Characterization of the differences in strength and power between different levels of competition in rugby union athletes

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ABSTRACT

Levels of strength and power have been used to effectively discriminate between different levels of competition**;** however there is limited literature in rugby union athletes. To assess the difference in strength and power between levels of competition, 112 rugby union players including 43 professionals, 19 semi-professionals, 32 academy level, and 18 high school level athletes, were assessed for bench press and box squat strength, and bench throw and jump squat power. High school athletes were not assessed for jump squat power. Raw data along with data normalized to body mass with a derived power exponent were log-transformed and analyzed. With the exception of box squat and bench press strength between professional and semi-professional athletes; higher level athletes produced greater absolute and relative strength and power outputs than lower level athletes (4% - 51%; small to very large effect sizes). Lower level athletes should strive to attain greater levels of strength and power in an attempt to reach, or to be physically prepared for the next level of competition. Furthermore, the ability to produce high levels of power, rather than strength, may be a better determinate of playing ability between professional and semi-professional athletes. **Key Words:** Allometric scaling, elite athletes, professional athletes, in-season.

INTRODUCTION

The ability to produce high levels of muscular power is critical for successful performance in most contact sports such as American football and rugby league (5, 27). Furthermore, it has been suggested that possessing high levels of maximal strength is the most important factor influencing power production (8, 35, 38). Although maximum strength and power tests are not measures of sporting ability, they are believed to represent performance characteristics of playing potential in many sports (1).

Since the introduction of professionalism in rugby union in 1995, rugby players have become bigger and stronger (33, 36). Indeed, in just a short period from 2004-2007 players had an average increase in strength of 3-5% for upper-body and 5-15% for the lower-body (36). Additionally, the southern hemisphere super rugby competition, which consisted of ten teams in 1995, has now expanded to a 15 team competition. As a consequence players are competing in a greater number of games throughout the calendar year. Due to the greater number of teams and increased competition demands, a greater pool of players is therefore required. Recently, it has been suggested that younger players are being selected to fill the void (36).

Levels of strength and power have been used to effectively discriminate between different levels of competition in a range of sports including, American Football (22), rugby league (4, 7, 11), volleyball (34), kayaking (23), and ice hockey (15). Fry and Kraemer (22) have evaluated physical performance characteristics of 19 American football collegiate programs (981 participants) across three different levels of competition

(NCAA division I, II, and III). Bench press performance was significantly different between all levels of play, revealing that division I athletes were 6% and 11% stronger than division II and III athletes, respectively. Additionally, vertical jump performance was significantly greater in division I than in division II and III athletes. Interestingly back squat performance did not clearly differentiate between levels of competition. These findings are supported by Baker (4, 6, 7), who reported significant differences in bench press strength, and upper and lower-body power between different levels of competition in rugby league athletes in Australia. However, in contrast to findings by Fry and Kraemer (22), Baker and Newton (11) also reported significantly greater lower-body strength in higher level athletes.

Correlations between the change in strength and the change in power have been reported to reduce as players become more elite. For example, Baker (5) reported that the relationship between the change in strength and power was $r = 0.73$ and $r = 0.39$ in state level and national level rugby league athletes, respectively. These findings suggest that as players become more highly trained, improving one aspect of performance may not transfer to improvements in the other performance measure. Determining the relationships between strength and power between different levels of competition may provide insight into what training methods may be more effective for different playing levels. Indeed, if relationships between strength and power are weak in professional athletes, these finding may suggest that more specific power-orientated training methods may be of greater benefit. If the opposite is true, and there is a large transfer of training (large correlations), traditional strength training methods may be equally beneficial for developing power.

There is currently limited literature reporting differences in physical performance between separate levels of competition in rugby union athletes. If indeed younger players are being selected as a result of greater competition requirements, a better understanding of strength and power across different levels of competition in rugby union is required. These findings will provide normative data for coaches and conditioners who are responsible for developing younger players. Normative data may provide clearer direction when allocating training time to focus on individual needs, allowing them to effectively prepare athletes for transition through to the next level of performance. While better understanding of the relationship between strength and power may provide a guideline as to which training methods may be more beneficial for improving performance on an individual basis. Therefore, the aim of this investigation was to characterise differences and determine the relationship between strength and power in athletes across different levels of competition in rugby union. We hypothesize that athletes who compete at a higher level will produce greater levels of strength and power that that of athletes at lower levels.

METHODS

Experimental Approach to the Problem.

In order to characterise strength and power across different levels of play in rugby union athletes, 112 participants from four distinct levels of competition (professional, semi-professionals, academy, and high school 1st XV) volunteered to participate in this investigation. All players were tested on two separate occasions to determine individual strength and power. The first occasion participants were tested for upper- and lower-body strength (bench press and box squat, respectively). On the second occasion players were tested for upper- and lower-body power (bench throw and jump squat, respectively). All players had been performing these exercises in their regular resistance training sessions. Players were given verbal encouragement throughout all strength and power assessments. All players completed testing during their in-season phase of competition. Exercises were selected due to their common usage in power training programs and research studies along with their ability to represent upper and lower-body power (3, 10, 14, 19). Peak power was selected as the dependent measure as it has been reported to have the greatest association with athletic performance (21). All testing took place between 8:00 - 10:00 am. Additionally, players were instructed to maintain a high level of hydration and nutritional intake in the 24 hours leading up to each testing occasion. Players were instructed to abstain from caffeine 12 hours prior to each testing session

Subjects

A total of 112 rugby union players including 43 professionals competing in an international and provincial competition full time; 19 semi-professionals competing in the provincial competition (and who have not played in the professional level) for six months of the year; 32 academy level players competing in either age group provincial level or B-level provincial competition; and 18 high school (secondary school) level players competing in a regional high school competition were involved. Subject characteristics are presented in Table 1. Players were informed of the experimental risks and signed an informed consent document prior to the investigation. This investigation was approved by an Institutional Review Board for the use of human subjects. Due to injury from training or competition prior to assessment, eight professional and ten academy players did not take part in any of the lower-body testing. Additionally, due to their limited training history no high school players performed the jump squat.

Insert Table 1 about here

Procedures

Bench Press and Box Squat

Maximal strength was assessed using the bench press and box squat exercises using methods previously described (3). Briefly, players were required to perform three sets (50, 70, 90%) of sub-maximal (four-six repetitions) bench press or box squat followed by one maximal set (100%) of one-four repetitions. For the bench press players used a self-selected hand position, and were required to lower the bar to approximately 90° angle at the elbows and then pressed the bar in a vertical movement so that the arms were fully extended. During the box squat, players used a self-selected foot position and were required to lower themselves to a sitting position briefly on the box and then return to a standing position. The box height was adjusted for each athlete to allow the top of the thighs to be parallel to the floor while in the seated position. A three minute rest period separated all sets. Each maximal set was used to predict each player's one repetition maximum (RM) bench press (r=0.993) and box squat (r=0.969) using the following equation (29, 30):

$$1RM = (100*weight)/(101.3-(2.67123*reps))$$

Bench Throw

Upper-body peak power was assessed using a bench throw exercise performed in a Smith Machine. Players warmed up with two sets of four repetitions of bench press at 50% of their 1RM. Players then completed two sets of four repetitions of bench throw at 50% and 60% of 1RM (3, 9). Players used a self selected hand position and lowered the bar to a self selected depth (approximately 90° angle at the elbow). Players were then required to propel (throw) the bar vertically as explosively as possible. A three minute rest period separated all sets.

Jump Squat

Lower-body peak power was assessed using a jump squat exercise performed in a Smith Machine. Players warmed up with two sets of four repetitions of 90° squat at 55% of their 1RM. Players then completed two sets of four repetitions of jump squat at 55% and 60% of 1RM (3, 10). Players used a self selected foot position and lowered the bar to a self selected depth (approximately 90-100° angle at the knee). Players were then required to jump as explosively as possible. A three minute rest period separated all sets.

A GymAware® optical encoder (50 Hz sample period with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) was used to collect peak power for each repetition of bench throw and jump squat using the methods described elsewhere (20). Briefly, GymAware® consists of a spring-powered retractable cord that passes around a pulley mechanically coupled to an optical encoder. The retractable cord is then attached to the barbell and velocity and distance are calculated from the spinning movement of the pulley upon movement of the barbell. The encoder gives one pulse approximately every three millimeters of load displacement, with each displacement value time stamped with a one-millisecond resolution. The mass of the bar (as entered into a personal digital assistant), the entire displacement (mm) of the barbell, and time (ms) for the movement are used to calculate peak values for power (20).

Statistical Analyses

All data were log-transformed to reduce non-uniformity of error, with effects derived by back transformation as percent changes (28). Standardized changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-subject standard deviation. Standardized changes of 0.00-0.19; 0.20-0.59; 0.60-1.19; 1.20-1.99, <2.00 were interpreted as trivial, small, moderate, large, and very large effects, respectively (37), a modification of Cohen's thresholds of 0.2, 0.5, and 0.8 (16). To make inferences about the true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects (12).

To help explain any differences in performance, all performance data were also normalized to body mass using allometric scaling with a derived power exponent (17, 18). The equation for normalizing performance to body weight was: *normalized performance* = Y/X^b, where Y is the performance, X is the body mass, and b is the power exponent. The derived power exponent was determined by plotting performance and body mass on a log-log scale. The slope of the linear regression line was then used as the derived power exponent. Allometric scaling is generally superior to ratio scaling (performance/body mass) as ratio scaling penalizes heavier athletes.

Interclass correlation (r) and coefficient of variation (%) for all measures have previously been assessed in our laboratory on professional rugby players were 0.900 and 5.0% (bench throw), and 0.904 and 4.8% (jump squat), 0.915 and 4.3% (bench press), and 0.915 and 4.6% (box squat), respectively. Additionally, interclass correlation and coefficient of variation were also assessed on the high school level players and were 0.860 and 6.3% (bench throw), 0.950 and 2.2% (bench press), and 0.790 and 7.0% (box squat), respectively. Validity of the Gymaware® optical encoder has been previously reported elsewhere (20).

RESULTS

Magnitudes of the difference between the characteristics of the player are presented in Table 2. With the exception of height, magnitudes ranged from small to very large in favor of the players in competing at a higher level of competition. Raw data (mean ± SD) for each level of competition is presented in Table 3. Correlations between strength and power are presented in Table 4.

Insert Table 2 about here

Insert Table 3 about here

Insert Table 4 about here

The derived power exponents calculated for scaling to body weight were 1.073 ±0.193 (±90% confidence limits), 1.379 ±0.272, 1.089 ±0.302, and 0.910 ± 0.242 for bench press, bench throw, box squat and jump squat, respectively. The percent difference in absolute and allometrically scaled relative data between levels of competition is presented in Table 5.

Insert Table 5 about here

DISCUSSION

The aim of this investigation was to characterise differences in strength and power in athletes across different levels of competition in rugby union. As expected, greater absolute strength and power outputs were observed in athletes that participated in a higher level of rugby union competition. The only measure that did not discriminate between levels of competition was box squat strength between professional and semi-professional athletes. When performance was normalized for weight, the magnitudes of the difference were reduced for all measures and both bench press and box squat strength could not discriminate between professional and semi-professional levels of competition.

Differences in strength and power between the athletes in different levels of competition are likely due to maturation and body mass. As the level of competition increased, the chronological age and training age of the athletes also became larger (moderate to very large effect sizes). Maturation and training age plays a large role in the ability to produce high levels of force and power. Older athletes, or athletes with greater training ages will likely have developed more efficient movement patterns in the strength and power tasks assessed, have enhanced ability to activate musculature (e.g. increased synchronisation of motor units, decreased antagonist co-activation), and reduced inhibitory feedback from force regulators (e.g. Golgi tendon organs) allowing for greater production of force and power (11, 13, 26, 32).

These findings may also suggest that by the time athletes are competing at a higher level there is less scope for improvement. Indeed, the greatest improvement in strength and power from one level of competition to the next was in the period from high school into an academy system. Based on our findings, by the time athletes are training in an academy system and have a training age of only 1.5 years, approximately 81% of strength and 71% of power has already been developed. Therefore, the majority of physical development appears to be attained throughout the first 1-2 years of training within a structured environment. This physical development is particularly important to emphasise as it highlights the importance of having appropriate development pathways set in place. If athletes are indeed being selected from a younger age, then attention needs to be given throughout this level of development to ensure the maximal gains are achieved.

Higher level athletes had a greater body mass than their lower level counterparts. Although body composition was not assessed, it could be assumed that the heavier higher level athletes had a greater muscle mass than that of the lower level athletes (24, 25). Increased muscle mass is an important determinate of muscle strength. Indeed, Stone and colleagues (38) suggested that possessing greater levels of maximal strength may affect peak power output in that "(a) A given weight would represent a smaller percentage of maximal strength for a stronger person; thus, this weight would be easier to accelerate. (b) A person with greater maximum strength may have larger or greater percentage of type II muscle fibres" (38). As such, assuming skill level is equal; a larger player with greater muscle mass or a player with greater type II muscle fibre percent may be more effective in some aspects of rugby where physical domination of an opponent or maximal speed and acceleration are critical for successful performance e.g. tackling, breaking through the defensive line.

Normalizing performance to body mass reduced the magnitude of the difference between the levels of competition. These finding are in agreement with the contention that body mass contributes to performance during functional performance tests (17, 18). When performance was normalized for body mass, semi-professionals had a greater squat strength (3%) than the professionals, although these findings were unclear-trivial.

However, professional athletes still possessed greater power output than the semi-professionals. These findings suggest that while body mass and strength are important in producing power, there are other significant factors that contribute to power production. This is further highlighted by the negative correlation between lower-body strength and power in the professionals.

As athletes become more elite, increases in strength may not reflect increases in power output (4). Consequently, conditioning coaches may place more emphasis on other training methods more likely to enhance power once an ‘adequate’ strength base has been obtained (4). For example, professional athletes may complete a greater volume of modified Olympic lifts, intensified plyometrics, and advanced lifting programs such as complex and contrast training. As rugby players have only a limited training time available, a change in emphasis would result in less training volume dedicated to improving strength, and likely result in strength maintenance rather than improvement. This change in training emphasis may help explain why the professionals, although not stronger, had a greater power output than the semi-professional players.

Similar to findings by Fry and Kremer (22), lower-body strength values in the current investigation were not substantially different between the top two levels of competition. Fry and Kremer (22) speculated that methodological issues (scores obtained by different researchers, discrepancies in squat depth, use of knee wraps) may have been a reason for the similar scores of each competition group. However, in the current investigation all testing sessions were conducted by the same researcher to ensure standardized lifting technique was performed by all athletes. As such, lifting technique or use of lifting aids can be ruled out. It may be possible that the lack of difference in lower-body strength is due to differences in training mode and volume. Professionals typically perform a lower amount of resistance training volume throughout the year compared to semi professionals due to longer in-season training phases. The greater length of the in-season phase in the professional athletes substantially decreases the time available for off-season training phases where strength and power can be developed (2, 3). Additionally, due to longer in-seasons, professionals typically perform a greater volume of non-resistance training (e.g. team training) throughout the year. This greater non-resistance training volume may attenuate improvements in strength and power due to the inability of the body to simultaneously adapt to contrasting training stress (31). Furthermore, with longer in-season phases and greater competition demands, there is an increased likelihood of injury occurring or need for increased player management; which from an applied perspective, typically results in an unloading of lower-body training intensity and volume. All these factors are likely to limit physical development, especially in the lower-body.

Upper-body correlations between strength and power ranged from 0.40 in the professionals to 0.92 in the high school athletes. The shared variance of these measures (r^2 as a %) suggest that up to 85% of bench throw power in high school athletes can be explained by bench press strength, while only 16% of bench throw power in professionals can be explain by bench performance. These findings show that to improve power in professionals, other training methods separate from increasing maximal strength need to be identified and implemented. In contrast, to improve bench throw power in lower level athletes, maximal strength training may have the greatest transfer to power. It may also be suggested that greater transfer of training adaptation occurs in lower level athletes, whilst, the higher level professionals need greater specificity in training to ensure improvements are made.

Lower-body correlations between strength and power were lower than that previously reported in other rugby codes (8). The professional athletes in the current investigation actually had a negative correlation between box squat and jump squat. The difference in movement patterns of the lower-body exercises selected may have influenced the relationships observed. Indeed the box squat exercise all but eliminates any contribution of the stretch shortening cycle; whereas, the jump squat is performed with a countermovement which maximises the stretch shortening cycle.

Findings from the current study suggest that both strength and power can discriminate between the higher two (professional and semi-professional) and lower two (academy and high school) levels of competition. Notwithstanding this, the ability to produce high levels of power, rather than strength, may be a better determinate of playing ability between professional and semi-professional athletes. Therefore, higher level athletes wanting to enhance playing potential should focus on methods to improve power. However, it must be noted that our findings do not suggest that once a certain threshold of strength has been reached that it is not longer important to keep developing it. Our findings simply show that as athletes become more elite it becomes more difficult to improve some aspects of performance (which is likely due to increased competition demands) and that other mechanism for improving power, rather than increases in strength are required.

PRACTICAL APPLICATIONS

As strength and power output can discriminate between different levels of competitions; younger athletes should strive to attain greater levels of strength and power in an attempt to reach, or to be physically prepared for the next level of competition. These findings also suggest that appropriate pathways that nurture physical development, such as academies or development squads, are a critical component within a professional structure to ensure player succession. Nonetheless, practitioners must be cautioned to not attempt to accelerate these physical attributes too quickly in the young untrained players and each individual should be viewed and approached differently based on individual training history, playing position, injury history and physical maturity.

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Table 1. Characteristics of rugby union players from four distinct playing levels during the in-season training phase.

	Age (years)	Height (cm)	Body weight (kg)	Training age* (years)
Professional (n=43)	24.4 ± 2.7	184.7 ± 6.2	103.4 ± 11.2	5.6 ± 2.3
Semi-professional (n=19)	20.9 ± 2.9	187.2 ± 7.6	100.7 ± 11.5	2.9 ±1.9
Academy (n=32)	19.6 ± 1.8	186.9 ± 6.5	95.6 ± 11.0	1.5 ± 1.1
High school (n=19)	16.6 ± 0.8	180.9 ± 8.4	86.5 ± 13.7	0.7 ± 0.5

* Training age refers to the time spent within a supervised and monitored program.

Table 2. Magnitudes of the difference in player characteristics between rugby union players from four distinct competition levels during the in-season training phase.

		Professional	Semi-professional	Academy
Semi-professional	Age	Moderate	-	-
Academy		Very large	Large	-
High School		Very large	Very large	Very large
Semi-professional	Height	(negative)Small	-	-
Academy		(negative) Small	Trivial	-
High School		Trivial	Moderate	Small
Semi-professional	Weight	Small	-	-
Academy		Moderate	Small	-
High School		Large	Moderate	Moderate
Semi-professional	Training age	Moderate	-	-
Academy		Very large	Very large	-
High School		Very large	Very large	Moderate

Table 3. Maximal strength and power (mean ± SD) between rugby union players from four distinct competition levels during the in-season.

	Professional	Semi-professional	Academy	High School
Bench Press (kg)	141 ± 21	134 ± 13	115 ± 16	85 ± 13
Bench Throw (W)	1140 ± 220	880 ± 90	800 ± 110	560 ± 140
Box Squat (kg)	184 ± 32	182 ± 28	151 ± 30	100 ± 19
Jump Squat (W)	5240 ± 670	4880 ± 660	4430 ± 950	N/A

Table 4. Correlations of upper and lower-body strength and power in rugby union players from four distinct competition levels during the in-season.

	Professional	Semi-Professional	Academy	High School
Bench-Bench Throw	0.40	0.58	0.53	0.92
Box Squat-Jump Squat	-0.13	0.30	0.13	N/A

Table 5. Percent difference (mean ± 90% confidence limits) in absolute and allometrically scaled relative strength (bench press, box squat) and power output (bench throw, jump squat) from four separate levels of competition in rugby union players.

		Professional		Semi-Professional		Academy	
		Absolute (%)	Relative (%)	Absolute (%)	Relative (%)	Absolute (%)	Relative (%)
Semi-professional	Bench Press	4.5 ±6.1 Moderate	0.7 ±7.8 Unclear	-	-	-	-
Academy	Bench Press	18.9 ±5.9 Large	11.5 ±4.9 Moderate	14.7 ±6.5 Large	10.9 ±7.7 Moderate	-	-
High School	Bench Press	39.4 ±7.4 Very large	26.1 ±6.3 Very large	36.6 ±7.9 Very large	26.6 ±8.6 Very large	25.7 ±7.8 Large	16.5 ±6.2 Large
Semi-professional	Bench Throw	21.2 ±6.9 Large	17.2 ±8.9 Moderate	-	-	-	-
Academy	Bench Throw	29.0 ±6.5 Very large	21.1 ±6.4 Large	9.9 ±6.5 Moderate	4.8 ±7.9 Small	-	-
High School	Bench Throw	51.3 ±11.7 Very large	37.3 ±9.9 Very large	38.3 ±11.7 Very large	24.3 ±10.8 Large	31.5 ±11.5 Large	20.5 ±8.9 Large
Semi-professional	Box Squat	0.8 ±8.3 Unclear-trivial	-2.8 ±8.8 Unclear-trivial	-	-	-	-
Academy	Box Squat	18.3 ±9.2 Moderate	11.6 ±9.3 Moderate	17.7 ±10.3 Moderate	14.0 ±10.3 Moderate	-	-
High School	Box Squat	46.0 ±10.4 Very large	31.7 ±12.4 Large	45.6 ±11.3 Large	33.5 ±13.2 Large	33.9 ±12.0 Large	22.7 ±13.5 Large
Semi-professional	Jump Squat	7.0 ±6.7 Small	4.3 ±5.8 Small	-	-	-	-

Academy	16.6 ±9.0 Moderate	10.9 ±7.2 Moderate	10.3 ±9.9 Small	6.9 ±7.9 Small	-	-
High School	N/A	N/A	N/A	N/A	N/A	N/A