OPTIMAL LOADING FOR THE DEVELOPMENT OF PEAK POWER OUTPUT IN PROFESSIONAL RUGBY PLAYERS

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1Sports and Exercise Science Research Group, Swansea University, Swansea, United Kingdom; 2Bath Rugby, The Recreation Ground, Bath, United Kingdom; 3School of Exercise, Biomedical and Health Science, Edith Cowan University, Joondalup, Australia; and 4UKsport, Bath University, Bath, United Kingdom

ABSTRACT

Bevan, HR, Bunce, PJ, Owen, NJ, Bennett, MA, Cook, CJ, Cunningham, DJ, Newton, RU, and Kilduff, LP. Optimal loading for the development of peak power output in professional rugby players. J Strength Cond Res 24(1): 43–47, 2010—The ability to develop high levels of muscular 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. Our aim in the present study was to determine the optimal load required to observe peak power output during the ballistic bench throw (BBT) and squat jump (SJ) in professional rugby players. Forty-seven, professional, male, rugby players of (mean ± SD) mass 101.3 ± 12.8 kg and height 1.82 ± 0.08 m volunteered and gave informed consent for this study, which was approved by a university ethics committee. Players performed BBT at loads of 20, 30, 40, 50, and 60% of their predetermined 1 repetition maximum (1RM) and SJ at loads of 0, (body mass only), 20, 30, 40, 50, and 60% of their predetermined 1RM in a randomized and balanced order. Power output (PO) was determined by measurement of barbell displacement with subsequent calculation of velocity, force, and power. Relative load had a significant effect on PO for both the BBT (Effect size $\eta^2$: 0.297, $p < 0.001$) and SJ (Effect Size $\eta^2$: 0.709, $p < 0.001$). Peak power output was produced when the athletes worked against an external load equal to 30% 1RM for the upper body and 0% 1RM for the lower body.

KEY WORDS ballistic bench throw, jump squat, ballistic exercise

INTRODUCTION

The ability to develop high levels of muscular power is considered an essential component of success in many sporting activities. For example, Sleivert and Taingahue (19) reported negative correlations between relative peak power output (PPO) during the split squat and 5 m sprint time ($r = -0.65$) and relative PPO during the traditional squat and 5 m sprint time ($r = -0.66$), which may indicate that increasing PPO will lead to an improvement in sprinting performance, a primary performance outcome in many team sports. Consequently, researchers have examined the effectiveness of various training methods proposed to enhance power. These training methods have included athletes trying to develop power while working against their body mass (BM) (e.g., plyometrics) and also while working against external loads that equate to various intensities of their 1 repetition maximum (1RM) (40–70% during upper-body exercises (e.g., (3,17)), BM: 60% for lower body exercises (e.g., (4,10,20)), and 80–100% for Olympic-style weightlifting movements (e.g., (12,13)).

One training strategy consistently identified as a possible method for developing PPO requires athletes to train at the optimal load that maximizes PPO (8,14,16); however, to date, there is no uniform agreement between researchers on the optimal load for peak power production with researchers suggesting that PPO can be produced when working against external loads that equate to 0–80% of 1RM (3–5,11–13,16,21). 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 vs. peak power values, the use of different data collection equipment (e.g., equipment using displacement data only to calculate power vs. equipment using displacement and force data to calculate power), inclusion of barbell only or entire system mass in calculation (6), strength levels of the subjects (2), and the reporting of average vs. peak power values (e.g., (2,16)). For example, Baker (2) reported that stronger athletes produced maximal power output (PO) at lower percentages of their 1RM compared with weaker athletes in both the
Optimal Loading for Peak Power Output

ballistic bench throw (BBT) and squat jump (SJ), whereas Stone et al. (20) on the contrary reported stronger athletes to produce maximal power at higher percentage of maximum load (40% 1RM) in jump squat than weaker subjects (10% 1RM). Another confounding factor that adds to the conflict in the literature is the reporting of the optimal load of peak power vs. mean power development. For example, in the study by Baker et al. (4), they report that the optimal load for maximizing PO is in the range of 47–63% of the subjects’ 1RM for the lower body compared with the work by Cormie et al. (5) who report 0% of 1RM (BM only) as optimal. At first, these results may seem very conflicting, but in the study by Baker et al. (4), they are reporting the optimal load for average PO compared with Cormie et al. (5) who are reporting the optimal load for PPO.

Therefore, in light of the above, the aim of the present study was to determine the optimal load for PPO during the both the jump squat and bench press throw (BPT) in a group of professional rugby players.

METHODS

Experimental Approach to the Problem

During this within-subject design study, each subject was required to attend the laboratory on at least 3 occasions. The objective of the first testing session was to determine the subject’s 3RM for the squat and bench press; in addition, the subjects were familiarized to the study procedures that were to follow. During the experimental days, subjects were required to perform maximal effort bench press throws (BBT) and jump squats (JS) at various loads of their predetermined 1RM in a randomised and balanced order, with 3 attempts at each load to help identify the optimal load for peak power development.

Subjects

Forty-seven, 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 university ethics committee. Testing took place during the final week of pre-season training (end of August), and the players had just finished a phase of power development.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Weight (kg)</td>
<td>101.3 ± 12.8</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>184 ± 8</td>
</tr>
<tr>
<td>Age (decimal years)</td>
<td>25.5 ± 4.8</td>
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<tr>
<td>1RM bench press (kg)†</td>
<td>124 ± 19</td>
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<tr>
<td>1RM back squat (kg)†</td>
<td>181 ± 24</td>
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</table>

*Values are mean ± SD.
†Estimated from their 3RM strength testing.

Power Testing. On entering the laboratory for the optimal loading testing sessions, subjects completed an identical training. Players were recruited on the basis that they were engaged in a structured weight-training program for at least 2 years before the start of the study and were able to complete the BBT and JS with correct technique as assessed by a qualified strength and conditioning coach.

Experimental Procedures

Before the commencement of the main experimental trial, subjects visited the laboratory to become familiar with the testing methods and to have their 1RM bench press and back squat measured. During the familiarization trial, subjects practiced performing the JS and BBT. 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 stature and BM, subjects underwent a standardized warm-up that comprised 5-minute light intensity cycling, followed by a series of dynamic stretches with an emphasis on stretching the musculature associated with the BBT and JS depending on the testing session.

On test day 1 after the standardized warm-up, subjects performed a maximal effort BBT on a Smith machine at loads of 20, 30, 40, 50, and 60% of the subject’s predetermined 1RM in a randomized and balanced order, with 3 attempts at each load. Verbal encouragement was given to maximize performance.

On test day 2, lower body testing was carried out at the same time of day and in the same manner as upper body testing with the exception where weighted JS replaced the BBT as the modes of exercise and subjects completed an additional load of 0% 1RM (BM only) for the jump squats. Only 36 players performed the JS protocol because of injury or technical issues with the JS.

Consumption of water (500 ml) was permitted during each test. Room temperature was maintained between 20 and 24°C. Verbal encouragement was given to maximize performance.

Measurements

Strength Testing. Before the start of the strength testing session, all subjects underwent a standardized warm-up that comprised light intensity cycling for 5 minutes, followed by a series of dynamic movements with an emphasis on warming up the musculature associated with the squat or bench press. Subjects then performed 3 warm-up sets of 10 repetitions at 50% of their estimated 1RM. After the warm-up sets, subjects attempted 3 repetitions of a set load, and if successful, the load was increased until the subject could not lift the weight through the full range of motion. All subjects had been previously exposed to 3RM testing for both the bench press and squat.

A 5-minute rest was imposed between all attempts to allow subjects adequate time to replenish energy stores. The 3RM was determined after 2–3 attempts in all subjects. Both the bench press and squat movements were carried out as per the International Powerlifting Federation’s rules (9).
warm-up as done on the strength testing day. After a 10-minute recovery period, subjects performed a maximal effort BBT at loads of 20, 30, 40, 50, and 60% of the subject’s predetermined 1RM in a randomized and balanced order, with 3 attempts at each load and a 5-minute recovery period between each load. During each BBT, the subject was instructed and encouraged to lower the bar from the starting position and throw it as high as possible. To avoid the effects of deceleration and achieve maximal bar velocity, the bar was released at the top of the range of motion. During each throw, subjects were required to keep their head, shoulders, and trunk in contact with the bench and their feet in contact with the floor.

For the measurement of lower-body PPO, subjects performed maximal effort JS at loads of BM only, plus 20, 30, 40, 50, and 60% of the subject’s predetermined 1RM in a randomized and balanced order, with 3 attempts at each load and a 5-minute recovery period between each load. The JSs were performed with the subjects squatting down to a predetermined depth and explosively jumping to the highest height attainable.

**Ballistic Measurement System.** Peak power output from both the JS (summing BM and barbell mass as the load in the calculation) and BBT was calculated using the software provided with the Ballistic Measurement System (BMS) (Fitness Technology, Adelaide, Australia). The BMS was used to collect bar displacement data during both the JS and BBT. The BMS comprises a cable extension potentiometer (distance transducer) that produces a variable voltage output proportional to the extension of the 3-m cable. The data collection system (XPV6+; Fitness Technology) of the BMS and interfaced to the computer via USB then captured the displacement data at a sampling rate of 500 Hz. The BMS was calibrated against known distances for the range over which the JS and BBT were performed; this calibration was performed before all testing sessions. The reliability of the BMS has been assessed for the measurement of PPO during squat jump (SJ) (with additional weight) and BBT in a study by Alemany et al. (1). In this study, the authors reported intraclass correlation coefficients of 0.93 and 0.96 for peak power obtained during the BBT and JS, respectively.

**Statistical Analyses**
After a test for the normality of distribution, data were expressed as the mean ± SD. Statistical analyses were carried out using a repeated measures 1-way analyses of variance to determine whether there was a significant difference between the relative intensities for PPO during both the BBT and SJ. When significant F values were observed (p ≤ 0.05), paired comparisons were used in conjunction with Holm’s Bonferroni method for control of type I error to determine significant differences. The level of significance was set at p ≤ 0.05 in the present study, and all statistics were performed using SPSS 13.1 (SPSS, Inc., Chicago, IL, USA).

**RESULTS**

**Peak Power Output During Ballistic Bench Throw**
Maximum PPO during the BBT was observed at a relative intensity of 30% 1RM in our group of athletes (Table 2 and Figure 1). Statistical analyses revealed that relative intensity (% 1RM) had a significant effect on PPO during the BBT (effect size η²: 0.297; F = 1398.1, p < 0.001). Subsequent paired comparisons revealed a significant difference between the PPO obtained at 30% 1RM and the PPO at 20 and 60% 1RM (Table 2 and Figure 1). There was no significant difference between the PPO during both the BBT and SJ. When significant F values were observed (p ≤ 0.05), paired comparisons were used in conjunction with Holm’s Bonferroni method for control of type I error to determine significant differences. The level of significance was set at p ≤ 0.05 in the present study, and all statistics were performed using SPSS 13.1 (SPSS, Inc., Chicago, IL, USA).

**Table 2.** PPO during the BBT and jump squat with different relative intensities of 1RM*

<table>
<thead>
<tr>
<th>Load (% 1RM)</th>
<th>BBT (n = 47)</th>
<th>Jump squat (n = 36)</th>
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<tr>
<td>0</td>
<td>4,750.9 ± 529.4</td>
<td>4,529.6 ± 489.0</td>
</tr>
<tr>
<td>20</td>
<td>775.6 ± 25.3</td>
<td>4,256.1 ± 489.0</td>
</tr>
<tr>
<td>30</td>
<td>873.0 ± 24.2</td>
<td>4,130.2 ± 462.6</td>
</tr>
<tr>
<td>40</td>
<td>865.4 ± 23.1</td>
<td>3,982.1 ± 371.5</td>
</tr>
<tr>
<td>50</td>
<td>838.4 ± 23.7</td>
<td>3,859.1 ± 390.7</td>
</tr>
<tr>
<td>60</td>
<td>773.3 ± 24.3</td>
<td>3,717.7 ± 406.4</td>
</tr>
</tbody>
</table>

*PPO = peak power output; BBT = ballistic bench throw; 1RM = 1 repetition maximum.

**Figure 1.** Peak power output at loads of 20–60% 1RM during the BBT. †Peak values. BBT = ballistic bench throw.
difference between the PPO at 30, 40, and 50% 1RM during the BBT (Table 2 and Figure 1). In addition, the PPOs at 20 and 60% were not significantly different from each other (775.6 ± 25.3 W vs. 773.3 ± 24.3 W, p > 0.05), but both were significantly lower compared with all other intensities (Table 2 and Figure 1).

**Peak Power Output During Jump Squats**

Statistical analyses revealed a significant effect of relative intensity on PPO during the JS (effect size ω²: 0.709; F = 3078.4, p < 0.001). Maximum PPO was recorded during the JS performed at 0% 1RM. In addition, the PPO generated by the athletes when performing the JS with 0% 1RM was significantly higher than all other intensities. Also, there was a significant difference between the PPOs at all relative intensities when compared with each other (Table 2 and Figure 2).

**DISCUSSION**

The primary findings of the present study were that PPO was maximized at a relative intensity of 30% of 1RM during the ballistic bench throw (BBT) and 0% 1RM during the jump squat (JS) in this group of professional rugby players. The PPO achieved at 30% 1RM in the BBT was significantly different to those achieved with 20 and 60% but not 40 and 50%, which may indicate that the intensity at which PPO is achieved in the BBT is a very individual response and may occur somewhere between 20 and 60% of 1RM. This finding is supported by the research done by Mayhew et al. (14) and Siegel et al. (18) who reported that PPO was achieved at a load that equalled 50% 1RM and between 40 and 60% of 1RM, respectively.

To maximize the PO during any exercise, there must be a compromise between the 2 variables that contribute to power development, namely, force and velocity. When the external resistance is too high, the velocity of movement will be low and hence PPO will not be optimized (5). In the present study, this compromise was achieved at a relative load of 30% 1RM for the BBT and 0% 1RM for the JS. In a study by Kaneko et al. (11), they reported that PPO occurred at 30% of 1RM for the upper body, which has resulted in this article often being incorrectly cited as evidenced that the load that maximizes PPO is 30% of 1RM. Although it is true that PPO in that study was observed at intermediate movement velocities of approximately 30% of maximum shortening velocity and 30% of maximal isometric strength, only 4 loads, 0, 30, 60, and 100%, were used. Therefore, the load that actually maximized PPO could have occurred at any point between 30 and 60%.

In the present study, PPO was achieved with 0% 1RM in the JS, which was significantly higher than the PO at all other intensities. At first glance, this may seem quite contradictory to previous findings (e.g., (18–20)). For example, in the studies by Siegel et al. (18) and Sleivert and Taingahue (19), they reported that PPO was obtained when the subjects worked against external loads that equated to 50–70% of their 1RM. However, more recent work by Cormie et al. (5) and McBride et al. (15) found that the optimal load for PPO in their group of athletes was 0% 1RM (or BM only), which is in direct agreement to the findings of the present study. Cormie et al. (5) reported that this load elicited the greatest PO of all the examined loads (12, 27, 42, 56, 71, and 85%) and that the 0% 1RM load was light enough for athletes to generate very high velocities (peak velocity: 3.66 ± 0.26 m per second), and BM provided sufficient resistance to produce a substantial force output (peak force: 1,990 ± 338 N). Therefore, this load permitted the most favorable combination of force and velocity to maximize PO.

In a review by Dugan et al. (6), they suggested that the main discrepancy between the optimal load for PPO during the jump squat was the issue over the inclusion or exclusion of BM into the calculation of power. In both the present study and the studies carried out by Cormie et al. (5) and McBride et al. (16), we included BM into the calculation of lower body power for the main reason that according to Dugan et al. (6), the inherent contraction properties of the leg extensors and the resulting force and velocity of the system are determined by the total load, BM, and bar to be accelerated and they demonstrated that the exclusion of BM from the calculation of power causes a substantial shift toward the higher 1RM percentage for the optimal load.

Additionally, there are a number of other possible explanations for the discrepancies within the literature with regard to the optimal load for PPO such as the training status of the athlete. Baker (2) reported alterations in the optimal load for
PPO in response to changes in strength and training emphasis within the yearly training cycle.

Cormie et al. (5) suggest that the difference in acceleration profiles of lifts could mean that the optimal load for PO will occur at different loads. They suggest that because the JS is ballistic in nature and the deceleration phase is much smaller than in a traditional squat, greater velocities can be achieved and therefore maximum mechanical PO occurs at a lighter load than in the squat that has a much greater reliance on force for maximal power production (7).

Findings from the present study can be used to individually determine the optimal training load for developing PPO. Although there is still much debate with regard to the correct method for developing power in athletes (e.g., plyometrics, training at the optimal load, and complex training), there is support for the effectiveness of training at the optimal load for PPO and its effectiveness at improving performance. For example, in a study by McBride et al. (16), they compared athletes training at 30% of their 1RM (suggested optimal load) or 80% of their 1RM over an 8-week training period and reported that athletes training at the 30% load tended to have greater increases in 20 m sprint times compared with the athletes training at the 80% load. This finding is also supported by the much earlier work of Wilson et al. (21) who also found that training at 30% load was more effective than plyometrics using body weight alone. Improvements in PPO have been accompanied with increases in dynamic performance (e.g., jumping and sprinting) (16,20), with this evidence being used to reinforce the concept that training at the optimal load for PPO is an effective method for improving the muscle’s ability to generate power. Further support for this is provided by Kaneko et al. (11) reporting that subjects who trained at a load of 30% of maximal isometric force in an elbow flexor exercise for 12 weeks increased their PPO by 26%, which was significantly greater than the subjects who trained at 0, 60, or 100% of maximal isometric force.

In conclusion, the results from the present study indicate that relative intensity had a significant effect on PPO during the BBT and the JS and that peak values were obtained in our athletes when working against an external load that was equivalent to 30% 1RM in the BBT and with BM only in the JS.

**Practical Applications**

It is important that coaches are aware of the optimal load for peak power production. This study highlights individual responses to the optimal load for PPO; therefore, individual determination of athlete’s optimal load for PPO is required to effectively develop the athlete’s power-generating capabilities.

**References**


