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Optimised force-velocity training during pre-season enhances physical performance in professional rugby league players

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ABSTRACT

The effectiveness of 8-week force-velocity optimised training was assessed in highly trained professional rugby league athletes. Players (age 24 ± 3 years; body mass 94.9 ± 21.6 kg; height 181.3 ± 6.0 cm) were strength-matched and assigned to a force-velocity optimised group (OP; n = 15) or a general strength-power group (GP; n = 14). Tests included 10-m, 20-m sprints, 3 repetition-maximum squat and squat jumps over five load conditions to ascertain vertical force-velocity relationship. ANCOVA revealed there was a group effect for force-velocity deficit ($P < 0.001$), with the OP two-fold greater than the GP group (OP pre: 51.13 ± 31.42%, post: 62.26 ± 31.45%, GP pre: 33.00 ± 19.60%, post: 31.14 ± 31.45%, $P < 0.001$). There were further group effects for 3RM squat (OP pre: 151.17 ± 22.95 kg, post: 162.17 ± 24.16 kg, GP pre: 156.43 ± 25.07 kg, post: 163.39 ± 25.39 kg, $P < 0.001$), peak power (OP pre: 3195 ± 949 W, post: 3552 ± 1033 W, GP pre: 3468 ± 911 W, post: 3591 ± 936 W, $P < 0.001$), and SJ (OP pre: 39.79 ± 7.80 cm, post: 42.69 ± 7.83 cm, GP pre: 40.44 ± 6.23 cm, post: 41.14 ± 5.66 cm, $P < 0.001$). Prescribing F-V deficit training is superior for improving physical performance within highly trained RL players.

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Team sports; force-velocity profile; jumping; strength; power

Introduction

Rugby league (RL) is an intermittent sport, involving frequent high-intensity bouts of sprinting and collision, separated by short periods of low-intensity walking and jogging (Gabbett et al., 2012; Waldron et al., 2011). While success is underpinned by a high degree of technical and tactical skill, the movement demands and extensive collisions inherent in RL necessitate the development of numerous physical capacities. Despite distinct positional differences in match demand (Gabbett et al., 2012), the development of maximal strength and power remain essential for all RL athletes (Baker & Newton, 2008; Meir et al., 2011). At the elite level, peak power is related to change-of-direction skill (Delaney et al., 2015), acceleration (Baker & Nance, 1999), and tackling ability (Gabbet et al., 2011). In the early stages of strength training, increasing an individual's maximal strength may provide concomitant improvements in maximal power output (Cormie et al., 2010b, Cormie et al., 2011). However, as maximal strength increases, the relative influence on maximal power output diminishes (Argus et al., 2012; Baker & Newton, 2006) and further adaptation requires lower load, higher velocity training (Cormie et al., 2011).

The development of power requires the appropriate selection of training methods. Load and intensity underpin the resultant neuromuscular adaptation and have specific influence on both the magnitude of force, and contraction velocity (Cormie, McCaulley, McBride et al., 2007; Kawamori & Haff, 2004; McBride et al., 2002). This inverse relationship between force and velocity are commonly displayed graphically as the force-velocity (F-V) curve (Samozino et al., 2014). Acceleration of heavy loads appears to have a greater relationship to maximal force production (Hakkinen et al., 1986; Kraska et al., 2009), with correlative strength diminishing as contraction velocity increases (Kraska et al., 2009). The optimal load for power development is exercise specific (Cormie et al., 2008; Cormie, McCaulley, Triplett et al., 2007; Kawamori et al., 2005), and is proposed to influence both regions of an athlete's F-V curve (high force low velocity and low force high velocity; Harris et al., 2008; Loturco et al., 2013). Training at optimal load may allow the development of maximal power in a given exercise, but may not be the more efficient method to increase power during sport related movements requiring the acceleration of the athlete's own body mass. In RL, the development of power is essential to success due to its inherent relationship to sprinting and collision (Baker & Nance, 1999; Gabbet et al., 2011). Considering the specific nature of adaptation, and the variation in loads considered to be optimal for power development, a targeted strategy to determine an athlete's F-V weaknesses may improve training prescription. The aim of resistance training based on an athlete's F-V relationship is to both increase maximal power, and to influence maximal power production during targeted actions requiring the rapid acceleration of body mass. Therefore, it is possible that the use of a F-V assessment offers a more efficient method for power development in highly trained athletes, such as elite RL players by encouraging a shift towards an optimal F-V profile where power output is maximised during unloaded jumping. However, there is currently limited research evaluating the impact of this approach on training and improvements in sports performance.

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Assessing an athlete's unique F-V profile using the squat jump under a minimum of five load conditions is posited to be a more accurate representation of the athlete's maximal capabilities than assessing power output alone (Jimenez-Reyes et al., 2016; Morin & Samozino, 2016; Samozino et al., 2014, 2012). Samozino et al. (2014) have validated a mathematical approach which utilises these data to determine the ratio of difference between the athlete's maximal force production and maximal power output, known as the force-velocity imbalance (FV_{imb}). FV_{imb} is the normalized difference between the athlete's actual and predicted optimal F-V profile where power output during the acceleration of body mass is maximised. Consequently, as the optimal profile is computed to improve jumping performance, the associated F-V deficits can only be considered "weaknesses" where explosive jumping performance is targeted (Samozino et al., 2014, 2008, 2010). Both theoretical (Samozino et al., 2008, 2010), and experimental (Samozino et al., 2014) research has suggested that FV_{imb} should be considered in addition to peak power when assessing squat jump (SJ) performance, as this provides more comprehensive understanding of athletes' biomechanical deficiencies. Given the paucity of research concerning optimal load prescription for power development in well-trained athletes (Cormie et al., 2011; Stone et al., 2003), this might be a more appropriate programming method. Currently, there is a growing base of literature profiling athletes using the F-V assessment across a range of sports at the elite level (De Lacey et al., 2014; Rakovic et al., 2018). Research is emerging utilising optimised training to jumping F-V profiles in sub-elite athletes (Jimenez-Reyes et al., 2017, 2019). However, optimised F-V training has not yet been utilized among highly strength trained, professional athletes. A recent study utilised a horizontal F-V profile to inform sprint programming in elite female handball players (Rakovic et al., 2018), though the study did not utilise the FV_{imb} as a reference to determine biomechanical deficiencies. No significant difference between specific and general training programmes on 30-m performance were found, however the intervention only utilised sprint specific programming with no resistance exercise training, which may have limited the underpinning strength levels of the participants. Therefore, this study aimed to assess the efficacy of force-velocity optimised training for improving FV_{imb} and its transfer to sports-relevant tasks with a team of highly trained, professional RL athletes. It was hypothesised that force-velocity optimised training resulted in a greater magnitude of improvement in 3RM squat, sprint acceleration performance, SJ height, peak power, and reduction in FV_{imb}.

Methods

Participants

Twenty-nine professional rugby league players (age 24 ± 3 years; body mass 94.9 ± 21.6 kg; height 181.3 ± 6.0 cm) from a single club were recruited for this study following the provision of informed consent. All players had a minimum of 5 years resistance training experience and routinely performed all testing procedures. Any player who had sustained a lower-limb injury in the previous 6-months, resulting in more than 2-weeks without lower-body training was excluded. Study approval was granted by a local ethics committee and testing procedures complied with the Declaration of Helsinki.

Testing design

Three separate testing sessions were completed across a training week. To minimise the circadian rhythm effect on performance, testing was conducted at a similar time of day to which players were accustomed to training (Drust et al., 2005). Testing procedures were conducted at the onset of the specific preparatory phase of preseason. During the 48-h prior to the first day of testing, players refrained from high-intensity running and resistance training to prevent interference with force and power producing capabilities (McLellan et al., 2011; Twist et al., 2012). On the morning of testing day 1, anthropometric assessments and linear speed tests were conducted. After a 4-h rest period, players performed a second testing session, where lower-body strength was assessed using a 3 repetition-maximum (3RM) back squat exercise. Forty-eight hours later, players completed the third testing session, where squat jump height was assessed under a range of load conditions. The week following completion of the 8-week intervention period, all players completed an identical testing battery.

Anthropometry

Each player had their extended right leg measured in a supine position from the greater trochanter to the end of the toes held in plantarflexion (Samozino et al., 2008). The player then had the vertical distance between the ground and the right leg greater trochanter measured in a 90^0 knee angle squat position (*Hs;* Samozino et al., 2008), measured with a goniometer (Prestige Medical Ltd, Ireland). Body mass was measured to the nearest 0.1 kg using calibrated electronic scales (Tanita, Australia).

Linear speed

Players completed a standardised dynamic warm-up, consisting of low-intensity running exercise, muscle activation and mobility exercises (lunge variations, hip lifts, leg swings), specific running drills (A-march, A-skip, A-runs), and 3–4 progressive sprinting efforts over 10–20 m. Sprint assessment was conducted across 10- and 20-m intervals using an infrared timing system (Brower Timing Systems, Draper, USA). The ICC value for test-retest reliability is 0.95 (Shovlin et al., 2018). All sprint distances were marked to the nearest cm on an indoor synthetic track using a standard metric measuring tape. From a split-stance 50 cm behind a marked line, players were instructed to start when ready and sprint through the marked finish line as fast as possible. Each player had two attempts separated by a 2-min rest period.

Lower body strength

Prior to testing, all players performed a standardised warm-up, incorporating mobility and activations drills for the hip and ankle, followed by submaximal warm-up sets consisting of 6, 5, and 3 repetitions at progressively increasing loads with the final set within 10 kg of the goal 3RM. Initial loads were calculated using the players previous 3RM, measured at the start of preseason. After this, weight was gradually increased until a 3RM was reached following an established procedure (Baker & Nance, 1999). Players were required to squat until their quadriceps were parallel with the ground, with a band set at the appropriate height to provide a physical cue. A successful attempt at the prescribed target 3RM resulted in a repeat trial under additional load until the athlete and experimenter accepted a 3RM had been attained.

Jump testing

Prior to testing, a standardised warm-up incorporating mobility and activation drills for the hip and ankle were performed. Players were familiarised to the SJ movement by performing 2–3 sets of submaximal SJ at bodyweight. Following this, players performed a series of maximal SJ under five load conditions in a randomised order (Morin & Samozino, 2016; Samozino et al., 2014). External loads were 0, 20, 40, 60, and 80% of body mass, with barbells loaded to the nearest 0.5 kg using microplates (Eleiko Sport, Sweden). In the 0% body mass load condition, players were instructed to hold their hands across the torso, while in all other load conditions the barbell was placed across the shoulders. The SJ was initiated with a downward movement to a band fixed at each player's 90^{0} knee angle squat position, checked by the experimenter prior to each trial (Samozino et al., 2008). Before a verbally cued 1-s pause, the player jumped as rapidly as possible to their maximal height. To minimise the interaction of the stretch-shortening cycle (SSC), any countermovement was restricted to prevent alteration in the athlete's force-producing strategy (Harman et al., 1990; Jimenez-Reyes et al., 2014). The participants were instructed to maintain tension on the barbell, jump with the chest upright, and land in the same position as take-off with minimal perturbation. Failure to meet the technical requirements resulted in a repeat trial. The participants were required to perform two successful repetitions under each load condition, with intra-set rest set at 2-min and inter-set rest set at 4-min to ensure optimal recovery (Abdessemed et al., 1999; Lawton et al., 2006).

Jump height was obtained using the *My Jump 2* application on an iPhone 6 (Apple Inc., USA) at 240 frames-per-second and shown to be reliable and accurate method of measuring flight-time and jump height during the SJ, with an ICC value of 0.97 (Brooks et al., 2018; Gallardo-Fuentes et al., 2016). A purpose-built excel spreadsheet developed by Morin and Samozino (2016) was used, where mean force ($\bar{F}_{abs}$, absolute force in N; Equation 1) and velocity ($\bar{v}$, in m.s^{-1}; Equation 2) were calculated using jump height and vertical push-off distance (h_{po}), determined by the difference between *H*s and extended leg length. Total mass including additional external load (kg) is represented by *m*, while *g* signifies the gravitational acceleration (9. 81 m.s^{-2}):

$$\bar{F}_{abs} = mg\left(\frac{h}{hpo} + 1\right) \quad (1)$$

$$\bar{v} = \sqrt{\left(\frac{gh}{2}\right)} \quad (2)$$

Force-velocity relationships were ascertained using the best trial in each load condition and least squares linear regressions. Force-velocity curves were extrapolated to find maximal theoretical force (*F0*; normalised to body mass) and velocity (*V0*) as the x- and y- intercepts. This allowed the calculation of maximal power output normalised to body mass (P_{max}, in W.kg^{-1}) using Equation 3:

$$P_{max} = \frac{F0 \cdot V0}{4} \quad (3)$$

The theoretical optimal force-velocity curve ($S_{fv}opt$, normalised to body mass, in N.s.kg^{-1}.m^{-1}) posited to maximise jump performance was produced using P_{max} and h_{po}. Individual FV_{imb} (in %) were then computed using Equation 4 where 100% represents an optimal F-V profile (Samozino et al., 2012):

$$FV_{imb} = 100.\left|1 - \frac{Sfv}{Sfvopt}\right| \quad (4)$$

Training intervention

Upon completion of pre-intervention testing, athletes were strength-matched using their 3RM squat and alternately assigned to one of two groups; the optimised (OP; n = 15) experimental group, or the non-optimised (GP; n = 14) control group. All participants completed a 5-week general-preparatory cycle of training, which is a common periodization strategy adopted by RL clubs, emphasising strength and hypertrophy with an intensity relative volume (IRV = sets x repetitions x intensity) of approximately 350 units per week (De Lacey et al., 2014; McMaster et al., 2013). Training programmes for the OP group were assigned based on the percentage difference in profile from optimal, with the categories defined by Jimenez-Reyes et al. (2017) outlined in Table 1. The GP group consisted of two low-force deficient (60–90%), and 12 high-force deficient players (<60%) and received a standard 8-week strength-power programme. The OP group contained four low-force (60–90%), six high-force (<60%), three low-velocity (>110-140%), and two high-velocity (>140%) deficient players (Table 1). Each received an 8-week training programme, adjusted to their individual FV_{imb}, as outlined in Table 1. During the intervention, all programmes were matched for training volume. Intensity varied based on the FV_{imb} and individual load prescription. Session rate of perceived exertion (RPE) scores for breathlessness and leg fatigue were collected immediately following all training sessions both on- and off-field to account for individual training loads across all groups throughout the study.

Considering the sensitivity of the force-velocity curve to training type (Jimenez-Reyes et al., 2017; De Lacey et al., 2014), and the specificity of adaptation to contraction velocity (Cormie et al., 2011), force-oriented programmes focused on compound exercises at high loads, >80% 1RM, at resultantly

Table 1. Force-velocity imbalance and weekly training prescription (adapted from Jimenez-Reyes et al., 2017).

FV_{imb} catagories	Ratio of optimal threshold (%)	Exercise	Training intensity
High force deficit	<60	Squat	≥80% 1RM
		Box Squat	≥80%
		TBD	1RM
		Clean Pull	≥80%
		Squat Jump	1RM
		Jump Shrug	80% 1RM
			70% 1RM
			65% 1RM
Low force deficit	60–90	Squat	≥80% 1RM
		Box Squat	≥80%
		Clean Pull	1RM
		Squat Jump	80% 1RM
		Jump Shrug	70% 1RM
		Squat Jump	65% 1RM
			20–30%
			1RM
Balanced	>90-110	Squat	≥80% 1RM
		Clean Pull	80% 1RM
		Jump Shrug	65% 1RM
		Squat Jump	20–30%
		CMJ	1RM
		Depth Jump	10% BWT
			BWT
Low velocity deficit	>110-140	Jump Shrug	65% 1RM
		Squat Jump	20–30%
		CMJ	1RM
		Squat Jump	10% BWT
		Depth Jump	BWT
		Accelerated Band	BWT
		Jump	<BWT
High velocity deficit	>140	Jump Shrug	65% 1RM
		CMJ	10% BWT
		Squat Jump	BWT
		CMJ	BWT
		Depth Jump	BWT
		Accelerated Band	<BWT
		Jump	

Prescription based on six exercises per week, three sets per exercise, TBD = Trap bar deadlift, CMJ = Counter-movement jump, 1RM = one-repetition maximum, BWT = bodyweight.

low contraction velocities (Baker & Newton, 2006; McMaster et al., 2013). Velocity-oriented programmes focused on the movement of body mass and/or low external loads at high contraction velocities (Cormie, McCaulley, Triplett et al., 2007a). Loaded power movements were prescribed according to their optimal load, ranging between 20–70% 1RM (Baker et al., 2001; McBride et al., 2002; McMaster et al., 2013). As optimal load varies extensively, an extensive review paper was utilised to guide programming (Cormie et al., 2011). Programmes comprised three sessions per week, which is suggested to elicit the greatest improvements in strength and power (McMaster et al., 2013), with two lower-body lifts included in each session (Tables 2 and 3). Lower body lifts were conducted first in the session, while all other lower body strength-power exercises outside the experimental training were excluded. All remaining weight-room programme elements were standardised across both groups. Player's on-field training was maintained, including linear and multidirectional speed, running conditioning, and rugby technical skills. On-field skills and games could not be quantified due to a lack of GPS; however, speed training volumes and intensities were identical for both groups, while running conditioning was prescribed based on the athlete's maximal aerobic speed (MAS).

Table 2. An example training session for an athlete with a low velocity deficit (FV_{imb} 120%).

Order	Exercise	Sets	Reps	Intensity
1	Dumbbell CMJ	3	5	10% BWT
2	Power Jump Shrug	3	5	65% PC 1RM
3a	Bench Press w/Purple Band	3	5	NME
3b	Bench Throw	3	5	30% 1RM
4a	SL Hammy ISO w/MB Throw	3	6 each side	2 kg MB
4b	SA DB Row	3	6 each side	RPE 7
5	Trunk Rotation Circuit	2–3	6–8 each	RPE 7

Exercise 1 and 2 were variable based on an athletes force-velocity profile, exercises 3–5 were standard across all athletes with "a" and "b" denoting a superset, CMJ = counter-movement jump, BWT = bodyweight, 1RM = one repetition maximum, PC = power clean, NME = near maximal effort, ISO = isometric, MB = medicine ball, RPE = rate of perceived exertion.

Table 3. An example training session for an athlete in the general strength-power group.

Order	Exercise	Sets	Reps	Intensity
1	Seated Box Jump	3	3	-
2	Box Squat	3	5	NME
2a	Bench Press w/Purple Band	3	5	NME
2b	Bench Throw	3	5	30% 1RM
3a	SL Hammy ISO w/MB Throw	3	6 each side	2 kg MB
3b	SA DB Row	3	6 each side	RPE 7
4	Trunk Rotation Circuit	2–3	6–8 each	RPE 7

Where "a" and "b" are present exercises were to be performed as a superset, 1RM = one repetition maximum, NME = near maximal effort, ISO = isometric, MB = medicine ball, RPE = rate of perceived exertion.

Consequently, though the volume and intensity of each session were matched across groups, the exact distance of each repetition varied based on the individuals MAS score.

Statistics

All data were tested for normality using the Shapiro-Wilks test and checked for homogeneity of variance using Levene's test. A one-way ANCOVA was used with baseline test results (pre-measures) as a covariate to determine the change in $F0$, $v0$, S_{fv}, 3RM squat, 10- and 20-m sprint, SJ height, peak power, and FV_{imb} (dependent variables) between the OP and GP training groups (independent variables). The magnitude of difference between-groups was interpreted using Cohen's effect size (ES; Cohen, 1988) calculated using Microsoft Excel (2016). Following the ranges set by Rhea (2004) for highly trained subjects (≥5-years training experience), ES were set as trivial (<0.25), small (0.25–0.50), moderate (0.50–1.0), or large (>1.0). Smallest worthwhile change (SWC) was computed by multiplying the between subject SD with the classification level. Confidence intervals were calculated at 95% for the between difference score and statistical significance was set at $P < 0.05$. An independent samples *t*-test revealed there were no significant 3RM squat differences between groups prior to the intervention (OP: 151.17 ± 22.95 kg, GP: 156.43 ± 25.07 kg, $P = 0.56$). All statistical analysis was performed using SPSS Statistics 24 (IBM, USA).

Results

There were no differences between-groups for MAS running volume (OP: 26,854.53 ± 1,875.04 m, GP: 27,035.71 ± 1,873.09 m, $t_{(27)} = -0.26$, $P = 0.79$). There were no differences between-groups for "breathlessness" RPE (OP:

2416.84 ± 211.18 AU, GP: 2414.63 ± 208.76 AU, $t_{(14)}$ = 0.01, P = 0.49), or "leg-fatigue" RPE (OP: 2422.88 ± 226.54 AU, GP: 2440.75 ± 242.42 AU, $t_{(14)}$ = −0.14, P = 0.44) across the training period.

Result for $F0$, $v0$ and S_{fv} are present in Table 4. Group effects were found for $F0$ ($F_{(1,26)}$ = 8.50, P = 0.007), with higher values in the OP group (95% CI [0.80, 4.66], P = 0.007, Table 4). There was a group effect for $v0$ ($F_{(1,26)}$ = 5.35, P = 0.029), with higher values for the GP group (95% CI [0.46, 0.78], P = 0.029, Table 4). There was a group effect for S_{fv} ($F_{(1,26)}$ = 6.96, P = 0.014), with a larger score for the OP group (95% CI [0.36, 2.92], P = 0.014, Table 4). The averaged R^2 of the force-velocity relationship were 0.95 (pre-intervention), 0.97 (post-intervention), and 0.89 (pre-intervention), and 0.95 (post-intervention) for OP and GP respectively.

Individual changes for FV_{Imb} and mean F-V deficit changes are presented in Figure 1. Group effects were found for F-V deficit improvement ($F_{(1,26)}$ = 9.17, P = 0.005), with higher scores in the OP group compared to the GP post-intervention (95% CI [4.59, 24.01], P = 0.001, Figure 1). Pre-post effect sizes for the OP group versus the GP group were 0.35 (CI [−0.95, 0.26]) vs 0.10 (CI [−0.55, 0.69]).

Changes in 3RM squat across the training programme are presented in Figure 2. There was a group effect ($F_{(1,26)}$ = 12.72, P = 0.001), with greater values in the OP group post-intervention (95% CI [1.76, 6.56] P = 0.001, Figure 2). Pre-post effect sizes for the OP group versus the GP group were 0.47 (CI [−1.05, 0.16]) vs 0.26 (CI [−0.89, 0.36]).

The results for peak power are presented in Figure 3. Group effects were found ($F_{(1,26)}$ = 48.89, P = 0.001), with higher values for the OP group post-intervention (95% CI [175.65, 321.92], P = 0.001, Figure 3). Pre-post effect sizes for the OP group versus the GP group were 0.36 (CI[−0.95, 0.26]) vs 0.03 (CI [−0.75, 0.49]).

Individual changes for SJ height are presented in Figure 4. There was a group effect ($F_{(1,26)}$ = 38.81, P = 0.001), with greater values for the OP group post-intervention (95% CI [1.47, 2.88], P = 0.001, Figure 4). Pre-post effect sizes for the OP group versus the GP group were 0.37 (CI [−0.97, 0.24]) vs 0.12 (CI [−0.74, 0.51]).

Analysis of both sprint distances showed no differences post-training for either the 10-m (OP pre: 1.74 ± 0.07 s, post: 1.71 ± 0.06 s, GP pre: 1.75 ± 0.10 s, post: 1.72 ± 0.10 s, $F_{(1,26)}$ = 0.39, P = 0.54), or 20-m sprint (OP pre: 3.20 ± 0.12 s, post: 3.16 ± 0.11 s, GP pre: 3.21 ± 0.16 s, post: 3.17 ± 0.15 s, $F_{(1,26)}$ = 0.17, P = 0.68).

Table 4. Mechanical variables of professional rugby league players pre- and post-intervention.

	Group	Pre-Intervention	Post-Intervention	ES (CI)
$F0$ (N·kg^{-1})	OP	46.63 ± 13.95	47.01 ± 11.38*	0.03 (−0.63, 0.57)
	GP	34.65 ± 3.62	34.62 ± 3.59	0.01 (−0.61, 0.63)
$V0$ (m·s^{-1})	OP	4.02 ± 1.9	4.14 ± 1.81	0.06 (−0.66, 0.54)
	GP	5.02 ± 1.46	5.54 ± 1.64*	0.33 (−0.95, 0.30)
S_{fv} (N.s/m/kg)	OP	−14.42 ± 9.66	−13.76 ± 7.38*	0.09 (−0.68, 0.53)
	GP	−6.20 ± 3.04	−5.83 ± 2.91	0.12 (−0.72, 0.50)

ES = effect size, CI = confidence interval, $F0$ = theoretical maximal force, $V0$ = theoretical maximal velocity, S_{fv} = force-velocity curve, * = significant difference post intervention, $p < 0.05$.

Discussion

The aim of this study was to assess the effectiveness of an 8-week strength-power programme optimised to an athlete's F-V profile during a RL pre-season. This is the first study to investigate the efficacy of this approach to programming in a sample of senior, highly trained professional players and to evaluate the effect of this approach on physical outcomes that include maximal strength, sprinting, and jumping. The main findings from this study show F-V optimised training elicited greater changes in maximal strength, SJ, and vertical peak power compared to the non-optimised control group. Therefore, prescribing F-V deficit training is superior to typical training regimes for improving physical performance within highly trained RL players.

The greater F-V adaptations in the OP group provides support for the current theoretical (Samozino et al., 2008, 2010), and limited experimental research (Samozino et al., 2014), showing the effectiveness of targeted programming based on an athlete's vertical F-V imbalance. Jimenez-Reyes et al. (2017) demonstrated similar findings with semi-professional athletes; however, the participants had substantially lower strength levels than those included in the current study. Less strength trained individuals are shown to undergo a range of neurological adaptation during the early stages of training including increased rate coding and signal intensity (Aagaard et al., 2002). These adaptations diminish in magnitude as the individual's strength increases (Baker, 2002; Gabriel et al., 2006). Consequently, improving an athletes F-V profile cannot be assumed when only looking at studies featuring less strength trained individuals. However, despite differences in neurological adaptations in those with higher levels of strength training, this study shows this approach to also be effective. Emerging research may also explain the instances of increased FV_{imb} within the OP group. Morin et al. (2020) suggest the peaking effect of a training period may only be fully realised 4-weeks post-intervention. Consequently, the 5-week general preparatory cycle completed by all participants may have resulted in strength and power adaptations that were only fully realised part way through the experimental period.

Greater improvements in maximal strength were shown for the OP training group. Maximal strength improvements have been reported in elite rugby union (Hansen et al., 2011), with one study (Baker & Newton, 2006) demonstrating maximal strength improvements using traditional training methods across a similar time period to the current study. The differing distributions of F-V deficit between groups were a result of matching according to 3RM scores based on the standard training period prior to the intervention. While the authors feel this does not challenge the results, other researchers may consider matching groups based off F-V deficits. Interestingly, as 10 players from the OP training group, and 14 from the GP training group were velocity biased, this finding shows F-V optimised training may be a more effective method for improving strength than traditional training methods where a force deficiency exists. However, these adaptations may have been assisted by the previously mentioned peaking effect from the initial 5-week preparatory cycle (Morin et al., 2020). This delay in adaptation may also explain the increases in 3RM

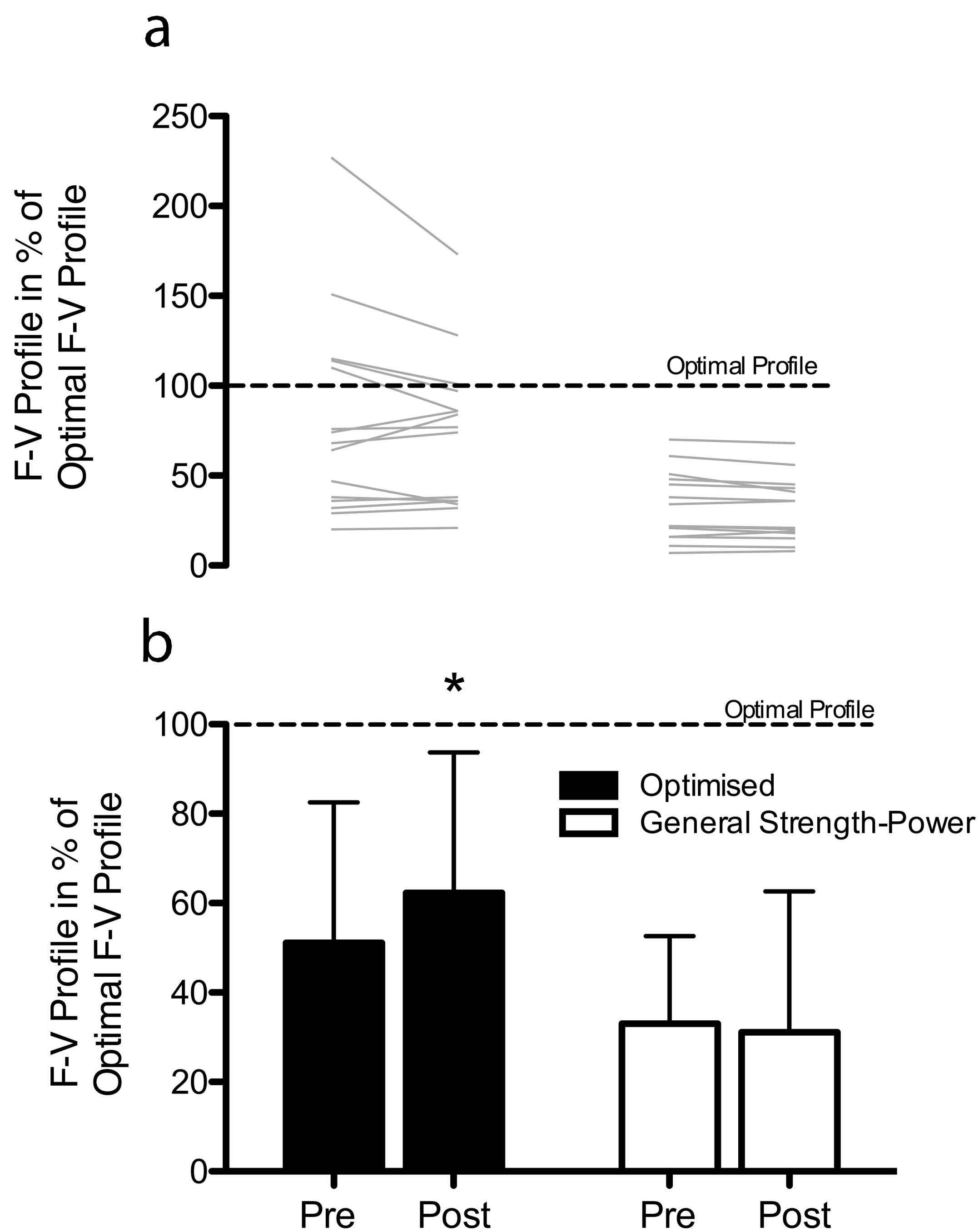

Figure 1. (a) Individual pre-post changes in FV_{imb}. (b) Mean changes in F-V profile as a percentage of optimal F-V profile. * = significant differences post-intervention, $p < 0.05$.

scores for athletes across both training groups. Similarly, the OP training group demonstrated greater improvements in peak-power compared with the GP training group. This is consistent with the reported improvements in peak power following a F-V optimised training programme (Jimenez-Reyes et al., 2017), with the current study now providing support in elite professional RL athletes. While increased maximal strength has been reported following 8-week pre-season programmes of traditional strength-power and cluster training (Hansen et al., 2011), these changes occurred without increases in vertical power (Hansen et al., 2011). Given the importance of both maximal strength and power production in RL (Baker & Newton, 2008), these findings collectively infer that the specific nature of F-V informed prescription is more effective method for targeting neuromuscular deficiencies. As concomitant improvements in power with maximal strength are typically more apparent among novice athletes (Argus et al., 2012; Baker & Newton, 2006; McBride et al., 2002), the development of power in elite athletes requires greater focus on contraction velocity specificity and optimal load prescription (Cormie et al., 2011; McBride et al., 2002). It seems the use of F-V optimised training may be an effective method to discern the optimal load prescription for a RL player's deficiency, thereby targeting the contraction velocities most in need of development.

Large differences were also found post-intervention between groups for the unloaded SJ. This aligns with existing

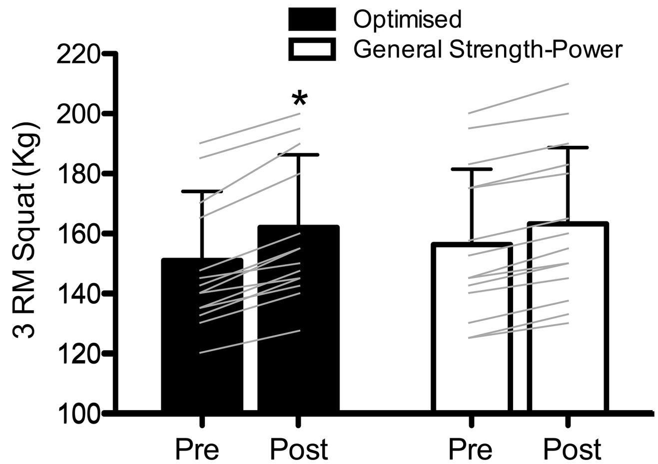

Figure 2. Mean changes in 3RM squat with individual pre-post changes. 3RM = 3-repetition maximum, * = significant differences post-intervention, $p < 0.05$.

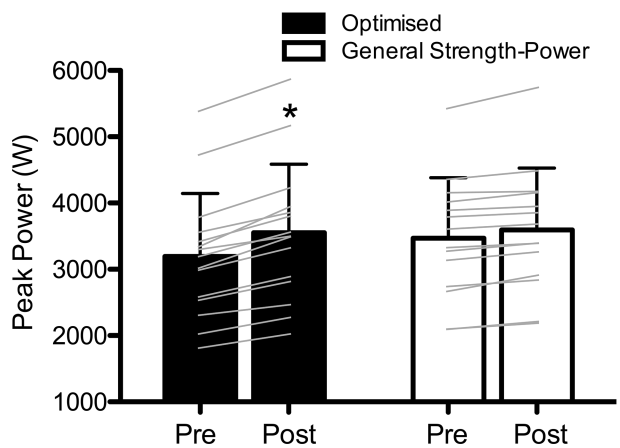

Figure 3. Mean changes in peak power with individual pre-post changes. * = significant differences post-intervention, $p < 0.05$.

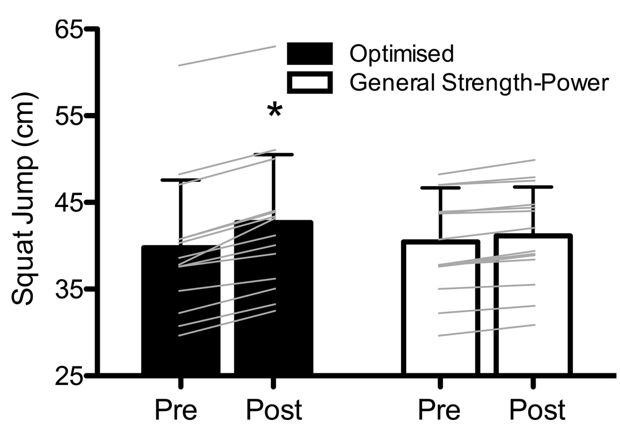

Figure 4. Mean changes in squat jump with individual pre-post changes. * = significant differences post-intervention, $p < 0.05$.

research demonstrating improvements in F-V deficit concurrently with increases in SJ height (Jimenez-Reyes et al., 2017). As greater changes were also found for maximal strength and peak-power, this finding is intuitive due to the force-producing strategy necessary for success in the SJ. In addition, training prescription for the OP was derived from each athletes FV_{imb} to shift them towards an optimal profile, which is computed to maximise jumping performance. Consequently, it is unsurprising differences between groups were present for jumping performance. In this investigation, athletes were required to perform a 1 s pause at the end of the eccentric phase of the movement, which limits the involvement of the stretch-shortening cycle and emphasises concentric rate of force development (Harman et al., 1990; Jimenez-Reyes et al., 2014). Performance is therefore dependent on the application of the highest magnitude of force in the short time available before toe-off throughout a concentric contraction regime. As maximal strength has increased alongside peak power, the OP group appear to be able to apply more force within the time available during the SJ, therefore improving jump height to a greater degree. Furthermore, the current study provides stronger evidence that the F-V relationship can be shifted towards the force side in order to optimise power output and improve strength concomitantly. Both the OP and GP training groups consisted predominantly of velocity biased athletes at baseline, which may suggest RL players can be characterised this way most commonly. Additionally, the higher values for $F0$ and S_{fv} post-intervention in the OP group support the effectiveness of a F-V optimised programme in shifting an athlete's profile more optimally. Conversely, as the GP group was entirely velocity biased and presented higher scores in $v0$, it seems a general programme may serve to increase an athletes existing imbalance. Consequently, the larger changes in maximal strength, peak power, and SJ suggest that a F-V optimised programme offers the most efficient approach for eliciting change over an 8-week period.

There were no differences between-groups for either the 10- or 20-m sprint. This was surprising as, research in professional RL has reported moderate-strong correlations between SJ and acceleration performance ($r = -.61$; Baker & Nance, 1999). This may be explained by the kinetic and kinematic similarities of the SJ and horizontal acceleration. During acceleration, the athlete is required to concentrically generate large amounts of force during ground contact times of approximately 200 ms (Morin et al., 2011; Rabita et al., 2015). As previously discussed, the SJ in this study involved a 1 s pause at the lowest point to limit the SSC involvement, and emphasise concentric RFD (Harman et al., 1990; Jimenez-Reyes et al., 2014), thereby increasing potential transfer to acceleration performance (Cunningham et al., 2013; Sirotic et al., 2011). As sprint training was matched between both training groups, it was expected that the larger improvement in SJ and peak power for the OP programme may partially transfer to early acceleration performance, but further work is needed in this regard. Jimenez-Reyes et al. (2018) reported that higher playing levels in elite Rugby resulted in lower correlation between sprinting and lower-body strength. The researchers suggest that the higher the performance level, the more the technical issues other than force production may be the limiting factor in sprinting performance. As the athletes in this study are high level professionals, this may explain the lack of transfer to 10- and 20-m sprint performance.

A potential limitation of the current study was the quantification of physical running intensities and volumes during on-field skills and match play. While our RPE measure is well-described and utilized in the RL literature (Lovell et al., 2013), more detailed training and match load data would have permitted greater control over training loads between groups. To address this limitation, running conditioning and speed volumes and intensities were matched, alongside collection of a differential training load score. A perceived exertion score for breathlessness, and for leg muscle fatigue was collected and multiplied by session duration following each training event to ascertain a differentiated training load. Recent literature posits this method as a more effective approach to assessing individual responses to training than a singular score for session rate of perceived exertion (RPE; McLaren et al., 2017). Moreover, measures of internal load derived from perceived exertion scores have been shown to positively associate with external loads derived through GPS (McLaren et al., 2018).

A further limitation is the relatively short duration of the intervention period and the pre- and post-intervention testing structure. While an 8-week specific preparatory period is common within a RL preseason, highly trained athletes may require more time for adaptation than a novice sample (Baker, 2002). Additionally, while the time allowance for this study required immediate testing following the 8-week period, the peaking effect suggested to occur 4-weeks post-intervention was not investigated (Morin et al., 2020). Future research assessing F-V profiles across the entire season would be of interest to RL practitioners, as it would highlight how any potentiation in performance following pre-season affects the F-V relationship. Therefore, the way in which the F-V optimised training approach is applied to RL players might require adjustment based on in-season changes. Finally, the current study presented an average R^2 of 0.89 in the GP group pre-intervention. Morin and Samozino (2016) recommended each individuals profile has an R^2 value above 0.95. Given the applied nature of this data collection, it was difficult to perform multiple extra jumps with the time constraints of testing 29 athletes. It is recommended that future research ensures R^2 values match the guidelines provided by Morin and Samozino (2016).

Conclusion

For the first time, we have demonstrated that programming based on rugby league players' vertical F-V profile is a more effective method for improving F-V deficiencies, maximal strength, SJ, and peak-power during an 8-week professional RL preseason. While larger effect sizes were found for the 10-m sprint, it appears vertical F-V profiling and programming may not be the most effective strategy for improving horizontal sprint performance. The use of a horizontal F-V profile may provide increased specificity to sprinting, and when combined with a vertical profile offer a broader assessment of an athlete's neuromuscular deficiencies. These findings add to the growing support for this approach to programming in a sample of elite professional athletes.

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No potential conflict of interest was reported by the authors.

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