Optimal Loading for Peak Power Output During the Hang Power Clean in Professional Rugby Players

Liam P. Kilduff, Huw Bevan, Nick Owen, Mike I.C. Kingsley, Paul Bunce, Mark Bennett, and Dan Cunningham

Purpose: The ability to develop high levels of muscle power is considered an essential component of success in many sporting activities; however, the optimal load for the development of peak power during training remains controversial. The aim of the present study was to determine the optimal load required to observe peak power output (PPO) during the hang power clean in professional rugby players.

Methods: Twelve professional rugby players performed hang power cleans on a portable force platform at loads of 30%, 40%, 50%, 60%, 70%, 80%, and 90% of their predetermined 1-repetition maximum (1-RM) in a randomized and balanced order.

Results: Relative load had a significant effect on power output, with peak values being obtained at 80% of the subjects’ 1-RM (4466 ± 477 W; \( P < .001 \)). There was no significant difference, however, between the power outputs at 50%, 60%, 70%, or 90% 1-RM compared with 80% 1-RM. Peak force was produced at 90% 1-RM with relative load having a significant effect on this variable; however, relative load had no effect on peak rate of force development or velocity during the hang power clean.

Conclusions: The authors conclude that relative load has a significant effect on PPO during the hang power clean: Although PPO was obtained at 80% 1-RM, there was no significant difference between the loads ranging from 40% to 90% 1-RM. Individual determination of the optimal load for PPO is necessary in order to enhance individual training effects.

Key Words: force platform, relative intensity, peak rate of force development, force–time curve

The ability to develop high levels of muscle power is considered an essential component of success in many sport activities. For example, Sleivert and Taingahue\(^1\) reported negative correlations between relative peak power output (PPO) during the split squat and 5-m-sprint time \((r = –.65)\) and relative PPO during the traditional squat and 5-m-sprint time \((r = –.66)\), which might indicate that increasing PPO will lead to an improvement in sprinting performance, a primary performance outcome.
in many team sports. Consequently, training at the optimal load for peak power development could have important implications for improving PPO and therefore sport performance. To date, there is no uniform agreement between researchers on the optimal load for peak power development, with researchers suggesting that PPO can be produced when working against external loads that equate to 40% to 70% of 1-repetition maximum (1-RM) during upper body exercises and 40% to 80% of 1-RM for lower body exercises.

This conflict in the literature with regard to the optimal load for PPO during upper and lower body exercises can in part be explained by numerous methodological differences in the various studies, such as the reporting of average versus peak power values and the use of different data-collection equipment (eg, equipment using displacement data only to calculate power vs equipment using displacement and force data to calculate power).

Another issue that makes comparisons between the various studies difficult is the different exercises used to measure the optimal load for PPO. Most studies have examined the optimal load for PPO during traditional upper (bench press or ballistic bench press) and lower (squats or jump squats) body resistance-training exercises. It is well established, however, that Olympic-style weightlifting movements (eg, snatch, power clean, and hang power clean) produce power outputs that are far in excess of those obtained during the traditional squat- and bench-press-type movements. For example, Stone reported a power output of 3000 W during a barbell snatch compared with 1100 W during a traditional squat exercise in the same lifter, which emphasizes the important role Olympic lifts play in the development of power.

To date, there has been a paucity of research examining the optimal load for PPO during the various Olympic-style weightlifting exercises. Only 1 study has directly examined the optimal load for PPO during the hang power clean. Kawamori et al reported the power outputs during the hang power clean in a group of NCAA Division II athletes at relative intensities ranging from 30% to 90% of 1-RM. They concluded that relative intensity had a significant effect on power output during the hang power clean and that PPO was generated at 70% 1-RM; however, there was no significant difference between the power outputs produced at 50%, 60%, 80%, and 90% 1-RM when compared with 70% 1-RM.

The aim of the current study was to determine the optimal load for PPO during the hang power clean in a group of professional rugby players.

**Methods**

**Experimental Approach to the Problem**

In the current study, 12 professional male rugby players performed maximal-effort hang power cleans on a portable force platform (Kistler portable force platform, model 9286AA) at loads of 30%, 40%, 50%, 60%, 70%, 80%, and 90% of each subject’s predetermined 1-RM in a randomized and balanced order, with 3 attempts at each load. After data collection the players’ hang power cleans at all relative loads were analyzed for power, ground-reaction force (GRF), velocity, and rate of force development (RFD).
Subjects

Twelve professional male rugby players (Table 1) from whom written informed consent had been obtained volunteered to take part in the present study, which was approved by the local ethics committee. Players were recruited on the basis that they had been engaged in a structured weight-training program for at least 2 years before the start of the study and were able to complete the hang power clean with correct technique as assessed by a qualified strength and conditioning coach. The average resistance-training experience of the present group of subjects was 2.5 ± 1.4 years.

Experimental Procedures

Before commencement of the main experimental trial, subjects visited the laboratory to become familiar with the testing methods and to have their 1-RM hang power clean measured. Forty-eight hours after the familiarization and strength-testing session, all subjects underwent an additional testing session.

Subjects reported to the laboratory on the morning of testing after having refrained from alcohol, caffeine, and strenuous exercise the day before. After the measurement of each subject’s height and weight and a standardized warm-up, subjects performed a maximal-effort hang power clean on a portable force platform at loads of 30%, 40%, 50%, 60%, 70%, 80%, and 90% of their predetermined 1-RM in a randomized and balanced order, with 3 attempts at each load. Verbal encouragement was given to maximize performance.

Strength Testing

Before the start of the strength-testing session, all subjects underwent a standardized warm-up composed of 5 minutes of light-intensity cycling followed by a series of dynamic movements with an emphasis on warming up the muscles associated with the hang power clean. Subjects then performed 3 warm-up sets of 3 repetitions at approximately 50%, 60%, and 70% of their estimated 1-RM. After this they attempted 1 repetition of a set load, and, if they were successful, the lifting weight was increased until they could not lift the weight through the full range of motion. The hang-power-clean technique was carried out as previously described. Subjects lowered the barbell to the hang position (just above the knee) and then with triple extension of the knee, hip, and ankle lifted the barbell explosively in a vertical plane and caught the bar on their shoulders in a quarter-squat position.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>102.1 ± 11.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>186 ± 6</td>
</tr>
<tr>
<td>Age (y)</td>
<td>25 ± 4</td>
</tr>
<tr>
<td>1-repetition-maximum hang power clean (kg)</td>
<td>107 ± 13</td>
</tr>
<tr>
<td>Professional rugby experience (y)</td>
<td>5 ± 3</td>
</tr>
</tbody>
</table>

Table 1 Physical Characteristics of Subjects at Baseline (N = 12)
subjects had been previously exposed to 1-RM testing for the hang power clean. A 5-minute rest was imposed between all attempts to allow subjects adequate time to replenish energy stores. The 1-RM was determined after 3 or 4 attempts by each subject.

**Power Testing**

On entering the laboratory for the power-testing session, subjects completed the same warm-up as on the strength-testing day. After a 10-minute recovery period they performed maximal-effort hang power cleans on a portable force platform at loads of 30%, 40%, 50%, 60%, 70%, 80%, and 90% of their predetermined 1-RM in a randomized and balanced order, with 3 attempts at each load and a 5-minute recovery period between loads. The hang power cleans were performed in the same manner as described in the strength-testing section, with subjects been instructed to lift the barbell as explosively as possible with correct technique.

**Force Platform**

A Kistler portable force platform with built-in charge amplifier (Type 9286AA, Kistler Instruments Ltd, Farnborough, UK) was used for data collection for the GRF time history during the hang power clean. Throughout the testing the GRF were sampled at 500 Hz, and the force platform’s calibration was confirmed before and after testing.

**Data Analysis**

The vertical component of the GRF of a subject performing a hang power clean was used in conjunction with the weight of the subject–bar system (the combined effect of the subject and the weight of the bar) to calculate the instantaneous power, velocity, and RFD of the subject–bar’s center of gravity.\(^\text{16}\)

Power was calculated using the standard relationship: Power (W) = vertical GRF (N) × vertical velocity of the center of gravity of the subject–bar system. The velocity of the center of gravity of the subject–bar system was calculated by numerically integrating the net vertical GRF (Net vertical GRF = vertical GRF – weight of the subject–bar system). Numerical integration was performed using the trapezium rule for intervals equal to the sample width. The area of a strip, of width equal to the sample width, thus represented the impulse during that time interval. Using the relationship that impulse equals change in momentum, the strip area was then divided by the mass of the subject–bar system to produce a value for the change in velocity of the center of gravity of the system. This change in velocity was then added to the center of gravity’s previous velocity to produce a new velocity at time equal to that particular interval’s end time.

Instantaneous RFD was calculated from the first derivative of the vertical GRF. Before numerical differentiation the vertical GRF was filtered using a dual-pass Butterworth filter (low-pass, 15-Hz cutoff). Filter settings were determined from a pilot study and based on Fourier analysis and inspection. Peak RFD (PRFD) was taken as the highest RFD in the concentric phase of the lift.

Test–retest reliabilities for peak power, peak GRF, peak velocity, and PRFD were intraclass correlations .96, .98, .98, and .95, respectively.
Statistical Analysis

After a test for the normality of distribution, data were expressed as mean ± SD. Statistical analysis was carried out using a repeated-measures 1-way analysis of variance (ANOVA) to determine whether there was a significant difference between the relative intensities for peak power (PP), peak ground-reaction force (PF), peak velocity of the center of mass of the player plus bar (PV), and PRFD. When significant $F$-values were observed ($P \leq .05$), paired comparisons were used in conjunction with Holm’s Bonferroni method for control of type I error to determine significant differences. Effect sizes (ES) are also presented in the Results section. The level of significance was set at $P \leq .05$ in the present study, and all statistical analyses were performed using SPSS 13.1 (SPSS Inc, Chicago, Ill).

Results

Power Output During the Hang Power Clean

Statistical analysis revealed that relative load (%1-RM) had a significant effect on power output during the hang power clean ($F = 20.56$, ES 0.70, $P < .001$). Peak values for power output during the hang power clean were observed at a relative load of 80% 1-RM in our group of players (Table 2, Figure 1[C]). The power outputs generated during the hang power clean at the relative loads of 50%, 60%, 70%, and 90% 1-RM were not significantly different from that at 80% 1-RM (Table 2, Figure 1[C]).

Paired comparisons revealed no significant difference between 30% and 40% 1-RM in terms of power output during the hang power clean (3246 ± 553 vs 3495 ± 669 W, mean ± SD; $P = .346$), but the power outputs at these 2 relative loads were significantly lower than those at other loads (Table 2, Figure 1[C]).

Table 2 Performance Characteristics During the Hang Power Clean at Various Relative Loads

<table>
<thead>
<tr>
<th>Load (% 1-repetition maximum)</th>
<th>Velocity (m/s)</th>
<th>Force (N)</th>
<th>Rate of force development (N/s)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>1.58 ± 0.23</td>
<td>2799.6 ± 422.1</td>
<td>27,999 ± 11,237</td>
<td>3246.0 ± 552.8</td>
</tr>
<tr>
<td>40%</td>
<td>1.50 ± 0.23</td>
<td>2945.5 ± 372.5</td>
<td>27,741 ± 11,190</td>
<td>3494.7 ± 669.1</td>
</tr>
<tr>
<td>50%</td>
<td>1.61 ± 0.21*</td>
<td>3087.9 ± 469.3</td>
<td>28,253 ± 10,841</td>
<td>3902.0 ± 572.1</td>
</tr>
<tr>
<td>60%</td>
<td>1.60 ± 0.17</td>
<td>3274.5 ± 526.6</td>
<td>29,802 ± 13,043</td>
<td>4203.7 ± 588.4</td>
</tr>
<tr>
<td>70%</td>
<td>1.61 ± 0.13</td>
<td>3327.1 ± 502.8</td>
<td>25,241 ± 12,307</td>
<td>4346.9 ± 600.0</td>
</tr>
<tr>
<td>80%</td>
<td>1.59 ± 0.12</td>
<td>3487.0 ± 526.6</td>
<td>28,948 ± 16,340</td>
<td>4467.0 ± 477.2*</td>
</tr>
<tr>
<td>90%</td>
<td>1.51 ± 0.12</td>
<td>3544.2 ± 551.9*</td>
<td>29,858 ± 17,663*</td>
<td>4357.5 ± 623.0</td>
</tr>
</tbody>
</table>

*Peak values were obtained.
Figure 1 — (A) Velocity, (B) force, (C) power, and (D) peak rate of force development (PRFD) at loads 30% to 90% 1-repetition maximum (1-RM) during the hang power clean. †Significantly greater than 30% to 70% 1-RM. *Significantly greater than 30% to 40% 1-RM.
Velocity During the Hang Power Clean

PV during the hang power clean was observed at the relative load of 50% 1-RM, with a PV of 1.61 ± 0.21 m/s. Statistical analysis generated by the ANOVA revealed that relative load (% 1-RM) had no significant effect on velocity produced during the hang power clean ($F = 1.265, ES 0.12, P = .29$; Table 2, Figure 1[A]).

Force Output and RFD During the Hang Power Clean

The repeated-measures 1-way ANOVA revealed a significant effect of relative load on GRF during the hang power clean ($F = 28.658, ES 0.76, P < .001$). PF was recorded at the highest relative load (90% 1-RM) during the hang power clean, which was not significantly different from the force recorded during the hang power clean at 80% 1-RM (Table 2, Figure 1[B]). The force produced during the hang power clean at 80% and 90% 1-RM was significantly greater, however, than the force produced at any of the other relative loads (Table 2, Figure 1[B]).

PRFD was also produced during the hang power clean at 90% 1-RM, but again this was not significantly different from the RFD at any of the other relative loads ($F = 0.445, ES 0.05, P = .85$; Table 2, Figure 1[D]).

Discussion

The primary finding of the present study was that PPO was maximized at 80% 1-RM during the hang power clean in our group of professional rugby players. There was no significant difference, however, between the power output at 80% 1-RM and the power outputs at 50%, 60%, 70%, and 90% 1-RM, which indicates that the optimal load for PPO is a very individual response (Table 2, Figure 1[C]). To maximize the power output during any exercise there must be a compromise between the 2 variables that contribute to power development, namely, force and velocity. For example, if the external resistance is too high, the velocity of movement will be low, and hence PPO will not be optimized. In the current study this compromise was achieved at a relative load of 80% 1-RM.

This maximal PPO at 80% 1RM is slightly higher than that reported by Kawamori et al (70% 1-RM). In the current study, however, and that by Kawamori et al there was no significant difference between the power output at a range of loads (50% to 90% 1-RM), which indicates large intraindividual responses to optimal loading for PPO. It is therefore difficult to determine whether these results are conflicting. If the interpretation is that they are, some researchers would suggest that the strength level of the athletes might have been a confounding factor. For example, Stone et al reported that the load that maximized PPO was higher during the squat jump in a group of stronger subjects (40% 1-RM) than in their group of weaker subjects (10% 1-RM); however, not all researchers agree with this hypothesis. In the present study the 1-RM for our group of subjects was 107 ± 13 kg compared with the 1-RM of 107 ±19 kg in the Kawamori et al study, which would suggest no real strength difference between the 2 subject groups. In addition, the different strength levels of the subjects in our study help explain the findings that the power outputs at 50%, 60%, 70%, 80%, and 90% 1-RM were similar. Subjects in the present study had 1-RM hang power cleans between 93 and
132 kg, again showing large variance in strength levels. According to Stone et al, this magnitude of variation would lead to subjects’ attaining their PPO at different relative loads. This point requires further investigation, however. The test–retest results (ICCs) for all performance measures in the present study were good and in line with previously published values for these measures. We are confident that variability in the results is attributable primarily to (true) individual variation and not simply to variability of testing measures.

Further support of our findings comes from the study by Haff et al, who reported that PPO was attained at 80% 1-RM during the hang power clean. In that study, however, the authors only examined the power outputs against 3 external resistances (80%, 90%, and 100% 1-RM) and failed to present statistical information on the comparison between the 3 measured relative intensities. Therefore, it cannot be discounted that PPO might have been attained at a relative load of less than 80% 1-RM.

The main finding of the present study will provide athletes with appropriate direction in the development of peak power during the hang-power-clean exercise. Training at the load that produces PPO can be effective in improving maximal muscle power, which in turn can lead to improvement in a range of dynamic performance variables. For example, Kaneko et al reported that subjects training at a variety of relative intensities (0%, 30%, 60%, and 100% maximum isometric force) produced their greatest gains in PPO at the relative intensity equal to the intensity at which PPO was produced during this elbow-extension exercise (30%).

The results of the current study indicate that higher relative loads are required to generate PPO during the hang power clean than during the more traditional squat jumps (40% to 80% 1-RM) and ballistic bench press (40% to 70% 1-RM). The potential factors contributing to these differences include the type of muscle action involved, strength level of subjects, and single- versus multiple-joint exercises.

Subjects in the present study produced PPO of 4554 ± 551 W at 80% 1-RM, which is higher than the PPO reported for the same players during the ballistic bench press (873 ± 24 W) and squat jump (4291 ± 84 W; unpublished data). This finding supports the work of Stone et al and emphasizes the need to incorporate Olympic lifts during power training of rugby players. In addition, this highlights the need to individually determine the optimal load for PPO for all major exercises used during training (eg, squat jumps, bench press).

Peak ground forces increased as a function of load (Table 2), which is in agreement with previous studies. In the study by Kawamori et al and in the present study PRFD was unaffected by relative load, which is in agreement with the findings of Schmidtbleicher, who reported that PRFD is equal for all loads higher than 25% of maximum force. Subjects in the present study produced a PRFD of 287 ± 147 N·s⁻¹·kg⁻¹ compared with 234.5 ± 95 N·s⁻¹·kg⁻¹ in the study by Kawamori et al; however, direct comparison between the 2 studies is very difficult in terms of PRFD because of varying ways of calculating PRFD. To determine a peak value for RFD it is necessary to obtain an instantaneous value by taking the first derivative of force with respect to time. Differentiation has a tendency to amplify any noise present in the raw signal, and therefore filtering the original force–time history is necessary to overcome this limitation. In the current study a Butterworth low-pass filter was used with a cut-off frequency of 15 Hz (dual pass) with different filter
settings altering the PRFD values, so direct comparison is not necessarily meaningful unless the same filter settings were used. The filter setting used in the study by Kawamori et al.\textsuperscript{16} was not stated in their Methods section.

In conclusion, the results from the current study indicate that relative intensity had a significant effect on PPO during the hang power clean and that peak values were obtained in our athletes when they were working against an external load equivalent to 80% 1-RM of their hang power clean. There was no significant difference, however, between the power outputs at the loads ranging from 40% to 90% 1-RM, which indicates that individual determination of the optimal load for PPO is necessary to enhance individual training effects. In addition, because of the various physiological demands placed on rugby union players during games, they require all the components of strength and power along the strength continuum. Therefore, players might benefit from training against a variety of training loads, for example, <30% 1-RM for speed–strength development and >80% 1-RM for strength–speed development.

**Practical Application**

The power output during Olympic-style lifts is greater than the power outputs during the more traditional squat and bench-press activities, so power-based training programs should incorporate Olympic lifts and their various derivatives. Training at the optimal load for PPO can be beneficial in improving maximal power output and athletic performance. It is important that coaches be aware of the optimal load for peak power production. This study highlights the large individual responses to the optimal load for PPO. Individual determination of athletes’ optimal load for PPO is required to effectively develop their power-generating capabilities.

**References**


