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Relationship of a Six-Second Peak Power Cycle Ergometer Test with Maximal and Ballistic Strength Tests in International Rugby Union Players

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ABSTRACT

The purpose of this study was to determine relationships between traditional tests of maximal and ballistic strength, with the results of a 6 s cycle sprint (6sCS) in international level Rugby Union (Rugby) players. Thirty-three international level male Rugby players participated in the study. Each player completed the 6sCS, sprint run, standing long jump, weighted and unweighted countermovement jumps, and a 1RM squat test. Pearson's correlations were carried out to determine relationships between absolute (PPO) and relative peak power output (relPPO) from the 6sCS with the other tests of maximal and ballistic performance for the whole population and for positional groups. For the cohort, significant relationships ($p \leq 0.05$) between relPPO and various measures of speed (r=0.63-0.73) and jump performance (r=0.48 to 0.53) were observed. In the Backs, there were large, significant relationships with weighted countermovement jump, standing long jumps, and 10 m sprint time (r=0.58 to 0.74). Large significant relationships were found with sprint and standing long jump performance in the Forwards (r=0.54 to 0.82). These significant relationships are most likely due to similarity in duration, energy system requirements, contraction types, and similarities in muscle groups recruited. Differences between position groups may reflect the physical qualities players possess to meet game demands. The study suggests that 6sCS may be a valuable addition to existing testing to evaluate maximal and ballistic intensity performance, provide data if jump or sprint tests are not possible and help set benchmark levels of these physical capacities in elite Rugby Union players.

Keywords: sport, performance, testing, phosphagen, maximal

INTRODUCTION

Rugby Union (Rugby) is a high intensity team sport, characterized by high speed running, sprinting, and change of direction with intermittent recovery (Pollard et al., 2018). There are also many sport-specific movements, such as tackling, ball-running, scrums, lineouts, and breakdowns contributing to a large total physical load (Jones et al., 2019). These short duration, all-out efforts can be defined as requiring "maximal neuromuscular activation" (Winter et al., 2016). Recent match-play profiling of elite Rugby players has reported a mean of 164 of these high efforts per game (Sheehan et al., 2022). Rugby players are divided into two positional groups with distinct and general roles. Forwards perform in scrums and lineouts to win the ball, perform less running and more impacts and static work requiring high force production, whilst Backs tend to perform in greater space, run and sprint greater distances, and have less collisions (Sheehan et al., 2022).

Due to the many maximal efforts, the sport has used a variety of tests to evaluate training and performances that rely predominantly on phosphagen pathways (Smart et al., 2014). The phosphagen pathways are the predominant source of energy for all-out activities up to approximately six-seconds in duration (Chamari & Padulo, 2015). Rugby specific movements such as sprinting, jumping, tackling and scrummaging all require neuromuscular activation reliant on phosphagen pathways (Brazier et al., 2018). Existing research has shown that these efforts are relevant to overall match performance, with small yet significant relationships found between sprinting speed and line breaks in professional players (Smart et al., 2014). In addition, higher level Rugby players have greater maximal upper and lower body strength (Argus et al., 2012) and better countermovement jump performance (Jones et al., 2019) when compared to lower level players.

Traditionally, the 30 second Wingate Anaerobic Test (WAnT) has also been the most commonly used test to assess anaerobic performance (Ayalon et al., 1974). Correlations have been found between WAnT and countermovement jump (Alemdaroğlu, 2012) as well as sprinting (Hoffman et al., 2000). However, the duration of the WAnT is significantly greater than maximal neuromuscular efforts in team and court sports. Individual effort duration in Rugby Union is typically less than 4 s at all intensities (Lacome et al., 2013). An alternative assessment, the six-second peak power test on a cycle ergometer (6sCS) has increased in popularity as a testing and training tool (Cushman et al., 2018; Jones et al., 2019; Wehbe et al., 2015). The shorter duration of the 6sCS may be a more practical and relevant test than the WAnT as it has a lower technical requirement with a duration similar to typical maximal and ballistic strength tests. Despite its increased use, there is limited research on the 6sCS. Further investigation is required to better understand its potential role as a low impact testing tool to assess a maximal neuromuscular effort and how it relates to other tests of maximal and ballistic strength. Therefore, the goal of this study is to evaluate the relationship between the 6sCS and other tests of maximal and ballistic strength in international level Rugby players.

METHODS

Participants

Thirty-three International male Rugby players participated in the study. All players were full-time professional Rugby players with an average of 4.3 ± 2.8 y playing at the international level. The purpose and procedures of the study were explained by the researchers and written informed consent obtained. The study was conducted according to the Declaration of Helsinki after approval from the University of Waikato Human Research Ethics Committee (HREC[health]#2019#05). Testing was conducted at the beginning of the pre-season period. All players were familiar with the testing procedures.

Six-Second Cycle Test

The 6sCS test consisted of 2 x 6 s sprints with 90 s recovery on a calibrated cycle ergometer (WattBike Pro, Nottingham, UK) using a protocol previously shown to be reliable with a Coefficient of Variation (CV) of 4.2% for peak power (Cushman et al., 2018). A five-minute warmup was completed before the test; whereby players pedaled at a self-selected light (RPE of 3) resistance at a cadence of 80 rev·min^{-1}, with a mandated 2-s maximal acceleration at the 3-, 4- and 5-minute mark. The warmup was followed by a three-minutes of complete rest seated quietly on the bike. Before the start, players assumed a seated position with the preferred foot at a position 45° forward of the top pedal position and the hands gripping the racing handlebars. Resistance was determined using manufacturer guidelines as outlined in the user manual (https://support.wattbike.com/hc/en-gb/articles/360013621359-6-second-test-Recommended-resistance-settings-) based on body mass and sex, using the Wattbikes adjustable air-braking system and magnet system to that regulates resistance to the wheel (WattBike, Nottingham, UK). Players below 85kg place the air setting on level 4, 86-95kg on level 5, 96-105kg on level 6, 106-115kg on level 7, 116-125kg on level 8 and above 125kg on level 9, with the magnetic resistance set to level 1. After a five-second countdown, the players performed the first six-second sprint from a stationary start, remaining seated, with a second six-second sprint after 90 s of passive rest replicating the protocols outlined previously (Cushman et al., 2018). Peak power output (PPO) and relative power in Watts per kilogram (relPPO) were recorded. Players were verbally encouraged to give maximum effort for the entire duration of each sprint. A CV of

3.0% has previously been reported for PPO in male team sport athletes (Wehbe et al., 2015).

Standing Long Jump

For the standing long jump (SLJ), players set up with their toes on the start line. In their own time, they swung their arms and jumped forward as far as possible, retaining balance on landing. The distance in centimetres from the start line to the rearmost point of the heel was recorded. Three warmups and three trials were completed. The CV for this test has previously been reported at 4.4% in physically active males (Hébert-Losier & Beaven, 2014).

Countermovement Jump

The countermovement jump (CMJ) test was conducted unweighted and weighted with a 40-kg barbell. Velocity and jump height were assessed using a linear transducer (Gymaware, Kinetic, Canberra, Australia) attached to a stiff wooden dowel (~50 g) across the shoulders behind the neck for the unweighted test and attached to a standard weightlifting bar for the 40-kg jump. The players descended to a self-selected point by bending at the hips and knees, then immediately jumped as high as possible. Three warmup and five test jumps were performed. Jump height and mean concentric velocity were recorded with the best result used for analysis. The CV for bodyweight CMJ height has previously been calculated at 4.7% and the 40 kg CMJ at 5.4% (Marques & González-Badillo, 2006).

Sprint Run

A 20 m sprint was used to assess running speed for Forwards and 30 m for Backs following national speed testing protocols outlined by Smart et al. (2014). Backs were tested over a longer distance due to their greater propensity to complete sprint efforts of longer distances (Watkins et al., 2021). A 15 minute warm up was completed prior, comprising 5 minutes of jogging, followed by mobility drills, skipping exercises, and 20 m runs at 60%-70%-80% and two runs at 90%. Dual beam timing gates (Swift Performance, Wacol, Australia) were placed at the start, 10 m and 20 m distances for Forwards, and also at 30 m for Backs. The players started 50 cm behind the starting gate to prevent inadvertently tripping the light beams (Smart et al., 2014). When ready, the players ran as fast as possible until they passed the final timing gate. Time in seconds for each section was recorded. Three trials were completed with 90 s recovery. The CV for these speed tests have previously been reported at <3.0% in professional Rugby players (Smart et al., 2014). Maximum velocity was assessed using a stationary radar device with a sample rate of 46.8 samples per second (Stalker ATS II, Applied Concepts Dallas, TX. USA). The device was mounted on a tripod 3-m behind the athlete. Players performed three maximal sprints, running directly away from the device. Maximum velocity was recorded in $km{\cdot}hr^{-1}$. Intra-class correlations >0.75 and CVs <5.4% have been reported previously (Cross et al., 2015).

Maximum Back Squat

The back squat was performed using standard weightlifting equipment (Eleiko, Halamstad, Sweden). Players performed a series of three warmup sets of three repetitions with increasing loads of 60%, 70%, 80% of one-repetition maximum (1RM). The weight was lowered to the point where the knee was at the same height as the hip and the middle of the thigh parallel to the ground. After the warmup sets, the players completed single repetition sets with increasing load until they could no longer perform the lift. The results were recorded in kilograms and percentage of body mass. The CV for a 1RM squat test has previously been recorded at 4.7% (Grgic et al., 2020).

Statistical Analysis

All data was transferred to a spreadsheet (Microsoft Excel 2016, Redmond WA, USA) for analysis. Results are recorded as means and standard deviation for the entire cohort and for the two positional groups (Forwards and Backs). Unmatched T-Tests were used to determine the difference in results between the two positional groups. Pearson's correlations were calculated to identify the magnitude of relationships between the 6sCS data with other measures of maximal and ballistic strength. The 95% Confidence Intervals were calculated for all correlation coefficients and magnitudes were reported according to recommendations by Hopkins et al. (2009). Specifically magnitudes of r <0.1 were deemed trivial r = 0.1-0.3 small, r = 0.3-0.5 moderate, r = 0.5-0.7 large, r = 0.7-0.9 very large, and r > 0.9 nearly perfect. Confidence intervals where the result overlapped both positive and negative values were deemed unclear. Levels of significance was set at $p \leq 0.05$.

RESULTS

Means and standard deviations for all tests are displayed in Table 1. There were several significant differences between positional groups. The backs had significantly higher relPPO (*p*=0.020), relative squat (*p*=0.01), SLJ (*p*-0.022) and maximum speed (*p*<0.001) as well significant lower 10m (*p*<0.001) and 20m (*p*<0.001) times. The forwards had significantly higher MPO (*p*=0.003) and 1RM Squat (*p*=0,048). All relationships between peak power output (PPO) and relative peak power output (relPPO) with other measures of maximal and ballistic strength are outlined in Table 2. Across the entire cohort, there was a large, significant relationship between relPPO and 10 m and 20 m time, maximum running velocity (Figure 1), SLJ, and countermovement jump height (Figure 2). There were also significant moderate relationships between relPPO and CMJ mean velocity and 40 kg CMJ mean velocity. There were no significant relationships with PPO for any of the measures.

Relationships for the position groups are listed in Table 3. For the Backs, there was a *very large* significant relationship between PPO and 40 kg CMJ mean velocity, *large* significant relationships between relPPO and 40 kg CMJ mean velocity and 10 m time, and a *moderate* significant relationship between relPPO and SLJ. For the Forwards, there was a *very large* significant negative relationship between relPPO and 10 m time, and *large* significant relationships between relPPO and maximum velocity and 20 m time. There were large but non-significant relationships between relPPO and CMJ mean velocity, CMJ jump height, and 40 kg CMJ mean velocity. There was only one significant relationship with PPO for the Backs (with 40 kg CMJ mean velocity) and no significant relationships observed with PPO in the Forwards.

Table 1. Testing Results for total group and positional groups

Measure	Group (n = 33) Mean (SD)	Forwards (n = 17) Mean (SD)	Backs (n = 16) Mean (SD)
Player Information			
Age (y)	27 (±3.5)	27 (±3.2)	26 (±3.8)
Height (cm)	186 (±7.5)	189 (±5.7)	182 (±7.6)
Body Mass (kg)	106 (±13.6)	116 (±9.7)	96 (±9.2)
6-s Peak Power			
Peak Power Output (W)	1789 (±291.0)	1874 (±271.6)	1695 (±287.0)
Mean Power Output (W)	1412 (±168.0)	1492 (±142.5) †	1325 (±152.9)
Relative Peak Power (W·kg^{-1})	16.8 (±2.2)	16.2 (±2.3)	17.5 (±1.9) *
Speed			
10 m Sprint (s)	1.70 (±0.09)	1.76 (±0.09)	1.65 (±0.04) †
20 m Sprint (s)	3.00 (±0.17)	3.10 (±0.16)	2.88 (±0.07) †
30 m Sprint (s)			4.02 (±0.12)
Maximum speed (km·hr^{-1})	30.6 (±2.5)	29.0 (±2.5)	32.2 (±1.7) †
Strength			
Squat (kg)	184.7 (±27.6)	193.9 (±33.9) *	175.4 (±15.8)
Relative Squat (kg·bw^{-1})	1.75 (±0.23)	1.66 (±0.24)	1.84 (±0.19) †
Power			
CMJ mean velocity (m·s^{-1})	2.89 (±0.25)	2.63 (±0.32)	2.72 (±0.17)
CMJ Jump Height (cm)	50.4 (±5.9)	48.7 (±5.7)	51.8 (±6.0)
40 kg CMJ mean velocity (m·s^{-1})	2.19 (±0.20)	2.20 (±0.27)	2.18 (±0.15)
Standing Long Jump (cm)	261.6 (±22.1)	250.6 (±26.2)	270.4 (±12.9) *

SD=Standard deviation
** = significant relationship p≤0.05 † = significant relationship p≤0.01*

PPO = Peak Power Output, relPPO = relative Peak Power Output, CMJ = Countermovement Jump, 40kg CMJ = Countermovement Jump with a 40 kg weight, 1RM Squat = one repetition maximum squat, % BW Squat = 1RM Squat expressed as a percentage of bodyweight, SLJ = Standing Long Jump, Maximum Speed = Maximum speed in km·hr^{-1}.

Table 2. Relationships between the 6-s Cycle Test and maximal and ballistic efforts for all players

Measure	R (95%CI)	Magnitude
Power		
relPPO – SLJ	0.54 (0.30, 0.73) †	*Large*
relPPO – CMJ Jump Height	0.53 (0.16, 0.77) †	*Large*
relPPO – 40kg CMJ mean vel	0.49 (0.11, 0.75) *	*Moderate*
relPPO – CMJ	0.48 (-0.11, 0.75) *	*Moderate*
PPO – 40 kg CMJ mean vel	0.29 (-0.13, 0.62)	*Small*
PPO – CMJ Jump Height	0.15 (-0.27, 0.52)	*Small*
PPO – CMJ	-0.01 (-0.42, 0.50)	*Trivial*
PPO – SLJ	0.03 (-0.26, 0.31)	*Trivial*
Speed		
relPPO – 10 m	-0.73 (-0.85, -0.55) †	*Large*
relPPO – 20 m	-0.65 (-0.82, -0.39) †	*Large*
relPPO – Maximum Speed	0.63 (0.35,0.80) †	*Large*
PPO – 20 m	0.14 (-0.22, 0.47)	*Small*
PPO – Maximum Speed	-0.12 (-0.46, 0.24)	*Trivial*
PPO – 10 m	-0.02 (-0.32, 0.29)	*Trivial*
Strength		
PPO – 1RM Squat	0.35 (-0.03, 0.64)	*Moderate*
PPO – % of BW Squat	0.34 (-0.04, 0.63)	*Moderate*
relPPO – 1RM Squat	-0.21 (-0.54, 0.18)	*Small*
relPPO - % of BW Squat	0.11 (-0.27, 0.47)	*Small*

** = significant relationship $p \leq 0.05$, † =significant relationship $p \leq 0.01$ CI = Confidence interval*

PPO = Peak Power Output, relPPO = relative Peak Power Output, CMJ = Countermovement Jump, 40kg CMJ = Countermovement Jump with a 40 kg weight, 1RM Squat = one repetition maximum squat, % BW Squat = 1RM Squat expressed as a percentage of bodyweight, SLJ = Standing Long Jump, Maximum Speed = Maximum speed in $km \cdot hr^{-1}$.

Table 3. Relationships between the 6-s Cycle Test and Maximal and Ballistic Strength Tests for the Positional Groups

	BACKS		FORWARDS	
Measure	**r (95% CI)**	***Magnitude***	**r (95% CI)**	***Magnitude***
Power				
PPO – CMJ Jump Height	0.33 (-0.22, 0.73)	*Moderate*	0.21 (-0.45, 0.72)	*Small*
relPPO – CMJ Jump Height	0.40 (-0.16, 0,77)	*Moderate*	0.59 (-0.02, 0.89)	*Large*
PPO – CMJ	0.15 (-0.42, 0.63)	*Small*	-0.01 (-0.61, 0.59)	*Trivial*
relPPO – CMJ	0.30 (-0.27, 0.72)	*Moderate*	0.60 (-0.01, 0.88)	*Large*
PPO – 40kg CMJ mean vel	0.74 (0.35, 0.91) †	*Very large*	-0.18 (-0.79, 0.50)	*Small*
relPPO – 40kg CMJ mean vel	0.69 (0.26, 0.89) †	*Large*	0.52 (-0.16, 0.78)	*Large*
PPO – SLJ	0.30 (-0.10, 0.06)	*Small*	0.22 (-0.25, 0.60)	*Small*
relPPO – SLJ	0.43 (0.05, 0.70) *	*Moderate*	0.59 (0.16, 0.60) *	*Large*
Sprint Performance				
PPO – 10 m	-0.35 (-0.67, 0.07)	*Moderate*	-0.43 (-0.73, 0.02)	*Moderate*
relPPO – 10m	-0.58(-0.80, -0.23) †	*Large*	-0.82(-0.92, -0.59) †	*Very Large*
PPO – 20 m	-0.33 (-0.72,0.22)	*Moderate*	-0.05 (-0.53, 0.45)	*Trivial*
relPPO – 20 m	-0.48 (-0.79, 0.05)	*Moderate*	-0.64(-0.86, 0.21) †	*Large*
PPO – Maximum Velocity	0.34 (-0.20, 0.74)	*Moderate*	-0.02 (-0.51, 0.48)	*Trivial*
relPPO – Maximum Velocity	0.33 (-0.22, 0.72)	*Moderate*	0.65 (0.21, 0.86) †	*Large*
PPO – 30 m	-0.35 (-0.70, 0.20)	*Moderate*		
relPPO – 30 m	0.46 (-0.78, 0.07)	*Moderate*		
Strength				
PPO – 1RM Squat	0.34 (-0.24, 0.74)	*Moderate*	0.23 (-0.34, 0, 68)	*Small*
relPPO – 1RM Squat	0.08 (-0.47. 0.58)	*Trivial*	-0.17 (-0.65, 0.39)	*Small*
PPO – % of BW Squat	-0.53 (-0.83, 0.03)	*Large*	0.12 (-0.44, 0.62)	*Small*
relPPO - % of BW Squat	-0.20 (-0.66. 0.37)	*Small*	0.08 (-0.47, 0.59)	*Trivial*

** = significant relationship p≤0.05 † = significant relationship p≤0.01*

PPO = Peak Power Output, relPPO = relative Peak Power Output, Sum of 8 = sum of 8 skinfolds, CMJ = Counter-movement Jump, 40kg CMJ = Countermovement Jump with a 40kg weight, 1RM Squat = one repetition maximum squat, % BW Squat = 1RM Squat expressed as a percentage of bodyweight, SLJ = Standing Long Jump, Maximum Velocity = Maximum velocity in km·hr⁻¹.

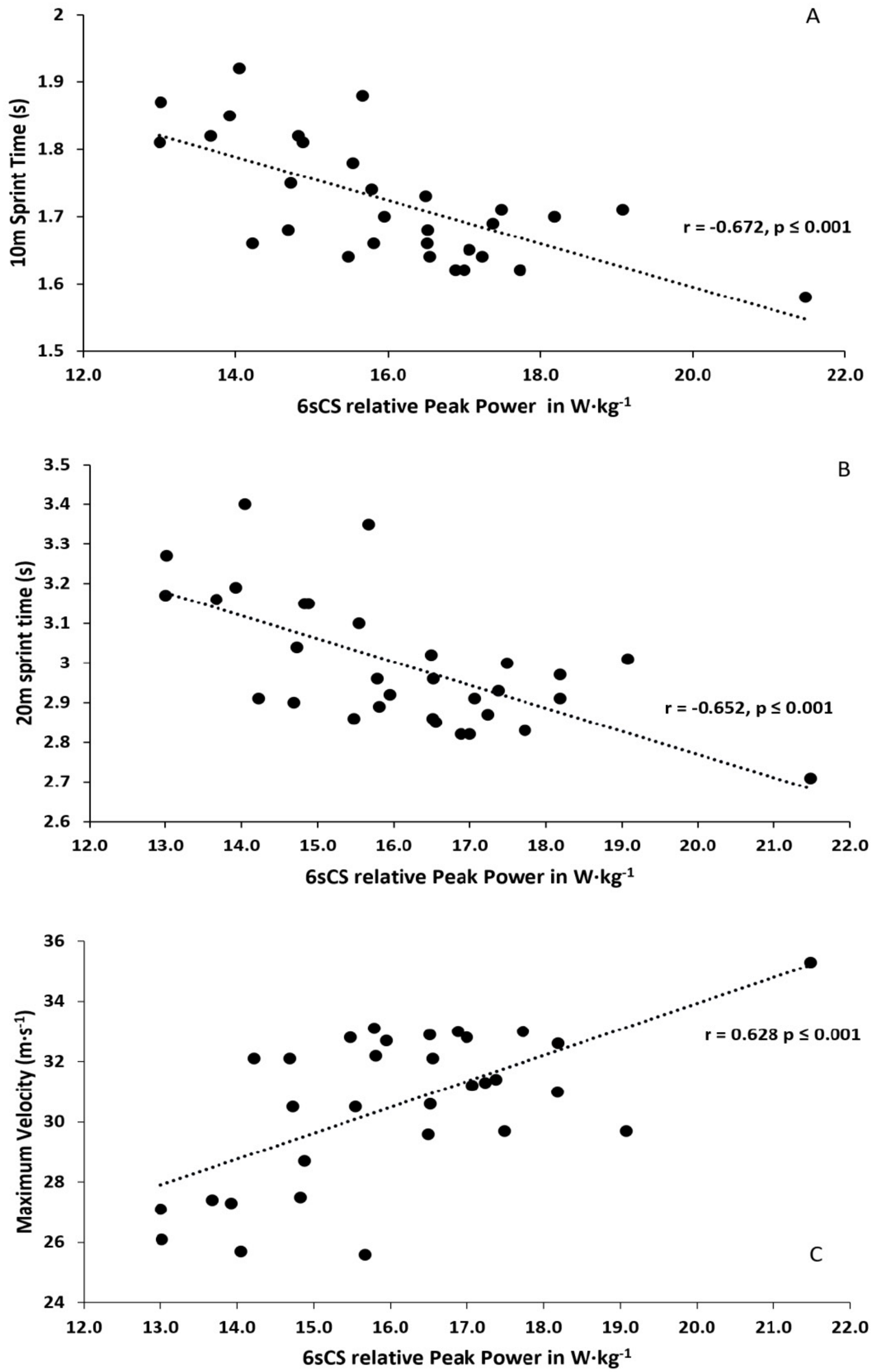

Figure 1. Scatter plot of relationships between relative peak power on six-second cycle sprint and sprint data. A. 10 m sprint time (seconds) compared to 6sCS relative Peak Power ($W{\cdot}kg^{-1}$). B 20 m sprint time (seconds) compared to 6sCS relative Peak Power ($W{\cdot}kg^{-1}$). C Maximum velocity ($m{\cdot}s^{-1}$) compared to 6sCS relative Peak Power ($W{\cdot}kg^{-1}$).

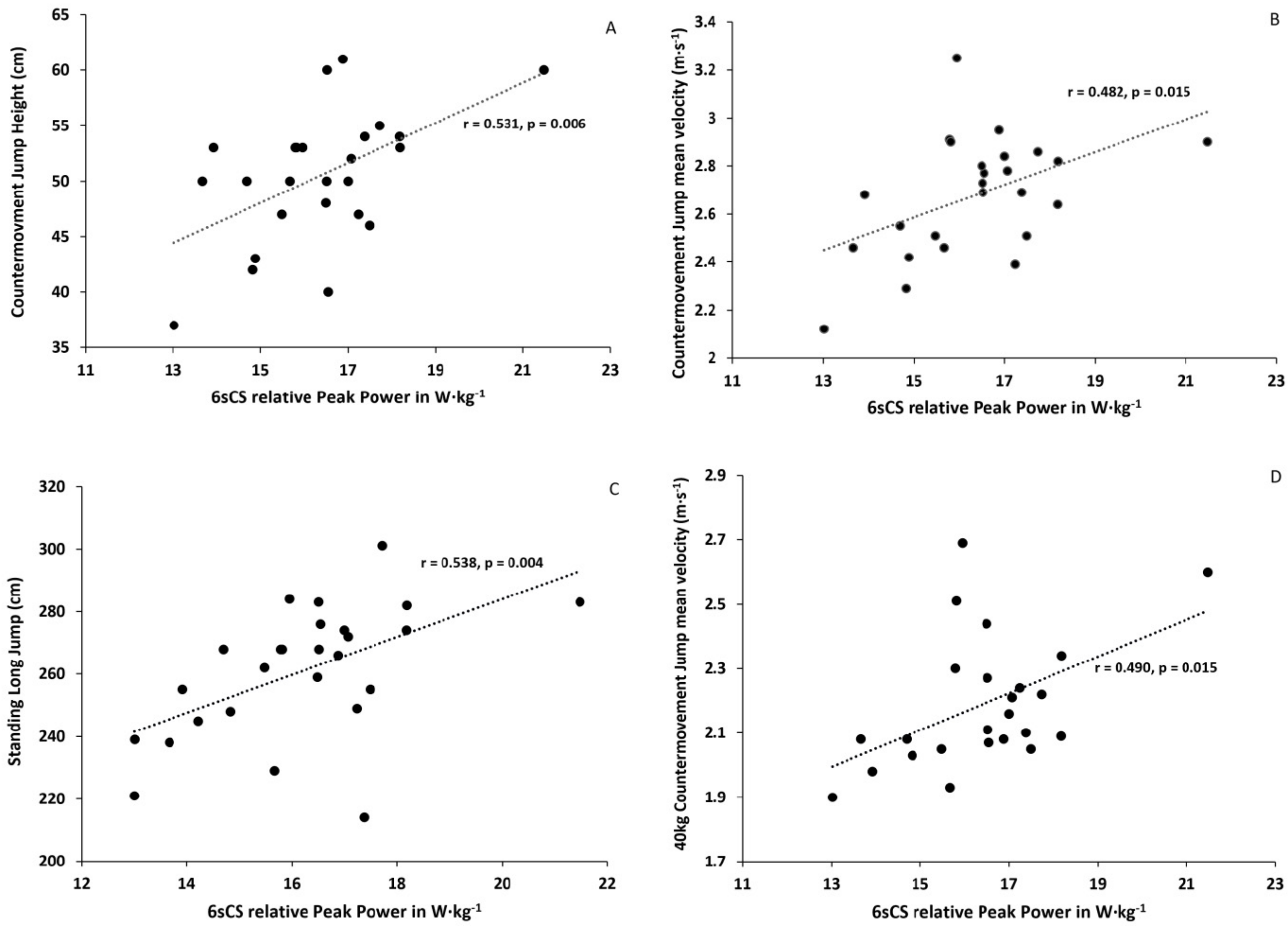

Figure 2. Scatter plot of relative peak power from six second cycle sprint and jump data. A. Countermovement jump height (cm) compared to 6sCS relative Peak Power (W·kg^{-1}), B. Countermovement jump mean velocity (m·s^{-1}) compared to 6sCS relative Peak Power (W·kg^{-1}), C. Standing Long Jump (cm) compared to 6sCS relative Peak Power (W·kg^{-1}), D. 40kg countermovement jump mean velocity (m·s^{-1}).

DISCUSSION

The purpose of the present study was to examine the relationship between common tests of maximal and ballistic strength and a 6sCS cycle in a cohort of international Rugby players. Significant difference between the positions were expected and aligned with previous research (Smart et al., 2013). For the entire cohort and for positional groups, we observed several significant relationships between relPPO with other measures, including running speed and jump performance. The differing magnitudes of relationships observed between Forwards and Backs may reflect different game demands and therefore different required physical qualities that players possess to meet those demands. Backs tend to cover a greater amount of distance in space and achieve higher running speeds, whereas forwards have greater involvement in contested possessions such as scrums, rucks and tackles (Watkins et al., 2021).

As a group, large and very large relationships were recorded between relPPO in the 6sCS with maximum velocity, and sprint time over 10 m and 20 m. Mean sprint times in both Forwards and Backs groups were within 2.5% (10 m), 0.7% (20 m) and 0.4% (30 m) of a similar cohort of professional level Rugby players (Smart et al., 2014). The relationships observed in the present study with international Rugby players are in agreement with previous research in other sports. Specifically, similar relationships were found between sprint running and cycling performance in a number of other sports such as Field Hockey (Aziz & Chuan, 2004), male youth Soccer players (Nikolaidis et al., 2018), and across a cohort of high school team sport athletes (Tharp et al., 1985). These tests used the longer WAnT to assess anaerobic performance. Unlike the WAnT which uses the highest average power output from the first five seconds (Bar-Or, 1987), the 6sCS records the highest power output, which has been calculated to be achieved in 1.83 s (±0.04) (Herbert et al., 2015). As a shorter, less demanding test, the 6sCS test could be performed more frequently. Unlike the aforementioned studies (Aziz & Chuan, 2004; Nikolaidis et al., 2018; Tharp et al., 1985), PPO did not correlate with any of the speed measures across the cohort. Research in Rugby (Baker & Newton, 2008) and Soccer (Comfort et al., 2014) have found similar relationships between relPPO and sprint performance. Six-second PPO has been shown to correlate significantly with match sprint distance achieved in Australian Rules football (O'Connor et al., 2023) indicating the test may have some merit in predicting physical load in other sports. It is likely that relative lower-body power metrics are a better correlate of sprint for heavier athletes like Rugby players, and by extension, on-field capabilities dependent on sprint performance such as line breaks, breaking tackles and scoring in international Rugby (Smart et al., 2014). Thus, the 6sCS may be a potentially less technical, lower-impact test of lower body power in Rugby athletes. Training interventions with short duration maximal sprints on a cycle ergometer have been shown to improve performance in short sprint running efforts (Nebil et al., 2014; Prescott, 2018; Thom et al., 2019). Using the 6sCS as a test of maximal intensity efforts may be used to help guide this form of training if it is used as an adjunct to traditional sprint running training.

The similar short duration of the sprint efforts and the time to achieve peak power on the cycle ergometer may be one reason for the large relationships between the 6sCS test and sprint performance (Dawson et al., 1997). Both tests share similar energy system requirements, and importantly, both the 6sCS and acceleration are reliant on high force concentric contractions (Bijker et al., 2002; Chelly et al., 2010). The stretch shortening cycle becomes more important for performance approaching maximum running velocity (Chelly et al., 2010). It could also be speculated that there is some similarity given the cyclic nature of the two tests as they require maximal output from each limb successively (Hoffman et al., 2000). We recognise that the study was conducted on international Rugby players, not international level cyclists or sprinters, and therefore, the relationships observed are likely to be different to more specialized participants.

Several relationships were also found between the 6sCS and jump test results. Jump performance for this group was higher than provincial level players for the SLJ (Argus et al., 2012), which may indicate high levels of lower body power are required to attain an elite level of performance in Rugby. Significant relationships were found previously between PPO and the CMJ and squat jump respectively in professional Basketball players (Alemdaroğlu, 2012), high school Basketball players (Nikolaidis et al., 2018), and Soccer players (Hoffman et al., 2000); however, relPPO was not recorded. Although there were a number of significant relationships between relPPO and jump tests, the magnitude of the relationships do not appear to be as high as the sprint data across the cohort. This lesser degree of relationship may be due to the greater use of the stretch shortening cycle in a jump test whilst a maximal sprint on the cycle ergometer is predominately concentric (Roe et al., 2017). The jump tests require a bilateral movement as opposed to both cycling and sprinting which involves alternating application of force to the pedals (Hoffman et al., 2000). The 40 kg CMJ mean velocity had the highest relationship with PPO of all the tests in the Backs with 6sCS explaining ~55% of the variance in the loaded jump concentric velocity. This test may be less reliant on the stretch-shortening cycle than the bodyweight CMJ, due to the greater inertial load i.e., body mass of the player plus the additional bar weight, that has to be overcome. Forwards are also generally heavier than Backs (~20 kg heavier in this cohort) and therefore must overcome a greater inertial load, making it harder to perform a maximal jump.

Even though the levels of relationship for the jump tests across the entire cohort were lower than for sprint tests, there were still some large and moderate significant relationships between the 6sCS and jump tests across the groups. Both jump tests and 6sCS require reaching maximal force output, a rapid explosive muscular contraction, whilst cycling (Brochner et al., 2018) and jumping (Vanezis & Lees, 2005) use the quadriceps muscles as a primary mover. The muscle groups required to perform the two tests were sufficiently similar to have some commonality in performance (Loy et al., 1995). Jump and plyometric training is a common training tool to improve lower body power; however, excessive jump training can lead to increased neuromuscular fatigue and muscle damage (Jamurtas et al., 2000). Maximal cycling efforts have been shown to improve lower body power in previous research (Nebil et al., 2014; Satiroglu et al., 2021). The 6sCS may be a valuable tool to guide training in players coming back from injury who may not be able to perform normal ballistic training methods.

The average squat strength across the group of ~185 kg is similar to previous research on an equivalent cohort (Dawson et al., 1997). Greater lower body strength has been recorded for professional

Rugby players when compared to academy and high school players (Argus et al., 2012) and between professional and semi-professional Rugby League players (Baker & Newton, 2008). No collective or positional relationship was apparent between back squat and 6sCS data. The results would suggest the 6sCS test and 1RM squat test are assessing distinct athletic qualities. The squat is a double leg movement that is performed at a slow speed 6sCS with high force and time-under-tension; and the time to develop the force is longer. Time to peak power is a critical factor in the bike sprint, whereas the ability to overcome the biomechanically weakest point, or sticking point, may be a greater factor in squat performance (Kompf & Arandjelović, 2017). The 6sCS, sprint and jump efforts all require maximal speed of movement in minimal time and could be considered tests of maximal and ballistic neuromuscular activation, whereas a squat test considered an assessment of maximal strength. Sprint and jump performance may be more similar to the 6sCS in that they require force development that are dependent on the speed of movement.

There were multiple large relationships between relPPO and the other tests of maximal and ballistic strength across the group and for positional groups. However, PPO was only significant in the backs group for 10 m sprint time. The ability to produce force in relation to body mass has been established in jumping and sprinting activities (Baker & Nance, 1999). Body mass has been shown to be critical factor for achieving PPO in the WAnT (Changela & Bhatt, 2012; Tharp et al., 1985). Athletes with higher body mass are more able to apply force to the pedals in the first few strokes, resulting in higher peak power. In other tests of maximal neuromuscular effort, greater body mass must be propelled forward or upwards, depending on the test, and therefore offers no advantage. This distinction may help explain the higher relationships between relPPO and the other tests of maximal and ballistic strength.

Off-feet conditioning methods, such as cycling, are sometimes used as a non-impact training option to reduce stress on the lower body (Fenemor et al., 2022). It is well established that training adaptations are higher in the training mode that is employed (Reilly et al., 2009). This can however become problematic when running loads continue to increase, leading to excessive fatigue (Hamlin et al., 2017). The 6sCS can provide measures that can be used to better program and evaluate off-feet conditioning programs conducted with maximal intensity efforts when they are employed in conjunction with normal running based training, and to guide training efforts to maintain the phosphagen pathways with injured athletes.

CONCLUSION

The results of this study found moderate and large relationships between results of the 6sCS test and sprint, SLJ, and CMJ tests in international level Rugby players. The 6sCS test may serve as a time efficient, low technical, non-impact test of maximal intensity efforts and as an addition to testing protocols for international Rugby players based on the shared variance with other tests. The 6sCS is performed off-feet and thus may also play a role with assessing heavier players or those with pre-existing injuries that would preclude jump testing as well as potentially assessing the capacity of the phosphagen energy system. Relative peak power output may be a preferred metric to collect in this population due to the magnitude of the observed relationships with known performance determinants.

CONFLICT OF INTEREST

The authors report no conflict of interests.

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