PF at 1RM. The 1RM and PF values were also normalized by dividing them by the athletes' BM (i.e., RS; RPF = $N \cdot kg^{-1}$).

Statistical Analyses

Data are presented as mean ± standard deviation and 90% confidence limits (CL). Data normality was checked through the Shapiro-Wilk test. Independent t-tests and magnitude-based inferences[16] were used to compare the variables assessed between the sports. The magnitudes of the differences were expressed as standardized mean differences. The smallest worthwhile change was set by using a small effect size (ES = 0.2) for each variable tested.[17] The quantitative chances of finding differences in the variables tested were assessed qualitatively as follows: 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; > 99%, almost certain. If the chances of having better and poorer results were both > 5%, the true difference was deemed unclear.[16] Additionally, the magnitudes of the standardized differences were interpreted using the following thresholds: < 0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0, 2.0-4.0, and > 4.0 for trivial, small, moderate, large, very large, and near perfect, respectively.[17] A Pearson-product moment was performed to determine relationships between vertical jump and sprint performances with MS, PF, and SDef at 40% 1RM. Correlation coefficients were qualitatively interpreted as follows: < 0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very-large; > 0.9 nearly-perfect.[17] Significance level was set at $P < 0.05$. The tests used demonstrated high levels of reliability and consistency (i.e., intraclass correlation coefficients > 0.90 and coefficients of variation < 5%).

Results

Table 1 shows the comparison of the vertical jump height and 30-m sprint velocity between rugby union players and sprinters. Almost certain and significant differences were observed for SJ, CMJ, and VEL 30-m between groups ($P < 0.0001$). Figure 1 depicts the comparison of the MS and RS between rugby union players and sprinters. Rugby union players demonstrated a likely and significant higher MS (*P* = 0.03), but a very likely and significant lower RS (*P* = 0.007) than sprinters.

*****INSERT TABLE 1 HERE*****

*****INSERT FIGURE 1 HERE*****

Figure 2 shows the comparison of the PF, RPF, and SDef values at the distinct relative loads and at 1RM between rugby players and sprinters. No significant differences were observed between rugby players and sprinters in any measure of PF (*P* = 0.59, 0.88, 0.91, 0.56, 0.29, 0.28, and 0.25, for 40, 50, 60, 70, 80, 90, and 100% 1RM, respectively). Sprinters revealed an almost certain and significant higher RPF than the rugby players in all loads tested (*P* < 0.0001 for all loads). In addition, rugby players demonstrated an almost certain to likely significant higher SDef at 40, 50, 60, 70% 1RM (*P* = 0.0005, 0.003, 0.002, 0.03, respectively) than sprinters. No between groups significant differences were revealed for SDef at 80 and 90% 1RM (*P* = 0.053 and 0.27, respectively). Finally, table 2 demonstrates the correlation coefficients between vertical jumps and VEL 30-m and MS, RS, PF, RPF and SDef at 40% 1RM (which represents the higher value of SDef assessed among all loading conditions).

*****INSERT FIGURE 2 HERE*****

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

Discussion

We examined the correlations among MS, RS, SDef, PF, and RPF and sprint and jump performance, and compared these mechanical variables between elite sprinters and professional rugby players. Our main findings were: 1) SDef was significantly lower in sprinters than in rugby players, but only at light or moderate loads (i.e., ≤ 70% 1RM); 2) despite the lack of significant differences in absolute PF, RPF was greater in sprinters; 3) MS was significantly higher in rugby players; conversely, RS was higher in sprinters; and 4) overall, all these strength-derived parameters were significantly related to athletic performance, at different levels of correlation. These results may have important implications for both training and testing purposes.

The rugby players performed better than the sprinters in the 1RM test (Figure 1A). Nevertheless, these differences were reversed when MS was normalized to individual BM (i.e., RS). These data are in line with those reported in previous studies, indicating that faster and more powerful athletes (assessed by means of vertical jumps) are also able to exert greater amounts of force against their own BM.[6, 13, 18] This may explain why elite sprinters are able to more effectively accelerate their bodies during unloaded sport activities, thus achieving superior performance during explosive unloaded motor-tasks, such as sprint and jump tests[13, 19] (Table 1). A similar pattern can be observed in RPF, although notably, the difference in absolute PF between sprinters and rugby players was not significant (Figure 1A). Since force is the product of mass and acceleration and considering the above-mentioned factors, it is reasonable to infer that sprinters can attain higher rates of acceleration against relative loads of similar magnitude (i.e., % 1RM) and, therefore, reduce (or even completely balance) the difference between absolute and relative levels of force application.[3, 13] Together these findings reinforce the notion that relative and more dynamic strength-based parameters should be used rather than absolute scalar measures (e.g., 1RM value) to evaluate and discriminate between athletes from different sports and competitive levels.[3, 9]

When compared to rugby players, sprinters presented lower degrees of SDef at 40, 50, 60, and 70% 1RM and similar degrees at 80 and 90% 1RM (Figure 1E). As previously stated, mechanically, the SDef reflects the percentage of MS potential which is not utilized during a submaximal motor-task[12, 20] (in this case, the HS performed at loads ≤ 70% 1RM). Based on these results, we can conclude that sprinters are potentially more effective than rugby players at applying force against light to moderate loads, using greater percentages of their MS at these intensities. For González-Badillo et al.[11] this mechanical phenomenon may be easily explained by assuming that a given subject does not have only one value of maximum force, but infinite maximum force values (namely "force peaks"), as many times as relative loads are measured. As a result, athletes able to achieve higher velocities against the same % 1RM will simultaneously present higher relative force peaks, relative power output, and smaller SDef against these respective loads.[11, 14] Accordingly, McBride et al.[21] reported that sprinters achieved higher peak velocities in comparison to power lifters in vertical jumps executed at various loading conditions. A similar trend was observed in the study by Hansen et al.[22], who revealed that faster rugby players produced superior peak velocities and relative peak power than their slower peers during loaded jump squats. Interestingly, these differences were not detected at 80 and 90% 1RM, which could be justified by analyzing the narrow range of velocity variation at 1RM measurements (and, hence, at heavier loads) in strength-power trained athletes.[7] Nonetheless, it is worth emphasizing that these maximum strength assessments may present lower levels of consistency among non-experienced (or even non-professional) lifters,[23, 24] partially compromising the extrapolation of our data to other populations. In summary, it appears that the ability to attain higher velocities against light and moderate percentages of HS 1RM is not solely a marker of lower SDef but is also a potential indicator of superior performance in some explosive motor-tasks, such as jumping and sprinting actions (at least in a sample composed of elite sprinters and professional rugby players). This hypothesis should be examined in future experiments comparing a large number of sport disciplines (e.g., soccer, rugby, handball, and track and field athletes) and subjects with different training backgrounds.

We decided to group all subjects together and perform a correlation analysis to investigate whether, regardless of their sport disciplines, athletes able to jump higher and sprint faster also displayed superior levels of MS, RS, PF, and RPF and inferior levels of SDef. As stated earlier, by examining these data (Table 2), we concluded that: 1) the relative strength-derived parameters (i.e., RS and RPF) were more related to functional performance than their absolute values (i.e., MS and PF); and 2) lower levels of SDef were significantly associated with better sprint and jump test results. Therefore, these findings not only reinforce our conclusions, but agree with previous research showing the importance of these relative measures for athletic performance.[4, 8] Moreover, this highlights the need to improve the ability to apply force against lighter loads (e.g., 40% 1RM), in order to reduce the SDef at loading ranges closer to BM, which probably has a positive and meaningful impact on a wide range of sport-specific activities, such as maximum acceleration, sprint, and jump efforts.[3, 25]

The present study is limited by its cross-sectional design and the selected characteristics of the sample (i.e., elite sprinters and professional rugby players), which restricts the robustness and reach of our outcomes. In addition, we collected the force variables using a linear velocity transducer (and not a force platform); hence, the results presented herein represent the force applied to the barbel, and not the total force applied to the “system” (i.e., barbell and lifter). However, it is crucial to underline that the HS

1RM test is one of the most frequently used and validated measurements of lower limb strength and that this procedure only provides a simple and limited scalar measure (i.e., "kg") as a reference value.[3, 26] Therefore, our findings shed light on the importance of considering different and more comprehensive strength-derived parameters even when using the traditional 1RM test. These parameters may be easily collected through the use of linear velocity transducers and may help coaches and sports scientists to better evaluate top-level athletes, as well as create more effective and specific resistance training approaches. Further studies are required to evaluate the evolution of RS, RPF, and SDef over the competitive season and assess their variations after distinct training interventions and relationships with more complex force-velocity based analyses.[19]

Practical Applications

RS, RPF, and SDef are important indicators of athletic performance and seem to be able to discriminate between faster and slower athletes, at least in a sample composed of sprinters and rugby players. Coaches are encouraged to systematically record these variables when applying the traditional 1RM test, in order to better assess the readiness of their athletes to effectively apply force against lighter loads (and, thus, against their own BM). These outputs may be collected through the use of simple and valid linear velocity transducers.[27, 28] From our data it is possible to suggest that training schemes able to improve the ability to produce force against submaximal loads (e.g., unloaded condition ["BM load"], and from 40 to 70% 1RM) will be equally able to increase both sprint and jump capacities. Mixed training approaches comprising traditional and ballistic strength and power exercises performed with light, moderate, and heavy loads, along with the application of plyometric drills may be necessary to tackle this complex but important training issue.[29] Ideally, these strategies should be specifically tailored to the needs and characteristics of each athlete.

Conclusions

Athletes with higher levels of RS and RPF and lower levels of SDef tend to sprint faster and jump higher than their weaker peers. Between sprinters and rugby players, the RS, RPF, and SDef parameters can be used as effective and practical indicators of functional performance.

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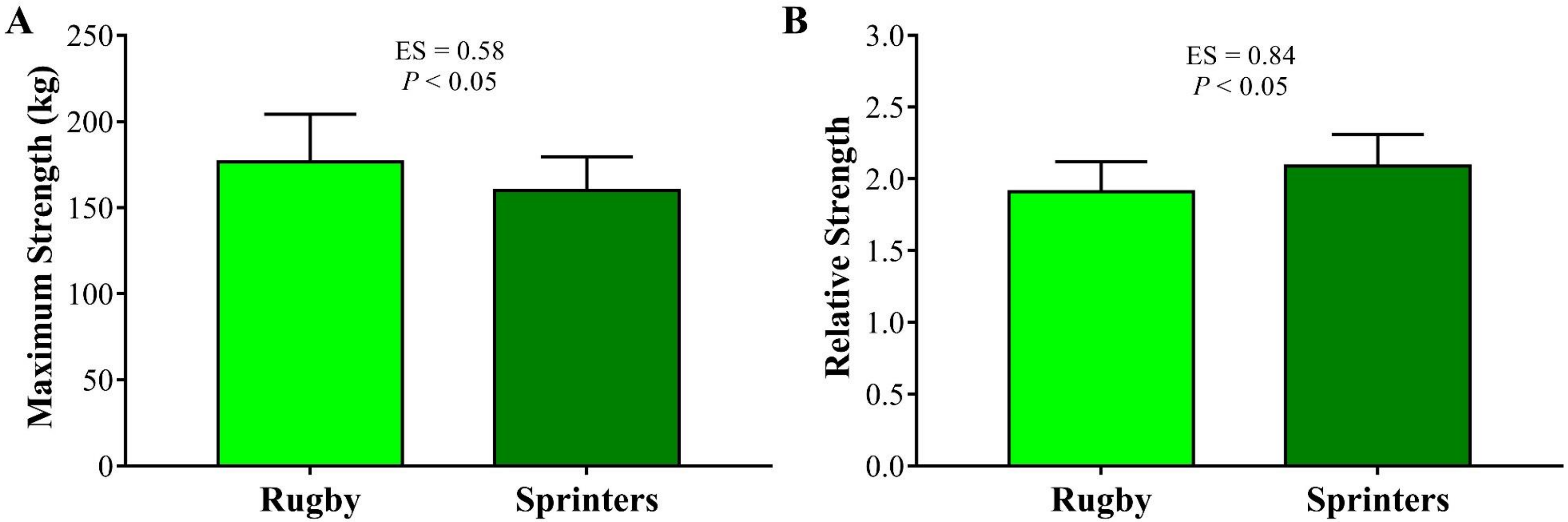
FIGURE CAPTIONS

Figure 1. Comparison of the maximum (A) and relative (B) strength in the half-squat exercise between elite sprinters and professional rugby union players.

Figure 2. Comparison of the peak force (A and B), relative peak force (C and D), and strength deficit (E and F) values at the distinct relative loads and at one-repetition maximum (1RM) in the half-squat exercise between elite sprinters and professional rugby union players. The figures on the left (A, C, and E) present means and their respective standard deviations; $*P < 0.05$. The figures on the right (B, D, and F) represent the effect sizes (ES) for each comparison along with 90% confidence limits (error bars). Grey areas represent the "smallest worthwhile changes" (ES = 0.2).


A
Maximum Strength (kg)
250
200
150
100
50
0
ES = 0.58
P < 0.05
Rugby
Sprinters
B
Relative Strength
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ES = 0.84
P < 0.05
Rugby
Sprinters

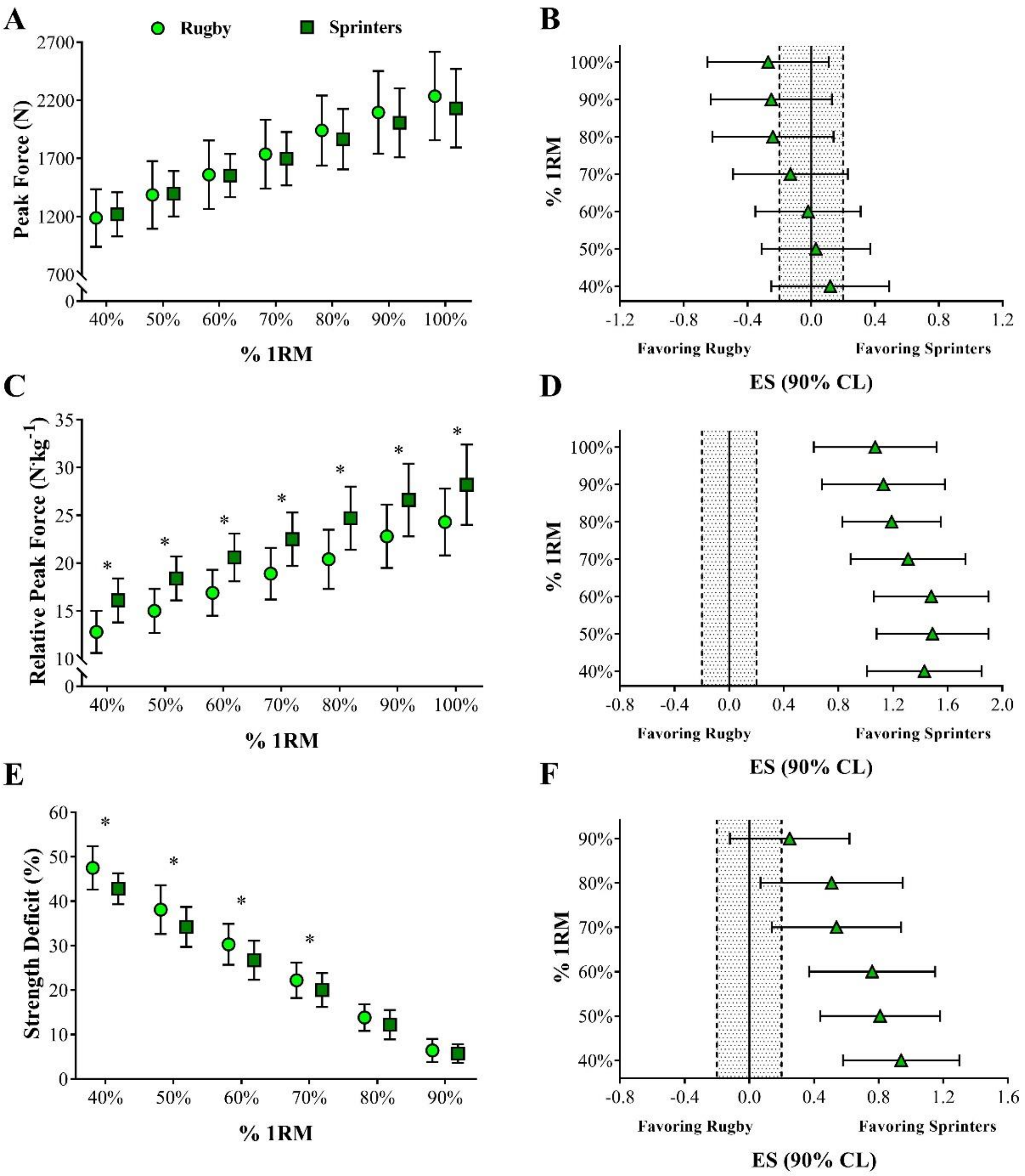

A
Rugby
Sprinters
Peak Force (N)
% 1RM
B
% 1RM
Favoring Rugby
Favoring Sprinters
ES (90% CL)
C
Relative Peak Force (N·kg-1)
% 1RM
D
% 1RM
Favoring Rugby
Favoring Sprinters
ES (90% CL)
E
Strength Deficit (%)
% 1RM
F
% 1RM
Favoring Rugby
Favoring Sprinters
ES (90% CL)

Table 1. Comparison of performance variables between elite sprinters and professional rugby union players.

	Rugby	**Sprinters**	**ES (90% CL)**
Squat Jump (cm)	38.5 ± 4.7	55.8 ± 4.5*	3.58 (3.13; 4.02)
Countermovement Jump (cm)	42.3 ± 4.9	59.5 ± 4.7*	3.38 (2.94; 3.81)
Velocity 30-m ($m \cdot s^{-1}$)	6.98 ± 0.30	7.84 ± 0.22*	2.79 (2.40; 3.19)

ES: effect size; CL: confidence limits; * indicates significant differences: $P < 0.05$.

Table 2. Correlation coefficients (*r*) between vertical jumps, sprint velocity, and different strength-derived variables in elite sprinters and professional rugby union players.

	SJ	**CMJ**	**VEL 30-m**
MS	0.34	0.32	0.26
RS	0.60*	0.60*	0.54*
PF	0.35	0.36	0.29
RPF	0.65*	0.68*	0.61*
SDef 40% 1RM	-0.50*	-0.52*	-0.56*

SJ: squat jump; CMJ: countermovement jump; VEL: sprint velocity; MS: maximum strength; RS: relative strength; PF: peak force; RPF: relative peak force; SDef: strength deficit; 1RM: one-repetition maximum. Strength-derived variables were measured in the half-squat exercise. * indicates significant relationships: $P < 0.05$.