

Investigating the Power-Load Relationship for the Jump Squat in Professional Rugby Players

Matriculation #: 0565706

ABSTRACT

The purpose of this study was to investigate the power-load relationship for the jump squat in professional rugby players. 11 male participants (age: 25.55 ± 3.30 years; height: 183.09 ± 6.12 cm; weight: 97.34 ± 11.61 kg) performed maximal effort jump squats at pre-determined load percentages until they reached their one-repetition maximum (1RM). Power output was tested during the 1RM protocol using the FT 700 Power System (Fittech, Australia). Data was statistically treated using a 1-way repeated measures ANOVA, and was analysed for peak power output (PPO) peak force (PF) and peak velocity (PV). The optimal load for PPO was found to be 10-20% 1RM but was not significantly different from 30-40% 1RM. It was concluded that high percentages of an individual's jump squat 1RM should be avoided when training for PPO.

INTRODUCTION

The ability to produce maximum power is considered to be a key factor in successful performance across a large spectrum of sports (Stone et al 2000). Training at the load which maximises power output, otherwise known as the optimal load, is suggested to be a popular method for improving peak power output (PPO) in athletes (Kaneko et al 1983, Wilson et al 1993, Newton et al 1999, Baker et al 2001, Kawamori & Haff 2004, Hoffman et al 2005, Cormie et al 2007a, Kilduff et al 2007, Thomas et al 2007).

In contrast, there exists a great deal of discrepancy in quantifying or determining the value of this optimal load. Previous studies have reported greatly differing values ranging from 0% one-repetition maximum (1RM) (Cormie et al 2007a, Cormie et al 2007b, Cormie et al 2008) to as high as 80% 1RM (Sleivert et al 2002, Kilduff et al 2007). Other studies propose a large variety of loads within this range at which peak

power is maximised, with findings ranging from 10-70% 1RM (Kaneko et al 1983, Wilson et al 1993, Newton et al 1996, 1997; Baker et al 2001, Stone et al 2003, Kawamori et al 2005, Thomas et al 2007). Accurate comparison of these studies is difficult due to a multitude of discrepancies, all of which may have contributed to the plethora of suggested optimal loads highlighted above.

For example, the majority of studies use very different load ranges in their testing, but none of these papers use a complete load range which ranges from 0-100% 1RM. When considering that Kawamori & Haff (2004) suggest that the optimal load for PPO can be found using a power-load curve (Figure 1), it is plausible to suggest that an incomplete power-load curve could inhibit the identification of the optimal load, as the full range of relative loads would not be tested. Briefly, the power-load relationship is suggested to revolve around the principle of maximal power output being based on the balance between force and velocity output. The peak of the curve is where these two variables are performed at values that in combination yield the maximum power output. Any deviation from this peak is then due to either the velocity of the movement being too high for sufficient force to be applied, or that the load is too high leading to low velocity of movement.

*****Insert Figure 1 about here*****

Studies suggest that Olympic lifts and their derivatives produce the highest power outputs in human subjects (Stone 1993, Haff et al. 2001) and are therefore considered to be the preferred training method to improve power production (Kaneko et al 1983). In contrast, some authors support the notion of ballistic exercises, such as the jump squat (JS), to be the form of training that maximises power output. Thomas et al (2007) state that “differences existed between ballistic and Olympic-style exercises in the optimal load(s) for maximal power output”, a fact

that is very important to consider when comparing previous studies as both Olympic (Kawamori et al 2005, Kilduff et al 2007) and ballistic (Baker et al 2001, Baker & Newton 2005, 2007; Cormie et al 2007a, 2008) lifts were used as experimental exercises to investigate PPO. In contrast, a group of studies included both types of exercises in their testing protocols (Cormie et al 2007b, 2007c; Thomas et al 2007) and subsequent analysis, rendering comparison between studies more difficult. Using both types of exercises to investigate PPO parameters may lead to confusion as the potential differences between the optimal loads could lead to contrasting or conflicting training recommendations.

Baker & Newton (2007) reported that maximum power output is achieved between 2 to 5 repetitions in both the JS and bench throw (BT) with power output dropping significantly after 5 repetitions. Bearing in mind the importance of repetition ranges, it is perplexing that some of the studies reviewed did not mention how many repetitions their participants completed at the various experimental loads (Cormie et al 2007b, 2007c, 2008). These studies may only have used one repetition at each load, which may have led to lower maximal power output data being recorded.

Various studies (Baker et al 2001, Hoffman et al 2005, Baker & Newton 2005, 2006; Thomas et al 2007) used a linear position transducer (LPT) to assess power output, a method Chiu et al (2004) proposed as being valid. Recent publications (Dugan et al 2004, Cormie et al 2007a) have, however, reported evidence that the use of a single LPT is an invalid means of power calculation due to the absence of ground reaction force data and the exclusion of horizontal displacement data, both of which can lead to overestimation of power output. Cormie et al (2007a) suggest that a force plate should be used in combination with a LPT to combat the inaccurate measurements obtained with the use of one LPT on its own. Interestingly, Kilduff et al (2007)

conducted their study using only a force platform but no LPT. The validity of this particular method was not mentioned or examined by Cormie et al (2007a).

A collection of authors have suggested that differences in strength levels may also contribute to differences in reported PPO (Baker 2001, Stone et al 2003, Kawamori & Haff 2004, Kawamori et al 2005, Kilduff et al 2007). Most of the reviewed studies used professional or semi-professional athletes as their sample population (Baker et al 2001, Baker & Newton 2006, 2007; Kilduff et al 2007, Sheppard et al 2008) with others using college-level (Hoffman et al 2005, Kawamori et al 2005, Cormie et al 2007b, 2007c) or comparatively untrained subjects (Baker & Newton 2005, Cormie et al 2007a, Hori et al 2008, Cormie et al 2008). It is plausible to suggest that strength levels differed between the respective populations which may have influenced the power outputs and conclusions obtained from the various studies.

This would also have had an effect on optimal load or training recommendations which, depending on the populations these were intended for, may be inaccurate.

The discrepancy regarding the optimal load for PPO has given rise to the theory that the optimal load must be determined individually as no universal consensus seems to exist (Baker 2001, Kilduff et al. 2007). This premise is supported by studies which found no significant difference between the optimal load and other experimental loads (Baker et al 2001, Kawamori et al 2005, Cormie et al 2007c, Kilduff et al 2007) or suggest that power output is maximised across a range of loads (Newton et al 1997, Baker et al 2001, Sleivert et al 2002, Thomas et al 2007).

Both experimental and optimal load values are typically expressed in terms of a percentage of 1RM. Dugan et al (2004) identified that the manner in which 1RM values are obtained is difficult to standardise, which is supported by the assortment of methodologies used in previous research. Many studies used 1RM values from

traditional resistance training exercises such as the squat or bench-press to calculate subsequent load percentages in power-testing exercises such as the bench throw (BT) or the jump squat (JS) (Baker et al 2001, Baker & Newton 2005, Hoffman et al 2005, Thomas et al 2007, Cormie et al 2007a, 2007b, 2007c; Cormie et al 2008). Several of the studies used absolute load increments in their testing and expressed these loads (along with the recorded power outputs) as a percentage of the group's mean 1RM (Baker et al 2001, Baker & Newton 2006, Cormie et al 2008). One study used maximal isometric strength to determine the load percentages used in power-testing (Clark et al 2008). Using loads and conducting analysis with values derived from 1RM bench press or squat results are potentially inappropriate due to a number of specificity issues. Ballistic exercises such as the JS and BT are the preferred power-testing exercises due to the absence of a deceleration phase which elicits greater power outputs (Newton et al 1996, 1999). These, however, are only loosely related to exercises such as the squat or bench-press due to differing kinematics, muscle activation and velocity of movement (Dugan et al 2004). It is important to note that a number of studies (Haff et al 2005, McGuigan & Winchester 2008) report that maximal isometric strength, commonly considered as inappropriate for determining experimental loads in dynamic exercises, is in fact highly correlated with said exercises and "provides a strong indication of dynamic performance" (McGuigan & Winchester 2008). The contradicting reports differ in exercise/existence of movement, but it is clear that more research in this area is warranted as testing relationships, and subsequent methods of load determination, are neither agreed upon nor standardised.

The current study has two main aims:

1. To investigate the power-load relationship for the JS in professional rugby players. The experimental hypothesis is that this relationship will follow a bell-shaped curve similar to that proposed by Kawamori & Haff (2004). In addition, it was hypothesised that the optimal load for PPO would occur between 60-70% 1RM but would not be significantly different from other experimental loads.
2. To create an efficient and standardised 1RM testing protocol which also allows power output testing across a complete load spectrum.

METHODS

Study Design

Each participant performed maximal effort JS at pre-determined loads until they reached their 1RM. Power testing was integrated into the 1RM testing. Collected data was analysed for PPO, peak force (PF) and peak velocity (PV).

Participants

11 professional male rugby players participated in this study (age: 25.55 ± 3.30 years; height: 183.09 ± 6.12 cm; weight: 97.34 ± 11.61 kg; JS 1RM: 183.64 ± 19.63 kg). The participants were aware of the methods and nature of the testing which was integrated into their regular conditioning program by the club conditioning coaches. All participants were experienced in strength and power training and had performed JS in the past.

Equipment/Data Collection

The FT 700 Power System (Fittech, Australia) was used as a performance platform and data collection tool. The system was connected to a laptop with the Ballistic Measurement System software (BMS, Innervations, Australia) and included a linear position transducer (LPT), a magnetic braking unit (MBU) and a 400Series force

plate (Fittech, Australia). As highlighted in the introduction; the combined use of a force plate and an LPT is considered a valid method to assess power output in human participants (Cormie et al 2007a). The MBU was used as an injury-prevention mechanism (Hori et al 2008) to unload the landing phase of each JS. The braking force was applied continuously (automatic function) and was adjusted for each load so that a participant never landed with more than 50kg bar load. This value was requested by the club strength & conditioning coaches.

Prior to testing, the force plate was calibrated using the BMS software. First, an unloaded plate output was recorded (Force A). As the plate was unloaded the “lower force” value was set at 0 Newtons. This was followed by a force output measurement with a load that exceeded the highest load that could feasibly be used during testing (Force B). The combined load used was then converted into Newtons to give the “higher force” value. In the current study we had the 4 heaviest participants stand on the plate and converted their combined bodyweight into Newtons. The LPT was calibrated by recording the displacement values of the bar at a top and bottom position with a known distance between them. 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 as this has been suggested to allow for the accurate measurement of power output in lower-body movements (Cormie et al 2007b).

Pilot Testing

The current study used a novel testing approach which did not use maximal squat values to determine or estimate JS 1RM. Instead, the use of maximal JS testing itself was utilised in order to increase exercise specificity and provide more valid data.

A pilot study was deemed necessary to establish a rough relationship between an athlete's squat and JS strength in order to provide a guideline for the loading protocols used in the JS testing. This pilot study was carried out using an experienced Olympic lifter who was deemed to be of a similar strength level to the strongest members of the experimental group. The results of the pilot study suggested that a 5RM squat roughly equated to a 1RM JS and as such this estimation provided a guideline for defining the loading protocols used in the current study.

JS 1RM + Power Testing

Participants reported to testing having refrained from strenuous exercise the day before. Each participant completed a 10 minute standardised dynamic warm-up as well as movements specific to the JS.

Both 1RM and power testing were integrated into one protocol to increase speed and efficiency of data collection. The JS testing protocol was adapted from the 1RM testing method outlined by Stone & O'Bryant (1987) and was modified to allow a complete load spectrum to be tested. The protocol required participants to perform maximum effort JS at 0-100% of their estimated 1RM which was calculated based on the guidelines provided by the pilot study. As only a few participants were able to provide individual 5RM squat values the remaining estimates were formulated by the club strength & conditioning coaches.

Each attempt was followed by a 3 minute rest period in order to allow adequate recovery. If a participant did not reach their 1RM at the provided estimate, a load increase of 5-10 kg was added after each further attempt and 2 minutes rest, based on suggestions made by Baechle & Earl (2008). An individual was 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 one further attempt at improving their 1RM following a 2 minute rest period.

The repetition values (3 reps \leq 40% estimated 1RM, 2 reps \leq 80% estimated 1RM, 1 rep $>$ 80% estimated 1RM) at given loads were modified to strike a balance between ensuring the detection of PPO (2-5 reps according to Baker & Newton 2007) and reducing the total volume along with potential injury risks. An overview of the loading protocol is presented in Table 1.

*****Insert Table 1 about here*****

When performing the jumps, participants were instructed to apply constant downward pressure on the barbell so it remained on their shoulders at all times. This was to combat the fact that power output measurements may be inaccurate if the bar leaves the shoulders due to LPT displacement differences. All individuals were instructed to treat each jump as a maximal effort and jump as explosively as possible, with the aim to reach maximum jump height in order to maximise power output (Newton et al 1996). Verbal encouragement was provided throughout testing. The depth of the initial eccentric portion of the JS was not regulated as in other studies (Cormie et al 2007c, Hori et al 2008). This was based on evidence which suggests that trained humans automatically adjust their squat depth to allow for maximal performance in movements that involve jumping (Bobbert et al 2008).

Statistical Analysis

Each participant's testing load (see testing protocol) was calculated as a percentage of his final 1RM in order to create an individual power-load profile. As this gave an array of relative load percentages all data was "banded" in order to allow group comparison and statistical analysis. Each individual's data was matched to the pre-determined bands (1 band = 10% relative load). If a participant had multiple jumps

in a given band then an average of those outputs was taken. Individual data was not statistically analysed.

Statistical analysis was executed using a repeated measures 1-way analysis of variance (ANOVA). Data was analysed for normality, sphericity and effect size, along with F-values and their corresponding significance statistics. If data was normal and F-significance values were below the designated alpha-level ($p \leq 0.05$), paired comparisons were done using the Bonferroni post hoc test in order to identify significant differences.

If data was not normal, a Kruskal-Wallis test was used along with a “Bonferroni correction” in the post hoc procedures in order to allow valid comparison (Connolly 2007). Unfortunately, calculating effect sizes using information from the Kruskal-Wallis test in SPSS was not viable as it is deemed inappropriate (Connolly 2007).

RESULTS

Group Data

An overview of the group average results including standard deviations can be seen in Table 2.

*****Insert Table 2 about here*****

PPO

Results are displayed in Figure 2. All data was normal and passed the sphericity test, apart from the 30-40% 1RM band. Therefore the data required transformation (square-rooting) to normalise. Initial sphericity significance value did not fulfil Mauchly test requirements so the more conservative Greenhouse-Geisser test was used ($0.375 \geq 0.05$). Load percentage of 1RM had a significant effect ($F=50.715$, Effect size= 0.91, $p \leq 0.001$) on PPO in the JS. PPO was maximised at 10-20% 1RM. PPO decreased as relative load was increased. Paired comparisons found that

PPO at 80-100% 1RM was significantly different to that recorded at 10-70% 1RM. PPO at 70-80% 1RM was significantly different from 10-60% 1RM. PPO at 50-70% 1RM was significantly different from 10-40% 1RM. No significant differences existed between PPO at 10-40% 1RM, 50-70% 1RM, 60-80% 1RM as well as between 70-80 and 80-100% 1RM.

*****Insert Figure 2 about here*****

PF

Results are displayed in Figure 3. Data was normal and passed the sphericity test. Initial sphericity significance value did not fulfil Mauchly test requirements so the more conservative Greenhouse-Geisser test was used ($0.245 \geq 0.05$). Load percentage of 1RM had a significant effect ($F=28.71$, Effect size= 0.86, $p \leq 0.001$) on PF in the JS. PF was maximised at 90-100% 1RM. PF increased as relative load was increased. Paired comparisons found that PPO at 80-90 and 90-100% 1RM were significantly different from all other loads, including each other. In addition, PPO at 70-80% 1RM was significantly different from 30-70% 1RM and PPO at 60-70% 1RM was significantly different from 30-60% 1RM. No significant differences existed between PPO at 10-60% 1RM. PPO at 10-20% 1RM was not significantly different from loads between 30-80% 1RM.

*****Insert Figure 3 about here*****

PV

Results are displayed in Figure 4. Data was not normal in three bands (10-20, 80-90 and 90-100% 1RM) and could not be normalised with transformation. Load percentage of 1RM had a significant effect ($F=60.83$, $p \leq 0.001$) on PV in the JS. PV was maximised at 10-20% 1RM. PV increased as relative load was increased. Paired comparisons showed that PV at each load was significantly different from all other

loads apart from 70-80 and 80-90% 1RM which were not significantly different from each other.

*****Insert Figure 4 about here*****

Individual Data

Power-Velocity

Results are displayed in Figure 5. Power output generally increased as movement velocity increased.

*****Insert Figure 5 about here*****

Power-Relative load

Results are displayed in Figure 6. Power output generally decreased as relative load increased.

*****Insert Figure 6 about here*****

Power-Force

Results are displayed in Figure 7. Power output generally decreased as force output increased.

*****Insert Figure 7 about here*****

DISCUSSION

The primary findings of this study are that PPO in the JS was achieved at 10-20% 1RM (Figure 2) and that PPO decreased as relative load increased (Figure 2).

Statistical analysis did however indicate the optimal load range not to be significantly different from 30-40% 1RM. These findings reject all but one of the experimental hypotheses. PF and PV data all followed similar patterns found in other studies; where PF was maximised at the highest load percentage (Figure 3) and PV was maximised at the lowest load percentage (Figure 3 and 5) (Kawamori et al 2005, Cormie et al 2006, Kilduff et al 2007).

The results support investigations that found no significant difference between the optimal load for PPO and other experimental loads (Baker et al 2001, Kawamori et al 2005, Cormie et al 2007c, Kilduff et al 2007). In addition, the current study is in agreement with studies reporting optimal load for PPO in the JS to occur at low percentages of 1RM (Wilson et al 1993, Stone et al 2003, Cormie et al 2007c, Thomas et al 2007, Cormie et al 2008, Sheppard et al 2008), and concurs with previous research that has found that JS PPO decreases as external load is increased (Dugan et al 2004, Cormie et al 2007b, 2007c, 2008; Sheppard 2008). A potential explanation for the low % 1RM optimal load results could be that studies suggesting higher % 1RM optimal load values all used LPT measurements only to determine power output. This method is proposed to be inaccurate and causes power output to be overestimated as mentioned by Cormie et al (2007a). As well as being inaccurate, this method only measures power through the bar and not the feet which is unspecific in terms of sporting performance. The importance of these findings cannot be overstated as they contest a plethora of popular theories, many of which provide the foundation of numerous athletic conditioning programs.

A key theory challenged by these findings is the existence of a power-load curve as suggested by Kawamori & Haff (2004). As highlighted in the introduction, this relationship is proposed to be a bell-shaped curve based on the balance between force and velocity production, with PPO being achieved at the optimal combination of the two. It also implies that at lower external loads movement velocity is too high for optimal force to be produced therefore not allowing PPO. The current study not only contests the shape of the traditional power-load curve (Figure 2) but also opposes the fact that higher PV outputs, and therefore lower loads, inhibit high PPO production. More specifically, it seems that PPO is maximised at the load that allows

the highest velocity output (Figure 5). A possible explanation for this could be that high-velocity movements require more Type II muscle fibre contribution, which is important as Type II fibres also produce the highest power outputs (Hunter et al 2005). This concept is reinforced by the fact that both PPO and PV increased as PF decreased (Table 2 and Figure 7), which makes it plausible to suggest that velocity output is in fact more important than force production for achieving PPO.

Conversely, the obtained results may be explained by the fact that the power-load relationship observed in this study is in fact the second half of the traditional curve outlined above. In other words, PPO at 10-20% 1RM represents the peak of the curve but due to the fact that this study did not investigate JS power output at even lower loads or in unloaded (less than bodyweight) circumstances, the first half of the curve was not displayed. Unloaded jumps would theoretically be possible in water or with the help of mechanical assistance. It is feasible that power output could be maximised at near-bodyweight loads, as the human body may simply be accustomed to producing the optimal force-velocity balance at a load that it most commonly needs to work against (i.e. bodyweight). An adapted example of this “modified power-load curve” is illustrated in Figure 2. This concept has not been mentioned before in previous literature and represents a novel theory.

*****Insert Figure 8 about here*****

Unfortunately, this study was not able to test participants over a complete range of absolute loads (all participants only completed jumps at 20, 40, 60, 70, 80, 85, 90, 95 and 100% of their predicted 1RM along with any additional attempts if 1RM was not reached). The testing of a complete load range was not possible due to time constraints imposed by the club, which is a common obstacle when testing with professional athletes. This means that the trends shown in this investigation may

have been different if all absolute loads could have been tested, and may have allowed results analysis without the need for banding data. In particular, the inclusion of bodyweight jumps may have provided further information towards the existence of the “modified power-load curve”, and whether the peak of the curve occurs at bodyweight or at a slightly heavier load. This is especially the case as some studies have already suggested body mass to be the optimal load for PPO in the JS (Cormie et al 2007b, 2007c, 2008; Sheppard et al 2008). It is important to note that these studies had relatively large increments between jumps at body mass and the subsequent load (12% 1RM, 20kg or 25% of body mass), which leaves the possibility that PPO in the JS could have been maximised at a load slightly higher than body mass. This suggestion is based on the theory that slight loading would increase the amount of time an individual would have to develop power, without the load being too heavy to interfere with velocity production. In addition, it is vital to consider that some of these studies excluded shank mass from the overall system mass and all power calculations (Cormie et al 2007b, 2007c). This was based on the premise that the “shanks and feet remain in a relatively static position during the [initial concentric] phase of the JS” (Cormie et al 2007b). As the shanks and feet are accelerated during a portion of the JS where peak power could potentially occur (e.g. when the heels are raised just before the toes leave the ground) it seems peculiar that this mass was excluded from all calculations. It is also perplexing that this mass was accepted as being 12% of body mass (Piscopo & Bailey 1981), a figure which would seem likely to be subject to individual differences.

The JS power-load relationship investigated in the current study is novel in terms of both how the loading parameters were established, and the fact that testing was performed at 100% 1RM. The information obtained in the initial pilot study

permitted the use of estimated JS strength to establish the loading protocol. This allowed all experimental loads to be expressed as a value of the actual exercise being used in the testing, and not in terms of a loosely related measure (e.g. 1RM squat) as is practised in all papers reviewed to date. The loading protocol was not randomised, which may have resulted in data being affected by a warm-up effect. This was a necessary limitation of the current study as a large load range was used. This range included maximal loads and therefore the inevitable warm-up effect was used as an injury prevention mechanism. Furthermore, incremental load progression as used in the current protocol is a key element of 1RM testing procedure (Stone & O'Bryant 1987), as it allows detection of true maximal strength (Baechle & Earle 2008). As mentioned in the introduction, strength levels are a crucial factor to consider when identifying the optimal load for PPO. Although all participants were professional rugby players, many participants played in different positions and as such JS 1RM values showed considerable variance (183.64 ± 19.63 kg). Differences in strength are suggested to contribute to different PPO production at different relative loads (Stone et al 2003), which may help explain the absence of a significant difference between PPO produced at 10-20% 1RM and 30-40% 1RM in the current study.

Kawamori & Haff (2004) propose that the general trend in the literature shows that studies using upper-body exercises support the notion of lower percentages of the 1RM to be the optimal load for developing muscular power. Conversely, studies using lower-body exercises mostly suggested a higher percentage of the 1RM as the optimal load. The current study does not support this trend. Notwithstanding, the "modified power-load curve" theory would support the possibility of this trend (i.e. PPO in the BT would be maximised in unloaded conditions). When taking into

consideration that the difference between upper and lower body optimal load values suggested in previous studies can range from 2% to as much as 60%, it quickly becomes clear that this is an important area to consider when investigating optimal loading. Studies using Olympic exercises and their derivatives (e.g. power clean, hang clean, hang pull) are difficult to include in this analysis as these exercises utilise a combination of upper and lower body power production. Perplexingly, no study to date has specifically investigated the difference between the upper and lower body optimal loading for PPO. The initial aim of the current study was to investigate the difference between optimal load values for PPO between the BT and JS but unfortunately vital equipment malfunctioned before the BT testing and was not repaired in time.

An additional factor that may influence optimal load production is training emphasis. Baker (2001) suggested that the optimal load value changes depending on the type of training being performed by an athlete at a given time. Baker proposed that optimal load values shift towards higher loads in periods of strength training (high resistance, low velocity), and towards lower loads during training phases placing an emphasis on speed development (low resistance, high velocity).

Unfortunately the training regime being performed by the participants at the time of testing was not documented. Despite this fact and based on Baker's proposals, it is plausible to suggest that the PPO values obtained in this study may be different from those that would be produced in phases of training with a different focus.

The optimal load value is suggested to be significantly different between genders (Thomas et al 2007). They reported that the optimal load for PPO was up to 10-20% 1RM higher for women than men in the JS. This has obvious implications for existing and future research as gender differences have not been extensively

investigated and/or mentioned, even in studies where a mixed gender sample was investigated (Sheppard et al 2008). Interestingly, all other reviewed papers apart from three (Haff et al 2005, Newton et al 2006, Thomas et al 2007) used male participants only which highlights the need for further research into gender differences, and means that any optimal load training recommendations may have to be revised when used with female athletes.

Atkinson & Nevill (2001) hint on the fact that statistical significance may be missed by some studies as the way in which data is commonly presented (i.e. by averaging and pooling data) can negate or mask significant differences. This has enormous implications for existing studies as previous training recommendations may have failed to identify the correct optimal loads for PPO based purely on a lack of statistical significance. It is proposed that the concept of an individually determined optimal load as outlined by Kilduff et al (2007) and Baker (2001) can be extended to include the concept of individualised statistics when investigating the optimal load for PPO. Not only does this allow for the establishment of an individualised power-load curve allowing easier comparison between individuals, it may also allow the identification of statistically significant differences which would potentially be overlooked using previous statistical analysis parameters. The use of individualised statistics has not been attempted before in the reviewed literature and would represent a novel intervention.

The current study provides the following directions for future research:

- 1) Investigation into the existence of the “modified power-load curve” by using unloaded testing circumstances in addition to bodyweight and loaded tests.
- 2) Further investigation of the effect of varying strength levels on PPO values.
- 3) Further examination of the differences in PPO between males and females.

- 4) Investigation of the differences between optimal load values/PPO values at different times within the season.
- 5) Investigation of the effect of different types of training (speed, strength, plyometrics) on the optimal load value for PPO.
- 6) Examination of the differences between optimal loads/PPO values between different rugby positions.
- 7) Investigation of the differences between the optimal load values for PPO between lower body exercises and upper body exercises.
- 8) Designing a valid individualised statistics protocol that may combat the potential negation of significant differences caused by averaging results.

CONCLUSION

Power training at the optimal load for PPO is accepted to be the principal method through which to improve maximal muscular power. The current study suggests 10-20% 1RM to be the optimal load for PPO in the JS for professional rugby players, but the power output at this load was not shown to be significantly different to that produced at 30-40% 1RM. This implies that athletes could train at these different loads whilst still attaining similar power outputs, allowing training to be customised in order to cater to specific sporting needs. In addition, results suggest that heavy loads should be avoided when training for PPO. Finally, when applying these recommendations to other sports, it is proposed that the different demands of the sport or discipline be taken into consideration as exclusively training at the optimal load for PPO may only be of value to certain athletes and not others.

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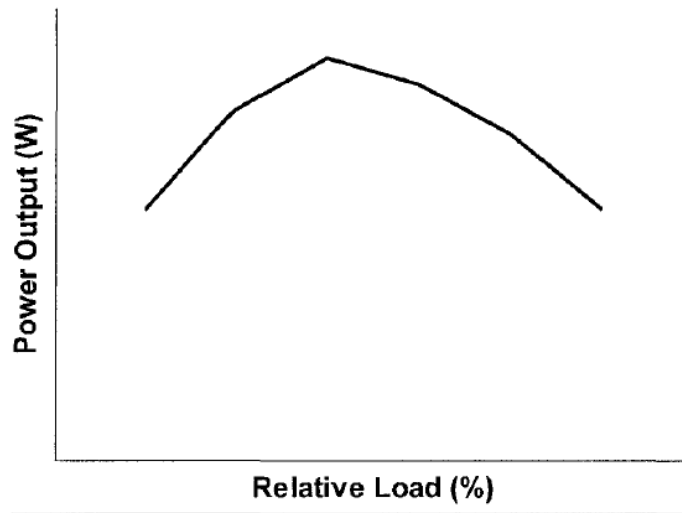


Figure 1- The power-load curve (Kawamori & Haff, 2004)

LOAD (% estimated 1RM)	REPETITIONS
0 (Bodyweight)	3
10	3
20	3
30	3
40	3
50	2
60	2
70	2
80	2
85	1
90	1
95	1
100	1
Load Progression After 100% of estimated 1RM: 5/10kg	1

Table 1- 1RM + Power testing loading protocol

Load percentage 1RM (%)	Peak Power Output (W)	Peak Force (N)	Peak Velocity (m/s)
10-20	4773.0 ± 898	2162.89 ± 336.8	2.2 ± 0.16
30-40	3953.3 ± 689.1	2237.33 ± 298.0	1.76 ± 0.09
50-60	3639.7 ± 580.7	2424.11 ± 365.6	1.51 ± 0.18
60-70	3504.6 ± 542.2	2558.92 ± 383.5	1.38 ± 0.21
70-80	3171.0 ± 650.6	2711.33 ± 439.2	1.18 ± 0.26
80-90	3027.1 ± 520.1	2864.34 ± 426.3	1.07 ± 0.21
90-100	2789.4 ± 422.2	3009.01 ± 423.4	0.94 ± 0.18

Table 2- Overall group average results with standard deviations

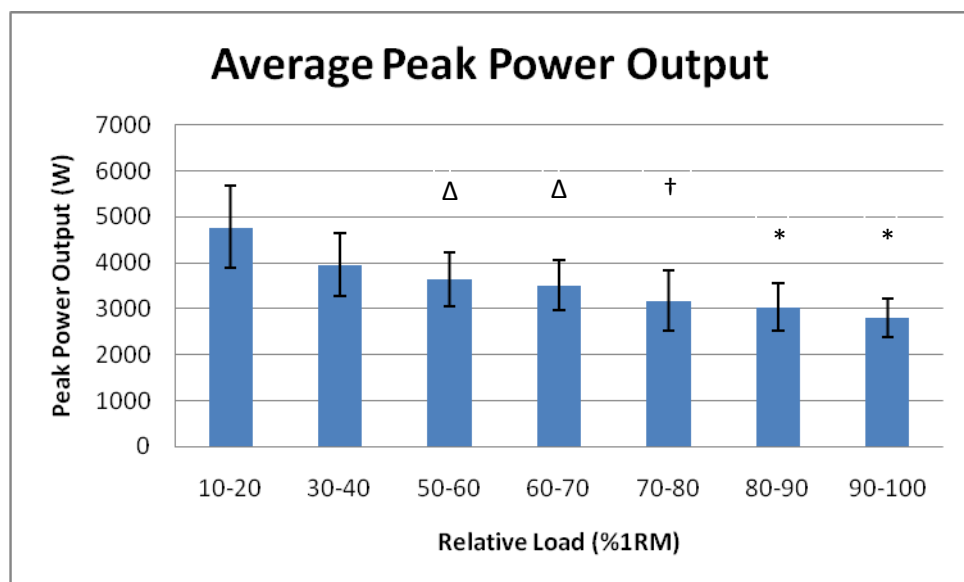


Figure 2- Group average PPO at relative loads. *=significantly different from 10-70% 1RM †=significantly different from 10-60% 1RM Δ=significantly different from 10-40% 1RM

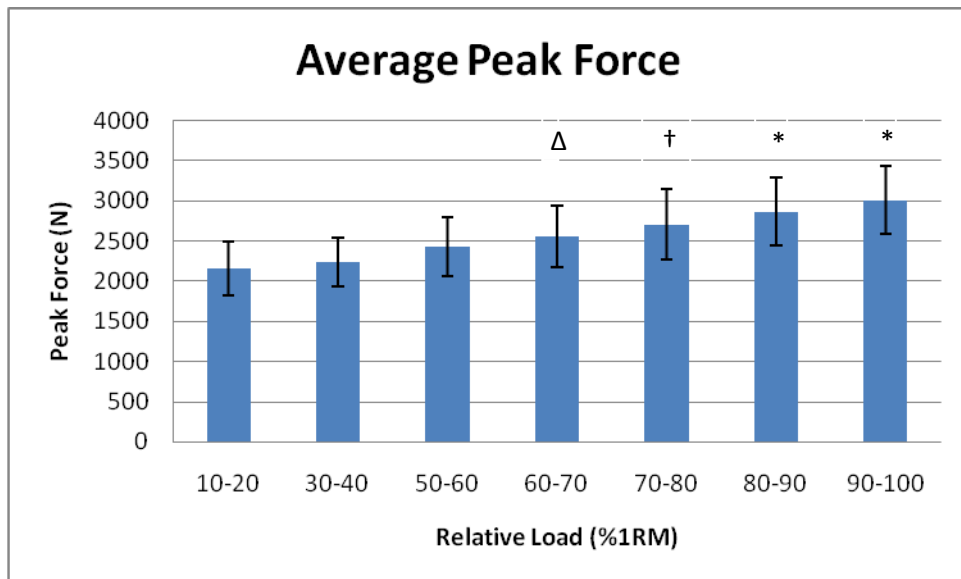


Figure 3- Group average peak force production at relative loads. *=significantly different from all other loads †=significantly different from 30-70% 1RM Δ=significantly different from 30-60% 1RM

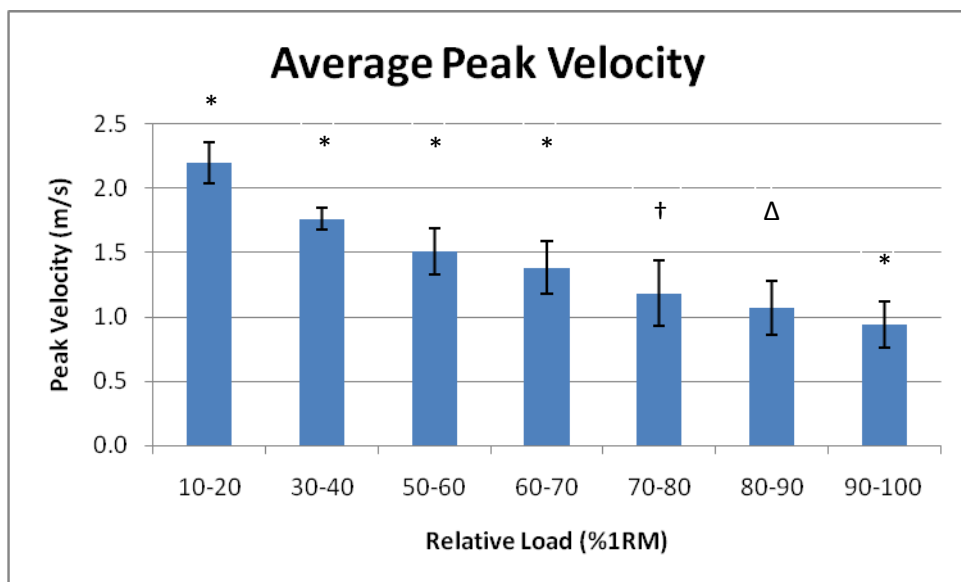


Figure 4- Group average peak velocity output at relative loads. *=significantly different from all other loads †=significantly different from all other loads except 80-90% 1RM Δ=significantly different from all other loads except 70-80% 1RM

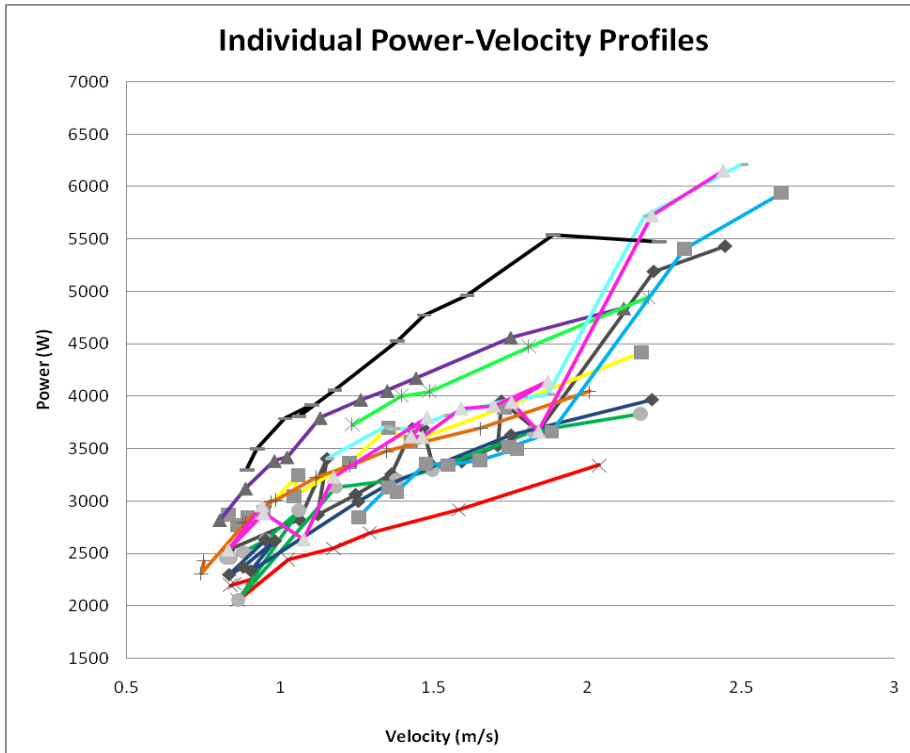


Figure 5- Individual power-velocity outputs

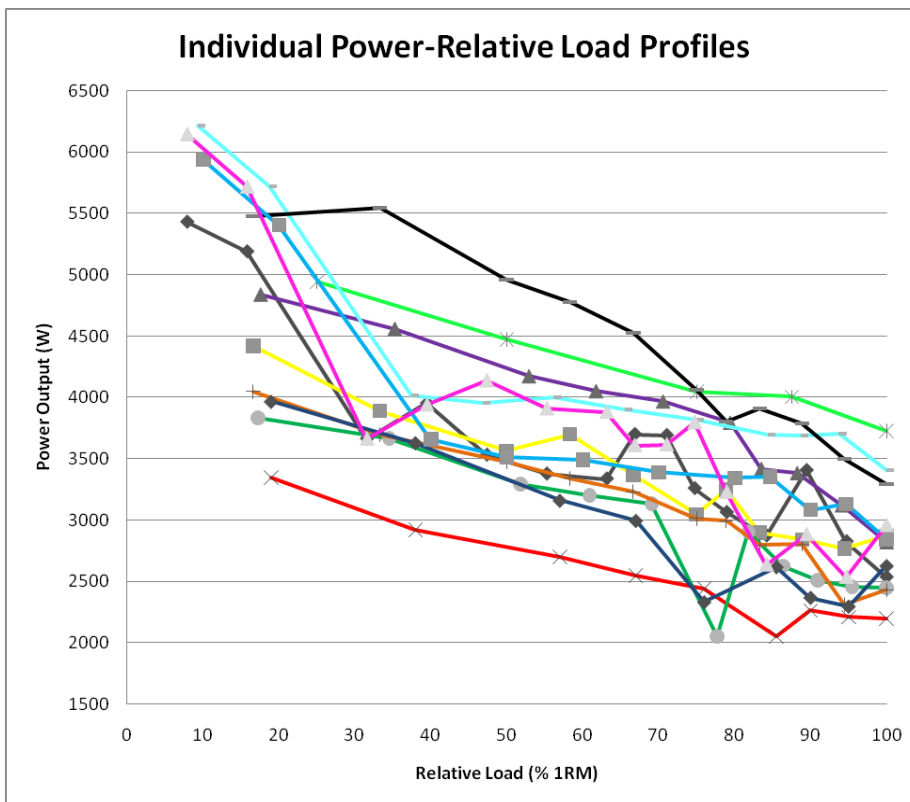


Figure 6- Individual power outputs at relative loads

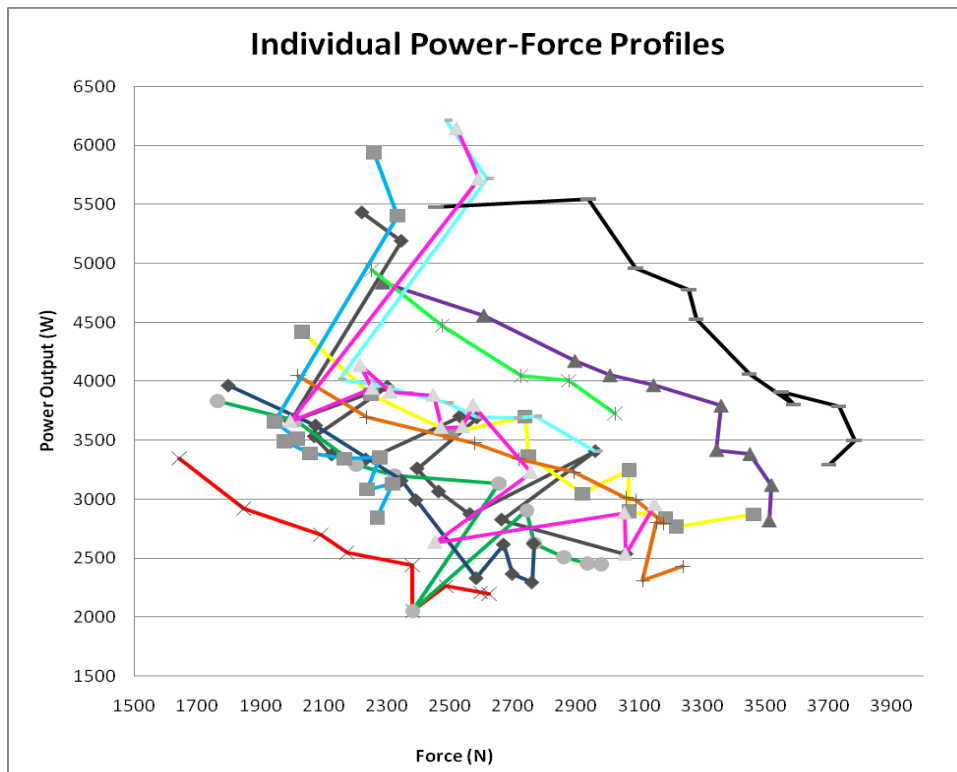


Figure 7- Individual power-force outputs

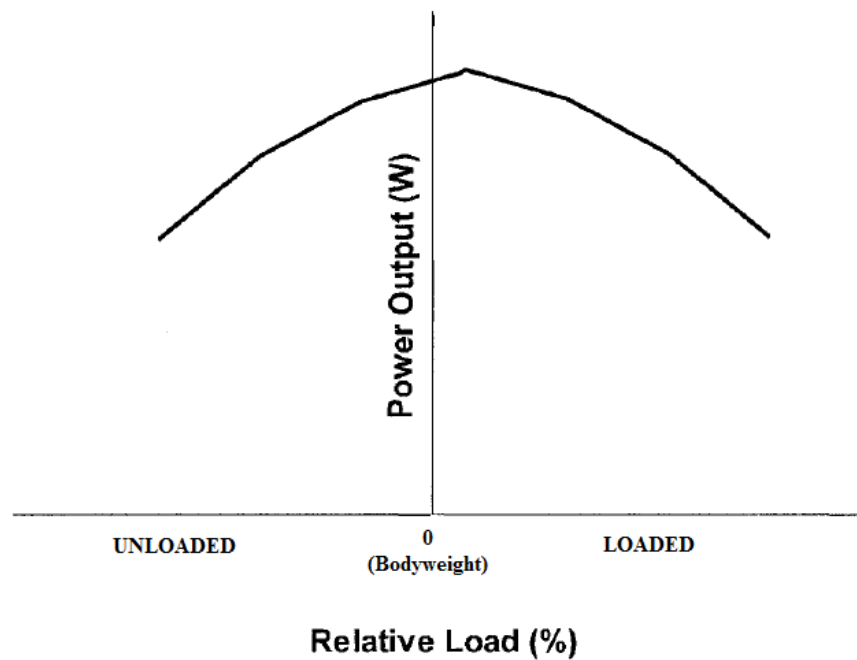


Figure 8- Example of the modified power-load curve adapted from Kawamori & Haff (2004)