PEAK POWER, FORCE, AND VELOCITY DURING JUMP SQUATS IN PROFESSIONAL RUGBY PLAYERS

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ABSTRACT

Turner, AP, Unholz, C, Potts, N, and Coleman, SGS. Peak power, force, and velocity during jump squats in professional rugby players. *J Strength Cond Res* 25(X): 000–000, 2011—Training at the optimal load for peak power output (PPO) has been proposed as a method for enhancing power output, although others argue that the force, velocity, and PPO are of interest across the full range of loads. The aim of this study was to examine the influence of load on PPO, peak barbell velocity (BV), and peak vertical ground reaction force (VGRF) during the jump squat (JS) in a group of professional rugby players. Eleven male professional rugby players (age, 26 ± 3 years; height, 1.83 ± 6.12 m; mass, 97.3 ± 11.6 kg) performed loaded JS at loads of 20–100% of 1 repetition maximum (1RM) JS. A force plate and linear position transducer, with a mechanical braking unit, were used to measure PPO, VGRF, and BV. Load had very large significant effects on PPO ($p < 0.001$, partial $\eta^2 = 0.915$); peak VGRF ($p < 0.001$, partial $\eta^2 = 0.854$); and peak BV ($p < 0.001$, partial $\eta^2 = 0.973$). The PPO and peak BV were the highest at 20% 1RM, though PPO was not significantly greater than that at 30% 1RM. The peak VGRF was significantly greater at 1RM than all other loads, with no significant difference between 20 and 60% 1RM. In resistance trained professional rugby players, the optimal load for eliciting PPO during the loaded JS in the range measured occurs at 20% 1RM JS, with decreases in PPO and BV, and increases in VGRF, as the load is increased, although greater PPO likely occurs without any additional load.

KEY WORDS optimal load, ballistic exercise, assessment

INTRODUCTION

In many sports, athletes are required to generate forces across a range of velocities, with a resulting power-load spectrum (27), similar to that originally characterized by force-velocity characteristics of isolated muscle by Hill in the 1930s. It is a common view in the strength and conditioning literature that peak power output (PPO) is an important determinant of performance because this represents the balance between force and velocity above and below which power output declines. However, the evidence regarding the strength of the relationship between PPO and performance is equivocal (12,43), and furthermore, recommendations regarding how best to train PPO are far from conclusive (10,12,17,27,29). Most recommended interventions include explosive lower-body exercises involving the triple extension of the knee, ankle, and hip that avoid a deceleration phase because they are considered closest to the actions of sprinting and jumping seen in many sports (27). Consequently, there has emerged an interest in characterizing the power-load relationship in athletes for a range of ballistic (1–4,9,11,25,30,31,35,36,39,40,42) or Olympic-style lifts (26,28,31) that elicit high PPO, for either the purposes of training prescription or monitoring responses to training. However, there is considerable disagreement in the literature regarding the relative loads that elicit PPO.

The inverted U-shape of the power-load relationship demonstrates that an optimal load exists for eliciting PPO and that there is some argument for training at such a load to increase PPO (1,2,17,18,25,27,32,33,42), although others argue of the importance of specificity, that is, training at a range of loads and velocities encountered during sports performance (9,41,43). For jump squats (JSs), an explosive triple-extension exercise that elicits high power outputs, loads ranging from body mass (BM) to as high as 80% of 1 repetition maximum (1RM), (2,4,9,17,25,30,31,36,39,40,42), has been identified as optimal for PPO, with an even greater range when Olympic lifts (15,26,28,31) and upper-body ballistic exercises are included (1,4). Such discrepancies appear to exist primarily because of differences in methodology (6,13). Contributing factors include the lift being tested (e.g., upper vs. lower body, technique, inclusion of a countermovement, single- vs. multijoint exercises); individual differences; calculation of average vs. peak power; inclusion of BM in calculations; data collection methods (e.g., linear position transducer [LPT] vs. force plate); reporting of load intensity (e.g., relative to 1RM of traditional compared with ballistic lifts). The resistance training history and strength level of participants have varied greatly in the existing research, and yet, for

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the well-trained athletes for whom accuracy in training load is arguably most important, there is no agreement regarding the optimal load for PPO. Some authors have suggested that strength trained athletes require higher relative loads than do less-trained individuals (32), yet other data suggest the opposite (22) or little difference (31,34).

Therefore, the aim of this study was to examine the influence of load on PPO, peak barbell velocity (BV), and peak vertical ground reaction force (VGRF) during the JS in a group of professional rugby players completing a single maximal testing session. Given the available evidence, it was hypothesized that there will be a significant effect of load on peak force, velocity, and hence PPO. It was further hypothesized that the optimal load for PPO and BV will be the lowest load measured and peak VGRF at the highest load.

METHODS

Experimental Approach to the Problem

To evaluate the impact of load on PPO during the JS in professional rugby players, a repeated measures design was used with multiple jumps performed at loads ranging from 20 kg to 100% 1RM JS in a single session after familiarization. The full-time professional rugby union players were in the midphase of the competitive season (multiple UK and European league and cup competitions), so it was imperative that the study design maximized efficiency of testing, such that training disruption was minimized, yet the protocols could be replicated easily in the gymnasium for monitoring purposes, while ensuring accuracy and player safety. The coaches were interested in exploring the use of a range of loads for subsequent training and the potential for using incremental JS for monitoring training in the future. Therefore, data collection was performed using a force plate with LPT to measure VGRF, BV, and power output. Peak power output was the key dependent variable, with VGRF and peak BV also investigated as the key parameters that underpin PPO. Load above BM was the independent variable, selected as the percentage of an initially estimated 1RM JS based on a previously determined 5RM squat, although the actual 1RM JS was deliberately assessed as part of the protocol.

The incremental protocol used does mean that there is a potential for an order effect (either a positive potentiation and learning effect or negative fatiguing effect) on the dependent variables, although this protocol was deliberately used in line with recommendations for 1RM testing of traditional lifts (25). Sheppard et al. (35) have shown such an approach to be reliable, valid, and sensitive to training improvements in athletes although they did not progress to as high relative loads.

Subjects

The study involved 11 professional male rugby players (BM 97.3 ± 11.6 kg; height 1.83 ± 0.12 m; age 25.6 ± 3.3 years; 1RM JS 183.6 ± 19.6 kg) from the same club that played a range of positions (5 front-row; 1 back-row; 3 half-backs; 2 wingers) as reflected in the considerable variation in size and 1RM values. Testing was integrated into their regular conditioning program, and the testing session took place in the middle of the competitive season during a strength and power maintenance phase characterized by low volume and high-intensity relative to preseason. All the subjects provided written informed consent, and the study was approved by the ethics committee of the university. Inclusion criteria were that players demonstrated sound technique during the JS, as assessed by an accredited strength and conditioning coach and were engaged full time in a supervised strength and conditioning program for at least 2 years.

Experimental Procedures

After familiarization with full testing procedures on a different day, the participants reported to testing hydrated and having refrained from strenuous exercise and alcohol consumption for at least 24 hours, and caffeine for at least 3 hours, before testing. Each participant completed a 10-minute standardized and supervised warm-up that included dynamic stretching and movements specific to the JS. The protocol required the participants to perform maximum effort JS at 20 kg–100% of their estimated 1RM JS. For those participants who were still successfully completing a JS at 100% of the estimated 1RM JS, the load was further increased until the participant did not complete the JS, as detailed below. During all the jumps, the athletes were instructed to jump as high as possible, and verbal encouragement was given.

Jump Squat Testing. The JS testing protocol was adapted from the 1RM testing method outlined by Stone and O'Bryant (38) and was modified to allow a complete load spectrum to be tested. The loading protocol used repetition values (3 reps $\leq$ 40% estimated 1RM, 2 reps $\leq$ 80% estimated 1RM, 1 rep $>$ 80% estimated 1RM) at given loads modified to strike a balance between ensuring the detection of PPO (2–5 reps [3]) and reducing the total volume to minimize fatigue. Each attempt was followed by a 3-minute rest period to allow adequate recovery. If participants did not reach their 1RM at the provided estimate, a load increase of 5–10 kg was added after each further attempt and 3 minutes of rest. Individuals were deemed to have reached their 1RM when their feet did not leave the ground, which was monitored and judged using the real-time force plate data. Each participant was allowed 1 further attempt at improving their 1RM after a 3-minute rest period.

When performing the jumps, the participants were instructed to apply constant downward pressure on the barbell so that it remained on their shoulders at all times (6). During pilot testing and familiarization, it was noted that when jumping with anything less than an Olympic barbell (20 kg), for example, a wooden broom handle for an essentially unloaded JS, the tension from the LPT and magnetic braking unit (MBU) (both located above the bar) made it very difficult to maintain contact with the shoulders. Therefore, loads <20 kg (including unloaded jumps) could not be explored accurately, and so this was not included in the protocol. The depth of the initial eccentric portion of the JS was not regulated, as in other studies (9,21). This was based on evidence that suggests that trained humans automatically adjust their squat depth to allow for maximal performance in movements that involve jumping (5).

AU3 *Power Measurement.* The FT 700 Power System (Fittech, Australia) was used as a performance platform and data collection tool. The system was connected to a laptop installed with the Ballistic Measurement System software (BMS, Innervations, Australia) and included a LPT, an MBU and a force plate (400Series, Fittech). The combined use of a force plate and an LPT is considered a valid method to assess BV (using LPT), VGRF (using force plate), and power output (LPT + force plate) in human participants (6,8,20). Using the same equipment and analysis, Sheppard et al. (35) previously demonstrated reliability of this approach in trained athletes (intraclass correlation coefficients ranging 0.8–0.9 for peak power, 0.95–0.97 for peak force, and AU4 0.75–0.83 for peak velocity). The MBU was used as an injury-prevention mechanism (21) to unload the landing phase of each JS, adjusted for each load so that a participant never landed with >50-kg bar load.

Before testing, the force plate and LPT were calibrated using loads and displacements spanning the range of values experienced during the JS. The sampling frequency was set at 500 Hz with sample periods being 20 seconds in length. The total system mass (bodyweight + bar load) was used in all data collection (7,31).

Analysis. Because the participants were tested at different absolute and relative loads (based on initial estimates), the data were normalized so that all the participants could be compared. The loads were expressed as percentage of the measured 1RM and then the dependent variables (PPO, VGRF, and BV) were interpolated to 'standard' percentage intervals of each individual's 1RM JS (20, 30, 40, 50, 60, 70, 80, 90, and 100% JS 1RM). Jump squats were not performed <20 kg (see above), and because this load represented various percentages of 1RM for each subject, the lowest percentage that all the subjects lifted was 20% 1RM.

Method of Interpolation. To interpolate the data sets, a cubic polynomial curve was fitted using Microsoft Excel to each of the 3 dependent variables plotted against the actual percentages of maximum load. This method was similar to that of Jandacka and Vaverka (23). These equations were then used to generate interpolated dependent variables corresponding to the 'standard' independent variables (20–100% 1RM JS at 10% intervals).

The fit of the equations was assessed in 2 ways. First, the common variance of the equation (R^2) was calculated. Mean (±*SD*) R^2 values for PPO, VGRF, and BV were 0.956 (±0.032), 0.927 (±0.092), and 0.990 (±0.012), respectively. Secondly, the standard error of the estimate was calculated and the 95% confidence interval for the regression was then computed (14). The 95% confidence intervals were 313.5 (±180.8) W, 144.6 (±85.1) N, and 0.087 (±0.050) $\text{m}\cdot\text{s}^{-1}$ for PPO, VGRF, and BV respectively. These values combined with the high R^2 coefficients indicated good curve fits.

Statistical Analyses

The standard level of significance was set at 0.05. The effects of load on PPO, VGRF, and BV were analyzed using 1-way repeated measures analyses of variance (ANOVA) after checking for normality using Shapiro-Wilk tests (14). The Greenhouse-Geisser adjustment of the degrees of freedom was applied if the Mauchly test of sphericity was compromised (14). Post hoc pairwise Bonferroni tests were then performed on significant results (14). Effect sizes were assessed using partial eta squared (partial η^2) values that were square rooted to give correlation coefficients (14) that were compared with the effect sizes given by Hopkins (19); 0.1–0.3 as small, 0.3–0.5 as moderate, 0.5–0.7 as large, and 0.7–0.9 as very large.

Friedman's nonparametric test was run for the BV data, instead of the ANOVA, because the data at 2 loads (90 and 100%) were not normally distributed. Post hoc Wilcoxon Matched Pair Signed Rank pairwise comparisons were made for each load against the subsequent load (e.g., 10 vs. 20%, 20 vs. 30%, etc.), with the α-level adjusted by dividing by the total number of post hoc tests (8).

Post hoc statistical power was calculated using G-Power software (Universitåt Kiel, Germany). The statistical power was 100% at α-levels of 0.05, 0.01, and 0.001, computed with the effect sizes (partial-eta squared) achieved in the ANOVA tests and the intertrial correlations. Finally a 'pseudo' a priori 95% power calculation was calculated to show that sample sizes of 2, 3, and 2 for the ANOVAs would have been sufficient to be 95% certain of finding the effect sizes actually seen.

RESULTS

Peak Power Output

For PPO, the result from the ANOVA showed a significant Load effect on PPO (Greenhouse-Geisser Epsilon = 0.318, $F_{2.5,\ 25.5} = 107.1$, $p < 0.001$, partial $\eta^2 = 0.915$, Very Large Effect), with PPO highest at 20% 1RM JS (4,509 ± 701 W; 46.9 ± 8.4 $\text{W}\cdot\text{kg}^{-1}$ BM) and decreasing as the additional load was increased. Pairwise comparisons showed significant differences between power outputs at all the percentages of maximum except between 20 and 30%. Figure 1 shows the F1 interpolated PPO, peak VGRF and peak BV plotted against load.

Peak Force

For peak VGRF, the ANOVA showed a significant Load effect on peak force output (Greenhouse-Geisser Epsilon = 0.164, $F_{1.3,\ 13.1} = 58.5$, $p < 0.001$, partial $\eta^2 = 0.854$, Very Large Effect), with VGRF increasing as the additional load was increased to a highest value at maximum load (2,126 ± 285 N).

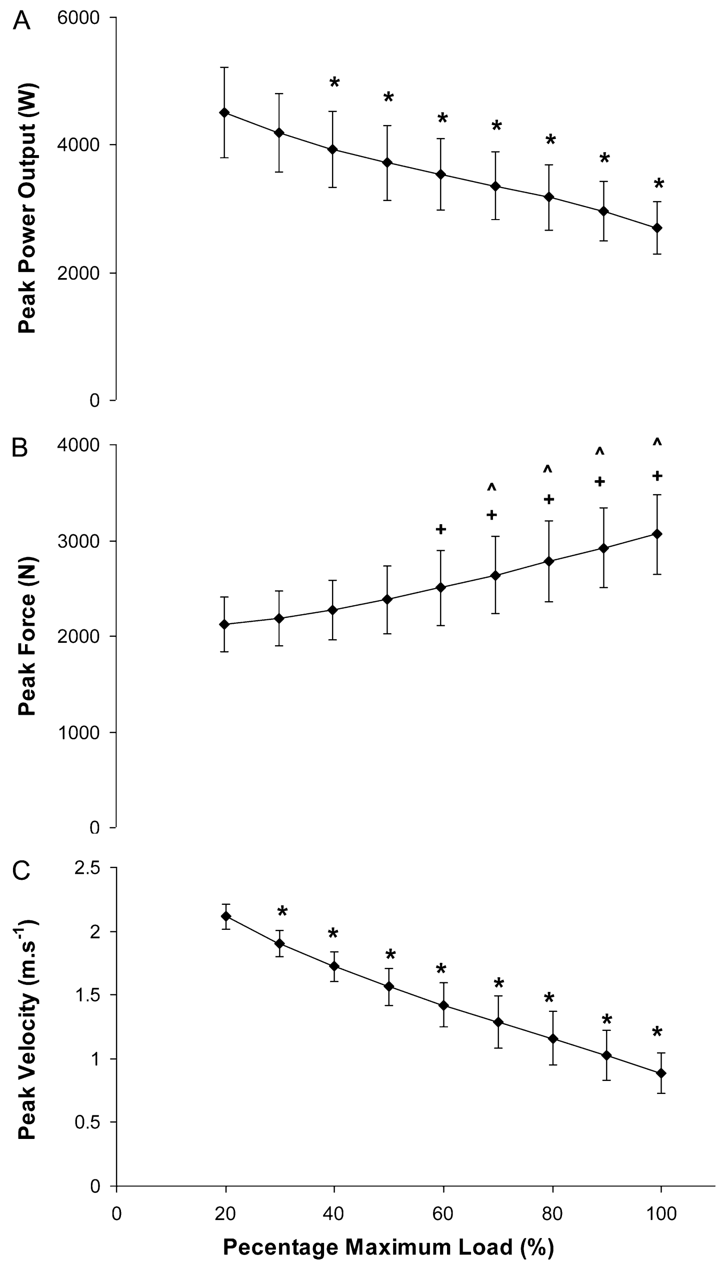

Figure 1. Interpolated peak power output (A), peak vertical ground reaction force (B), and peak bar velocity (C) vs. percentage maximum load during loaded jump squats at incremental loads. *Peak power output (PPO) or peak barbell velocity (BV) significantly lower than at 20% load, $p < 0.01$. +Force significantly greater than at 30% load, $p < 0.001$. ^Force significantly greater than at 20% load, $p < 0.001$.

The pairwise comparisons gave significant differences between forces at all percentages of maximum except 20 vs. 30, 40, 50, and 60% and 30 vs. 40 and 50%.

Peak Velocity

Peak BV occurred at 20% 1RM (2.1 ± 0.1 $m \cdot s^{-1}$) and BV decreased as additional load was increased. The Friedman test resulted in a Chi-Square value of 87.8 and a significance of $p < 0.001$. Pairwise Wilcoxon tests gave significance values of $p = 0.003$ for all comparisons, except for 90 vs. 100%, which was $p = 0.004$, all below the Bonferroni adjusted α-level of 0.006.

DISCUSSION

The purpose of this study was to evaluate the influence of load on PPO, peak VGRF and peak BV during loaded JSs in a group of professional rugby players. In support of our initial hypothesis, the incremental additional load had significant effects on all dependent variables. Peak power output was elicited at the lowest load tested (20% 1RM JS), with lower values as load was increased although this was not significant between 20 and 30% 1RM JS. Also in support of our hypotheses, the peak VGRF was elicited at the highest load (100% 1RM JS), with lower values at each lower load, although these differences were not significant between 20 and 60% 1RM JS. Additionally, in support of our hypotheses, the peak BV was elicited at the lightest load (20% 1RM JS significantly greater than all other loads) with anticipated decreases in peak BV as load was increased. To our knowledge, these are the first force, velocity, and power data in the maximum loaded JS across a range of loads up to 1RM in resistance-trained professional rugby union players.

This study identified the optimal load for PPO and measured PPO, BV, and VGRF at incremental loads with good data resolution, in comparison with many existing protocols that use only a few arbitrary loads and in a single in-season testing session without injury by using eccentric braking. Therefore, the data can be used to design training programs for these athletes based on optimal load (1,2,17,18,25,27,32, 33,42), and knowing how PPO, VGRF, and BV will be affected when training across a range of loads, as has been recommended by others (9,41,43). The analysis also demonstrated the value in using data interpolation techniques across this range to complete the profiles (16,23). Such data enable the force and velocity at each load to be explored to explain the individual power relationship in greater detail. Many authors propose that the optimal load, for example, should be assessed on an individual basis rather than using average fixed relative loads (1,2,28). Such information could be used to inform training prescription based on the sporting demands specific to that individual (i.e., emphasis on forces and velocities encountered) and identify specific weaknesses in the force-velocity relationship that could be targeted to provide the most effective training stimulus for that athlete (35). Another rationale behind individually assessing the wider range of loads stems from research findings where large bandwidths of optimal loads (without significant effect on PPO) have been reported (e.g. [9,28]), reflecting that the optimal load for PPO (even in relative terms) demonstrates considerable variability between individuals, with maximal strength possibly a key factor (39). For example, in this investigation, individual power curves show a range of gradients at the lowest loads such that some athletes were beginning to plateau (reach the peak of the power load curve and hence their own optimal load), whereas others would clearly have had higher PPO at lower loads. This may explain the lack of a significant difference in PPO between 20 and 30% 1RM in the current investigation, although this was close to significance. It is unlikely that this represents a type II statistical error, given the very large effect sizes and reported statistical power.

This observation highlights the limitation of the current investigation in not assessing PPO in the JS with BM only. However, this was a factor of the study design because of technical factors discussed in the methods section. Interestingly, in some studies, it is unclear if the lowest loads also included barbell mass and therefore are truly unloaded jumps. In any case, a very recent study (34) has further extended this range of loads in JS by using unloading apparatus, and loading, during the JS in resistance trained (RT) athletes. Nuzzo et al. (34) presented data in support of the Maximum Dynamic Output Hypothesis (24), which postulated that in untrained healthy individuals the optimal load for jumping should be BM because this is the load that the leg extensors are habitually contracting against. Nuzzo et al. (34) showed that JS with BM-only elicited significantly higher PPO than lower and greater loads, even in this RT population. This finding is in contrast to the commonly cited article of Stone et al. (39), which proposed that stronger athletes required higher relative loads to elicit PPO. A possible explanation for this finding, highlighted by Nuzzo et al. (34), was that the participants in their study were simply not as strong, with factors such as strength, BM and type of resistance training having been shown to have a significant effect on the power-load spectrum (2,7,39). In this regard, it is worth noting that the participants of this study were heavier and able to JS with loads typically greater than the 1RM squat in the study by Nuzzo et al. (mean JS 1RM 184 kg or 1.89 × BM vs. mean squat 1RM 168 ± 28 kg or 1.96 × BM), but lower than the 1RM squat in the strong group of Stone et al. (mean JS 1RM 212 kg or 2.0 × BM). Therefore, it remains to be confirmed if the optimal load for PPO is still BM-only in the strongest of athletes, for example, power lifters. Furthermore, this relationship importantly remains to be explored more accurately in other populations, for example, female and older and younger participants. Further explanation may reside in the depth of squat used during the JS protocols, which has variably been controlled.

As mentioned above, the finding that PPO occurs at lower loads during the JS is in contrast to some existing studies (2,36,37), although most of the studies cannot be compared because of the many methodological differences (6,13). The current data do support the findings of some of the well-controlled investigations using lower-body ballistic exercises in trained populations (31,39,40,42). For example, the findings and values are similar to those of Cormie et al. (9) and Sheppard et al. (35), who used a similar technology and also used trained athletes. Both of these studies demonstrated that PPO was recorded at the lightest loads used (BM only). However, the power outputs recorded in the current investigation (4,509 ± 701 W) are noticeably lower than recorded by Cormie et al. (6,437 ± 1, 046 W (9)) and Sheppard et al. (7,386 ± 324 W (35)), but similar to McBride et al. (3,775 ± 951 W [31]). The main underpinning factor in these differences appears to be the peak velocities achieved at the lightest loads (2.11 ± 0.10 $\text{m}\cdot\text{s}^{-1}$ in this study vs. 3.66 ± 0.26 (9) and 3.47 ± 0.23 $\text{m}\cdot\text{s}^{-1}$ [35]). Peak forces in this study at the lowest load (2,126 ± 285 N) were closer to those of Cormie et al. (1,990.5 ± 339 N, [9]) and Sheppard et al. (2,330 ± 196 N [35]). One possible explanation for these findings is that the values in those studies were recorded during the JS with BM only, compared with BM + 20% 1RM in the current investigation. Based on the shape of the velocity-load relationship shown in Figure 1 and existing data (e.g., [31]), it is highly likely that higher velocities and power outputs would be recorded in our athletes jumping against BM only. Indeed the values reported by McBride et al. (31) support this, although their participants had lower 1RM squat values than the 1RM JS values in the current investigation, illustrating differences in strength levels.

Interestingly, the other available data for professional rugby players (4) reported similar values for PPO in the JS (4,256 ± 489 W) at a load similar to 20% 1RM JS (20% 1RM squat). However, the velocity data were not reported, and VGRF was not recorded (LPT only) meaning that PPO was estimated. As mentioned previously, Dugan et al. (13) and Cormie et al. (6) have demonstrated that for accurate measurement of force, velocity, and power output during the JS, a combination of force plate and LPT is required. Although all of the data are not available for direct comparison, because the PPO values are so similar in this study and in Bevan et al. (4), this may imply that the LPT alone may be of some practical use for the indirect estimation of PPO during the JS in professional rugby players. This would be considerably more feasible in many strength and conditioning settings where force plate equipment and analysis software may not be accessible, accepting the limitations regarding accuracy.

It is also worth noting that as the load was increased in the current investigation, peak velocity was the most sensitive variable measured, with significant differences between all loads. Peak VGRF changes were more variable, as shown by the error bars in Figure 1 and the lack of significant differences in peak VGRF between 20 and 60% 1RM JS. Combined with the comparison with existing data (9,35) above, this information highlights the importance of peak velocity for PPO during the JS and other ballistic exercises (16). Consequently, the monitoring of BV during training is recommended to ensure that athletes are achieving PPO in sessions, perhaps using a minimum threshold % of peak BV at that load.

Conclusions

Peak power output, peak VGRF, and BV are significantly affected by the amount of additional load during the loaded JS in professional rugby players. The PPO is elicited using the lightest load used (20% 1RM JS) with decreases in PPO at greater loads. As anticipated with incremental increases in load, peak VGRF increased and peak BV decreased. The power, force, and velocity relationship can be accurately measured in professional rugby players across a full range of loads (up to 1RM) for the JS in a single session in a competitive phase without injury when eccentric braking is used in combination with a force plate and LPT. Characterization across this full spectrum of loads on an individual basis will enable greater precision for monitoring training-induced improvements, assessing individual weaknesses, and for prescription of training.

Practical Applications

This study presents relevant data for professional rugby union players that can be compared with those of athletes trained for other sports. The findings add to the increasing body of evidence supporting that the optimal load for PPO during the JS occurs at the lowest loads used, even in trained professional rugby union players. Such information is useful for the strength and conditioning coaches seeking to train at the optimal load for PPO during the JS, although there are good arguments supporting training at a range of loads, and hence velocities, specific to the sport. This study illustrates how peak VGRF and peak BV are affected over such a range of loads accordingly, such that trainers can make more informed decisions. This study also demonstrates that it is feasible and safe to fully characterize the PPO, BV, and VGRF across a full range of loads up to 100% 1RM during a single session. However, based on existing evidence, for accuracy, it is recommended that a combination of force plate and LPT is used, and for safety, an MBU can also be employed. Such data enable the strength and conditioning coach to assess individual strengths and weaknesses across the force-velocity relationship, such that programs can be tailored accordingly and can accurately monitor the effectiveness of varying interventions across the range.

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