

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

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27 **ABSTRACT**

28 The effectiveness of 8-week force-velocity optimised training was assessed in highly trained
29 professional rugby league (RL) athletes. Players (age 24 ± 3 years; body mass 94.9 ± 21.6 kg; height
30 181.3 ± 6.0 cm) were strength-matched and assigned to a force-velocity optimised group (OP; $n=15$)
31 or a general strength-power group (GP; $n=14$). Tests conducted pre-and post-training included 10-
32 m, 20-m sprints, 3 repetition-maximum (3RM) squat and squat jumps (SJ) over five load conditions
33 to ascertain vertical force-velocity relationship. ANCOVA revealed there was a group effect for force-
34 velocity deficit ($P<0.001$), with the OP two-fold greater than the GP group (OP pre: $51.13 \pm 31.42\%$,
35 post: $62.26 \pm 31.45\%$, GP pre: $33.00 \pm 19.60\%$, post: $31.14 \pm 31.45\%$, $P<0.001$). There were further
36 group effects for 3RM squat (OP pre: 151.17 ± 22.95 kg, post: 162.17 ± 24.16 kg, GP pre: $156.43 \pm$
37 25.07 kg, post: 163.39 ± 25.39 kg, $P<0.001$), peak power (OP pre: 3195 ± 949 W, post: 3552 ± 1033 W,
38 GP pre: 3468 ± 911 W, post: 3591 ± 936 W, $P<0.001$), and SJ (OP pre: 39.79 ± 7.80 cm, post: $42.69 \pm$
39 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
40 superior for improving physical performance within highly trained RL players.

41
42 Key words: Team sports, force-velocity profile, jumping, strength, power

55 INTRODUCTION

56 Rugby league (RL) is an intermittent sport, involving frequent high-intensity bouts of sprinting and
57 collision, separated by short periods of low-intensity walking and jogging (Gabbett, Jenkins,
58 Abernethy, 2012; Waldron, Twist, Highton, Worsfold, Daniels, 2011). Whilst success is underpinned
59 by a high degree of technical and tactical skill, the movement demands and extensive collisions
60 inherent in RL necessitate the development of numerous physical capacities. Despite distinct
61 positional differences in match demand (Gabbett et al., 2012), the development of maximal strength
62 and power remain essential for all RL athletes (Baker and Newton, 2008; Meir, Newton, Curtis,
63 Fardell, & Butler, 2011). At the elite level, peak power is related to change-of-direction skill (Delaney
64 et al., 2015), acceleration (Baker and Nance, 1999), and tackling ability (Gabbett et al., 2011). In the
65 early stages of strength training, increasing an individual's maximal strength may provide
66 concomitant improvements in maximal power output (Cormie, McGuigan, & Newton, 2010, 2011).
67 However, as maximal strength increases, the relative influence on maximal power output diminishes
68 (Argus, Gill, Keogh, 2012; Baker and Newton, 2006) and further adaptation requires lower load,
69 higher velocity training (Cormie et al., 2011).

70
71 The development of power requires the appropriate selection of training methods. Load and
72 intensity underpin the resultant neuromuscular adaptation and have specific influence on both the
73 magnitude of force, and contraction velocity (Cormie, McCaulley, & McBride, 2007; Kawamori and
74 Haff, 2004; McBride, Triplett-McBride, Davie, & Newton, 2002). This inverse relationship between
75 force and velocity are commonly displayed graphically as the force-velocity (F-V) curve (Samozino
76 et al., 2014). Acceleration of heavy loads appears to have a greater relationship to maximal force
77 production (Hakkinen, Komi, & Kauhanen, 1986; Kraska et al., 2009), with correlative strength
78 diminishing as contraction velocity increases (Kraska et al., 2009). The optimal load for power
79 development is exercise specific (Cormie, McBride, & McCaulley, 2008; Cormie et al., 2007;
80 Kawamori et al., 2005), and is proposed to influence both regions of an athlete's F-V curve (high
81 force low velocity and low force high velocity; Harris, Cronin, Hopkins, & Hansen, 2008; Loturco et
82 al., 2013). Training at optimal load may allow the development of maximal power in a given exercise,
83 but may not be the more efficient method to increase power during sport related movements
84 requiring the acceleration of the athlete's own body mass. In RL, the development of power is
85 essential to success due to its inherent relationship to sprinting and collision (Baker and Nance,
86 1999; Gabbett et al., 2011). Considering the specific nature of adaptation, and the variation in loads

87 considered to be optimal for power development, a targeted strategy to determine an athlete's F-
88 V weaknesses may improve training prescription. The aim of resistance training based on an
89 athlete's F-V relationship is to both increase maximal power, and to influence maximal power
90 production during targeted actions requiring the rapid acceleration of body mass. Therefore, it is
91 possible that the use of a F-V assessment offers a more efficient method for power development in
92 highly trained athletes, such as elite RL players by encouraging a shift towards an optimal F-V profile
93 where power output is maximised during unloaded jumping. However, there is currently limited
94 research evaluating the impact of this approach on training and improvements in sports
95 performance.

96
97 Assessing an athlete's unique F-V profile using the squat jump under a minimum of five load
98 conditions is posited to be a more accurate representation of the athlete's maximal capabilities than
99 assessing power output alone (Jimenez-Reyes et al., 2016; Morin & Samozino, 2016; Samozino et
100 al., 2012, 2014). Samozino et al. (2014) have validated a mathematical approach which utilises these
101 data to determine the ratio of difference between the athlete's maximal force production and
102 maximal power output, known as the force-velocity imbalance (FV_{imb}). FV_{imb} is the normalized
103 difference between the athlete's actual and predicted optimal F-V profile where power output
104 during the acceleration of body mass is maximised. Consequently, as the optimal profile is computed
105 to improve jumping performance, the associated F-V deficits can only be considered 'weaknesses'
106 where explosive jumping performance is targeted (Samozino, Morin, Hintzy, & Belli, 2008, 2010;
107 Samozino et al., 2014). Both theoretical (Samozino et al., 2008, 2010), and experimental (Samozino
108 et al., 2014) research has suggested that FV_{imb} should be considered in addition to peak power when
109 assessing squat jump (SJ) performance, as this provides more comprehensive understanding of
110 athletes' biomechanical deficiencies. Given the paucity of research concerning optimal load
111 prescription for power development in well-trained athletes (Cormie et al., 2010; Stone et al., 2003),
112 this might be a more appropriate programming method. Currently, there is a growing base of
113 literature profiling athletes using the F-V assessment across a range of sports at the elite level (de
114 Lacey et al., 2014; Rakovic, Paulsen, Helland, Eriksrud, & Haugen, 2018). Research is emerging
115 utilising optimised training to jumping F-V profiles in sub-elite athletes (Jimenez-Reyes et al., 2017;
116 Jimenez-Reyes, Samozino, & Morin, 2019). However, optimised F-V training has not yet been utilized
117 among highly strength trained, professional athletes. A recent study utilised a horizontal F-V profile
118 to inform sprint programming in elite female handball players (Rakovic et al., 2018), though the
119 study did not utilise the FV_{imb} as a reference to determine biomechanical deficiencies. No significant

120 difference between specific and general training programmes on 30-m performance were found,
121 however the intervention only utilised sprint specific programming with no resistance exercise
122 training, which may have limited the underpinning strength levels of the participants. Therefore,
123 this study aimed to assess the efficacy of force-velocity optimised training for improving FV_{imb} and
124 its transfer to sports-relevant tasks with a team of highly trained, professional RL athletes. It was
125 hypothesised that force-velocity optimised training resulted in a greater magnitude of improvement
126 in 3RM squat, sprint acceleration performance, SJ height, peak power, and reduction in FV_{imb} .

127

128 **METHODS**

129 *Participants*

130 Twenty-nine professional rugby league players (age 24 ± 3 years; body mass 94.9 ± 21.6 kg; height
131 181.3 ± 6.0 cm) from a single club were recruited for this study following the provision of informed
132 consent. All players had a minimum of 5 years resistance training experience and routinely
133 performed all testing procedures. Any player who had sustained a lower-limb injury in the previous
134 6-months, resulting in more than 2-weeks without lower-body training was excluded. Study
135 approval was granted by a local ethics committee and testing procedures complied with the
136 Declaration of Helsinki.

137 *Testing Design*

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

150

151 *Anthropometry*

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

158

159 *Linear Speed*

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

169

170 *Lower Body Strength*

171 Prior to testing, all players performed a standardised warm-up, incorporating mobility and
172 activations drills for the hip and ankle, followed by submaximal warm-up sets consisting of 6, 5, and
173 3 repetitions at progressively increasing loads with the final set within 10kg of the goal 3RM. Initial
174 loads were calculated using the players previous 3RM, measured at the start of preseason. After
175 this, weight was gradually increased until a 3RM was reached following an established procedure
176 (Baker & Nance, 1999). Players were required to squat until their quadriceps were parallel with the
177 ground, with a band set at the appropriate height to provide a physical cue. A successful attempt at
178 the prescribed target 3RM resulted in a repeat trial under additional load until the athlete and
179 experimenter accepted a 3RM had been attained.

180

181 *Jump Testing*

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

200

201 Jump height was obtained using the *My Jump 2* application on an iPhone 6 (Apple Inc., USA) at 240
202 frames-per-second and shown to be reliable and accurate method of measuring flight-time and
203 jump height during the SJ, with an ICC value of 0.97 (Brooks, Benson, & Lyndell, 2018; Gallardo-
204 Fuentes et al., 2016). A purpose-built excel spreadsheet developed by Morin and Samozino (2016)
205 was used, where mean force (\bar{F}_{abs} , absolute force in N; Equation 1) and velocity (\bar{v} , in m.s⁻¹; Equation
206 2) were calculated using jump height and vertical push-off distance (h_{po}), determined by the
207 difference between H_s and extended leg length. Total mass including additional external load (kg)
208 is represented by m , whilst g signifies the gravitational acceleration (9.81m.s⁻²):

209 Eq'n 1: $\bar{F}_{abs} = mg\left(\frac{h}{h_{po}} + 1\right)$

210 Eq'n 2: $\bar{v} = \sqrt{\left(\frac{gh}{2}\right)}$

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

215 Eq'n 3: $P_{max} = \frac{F0 \cdot V0}{4}$

216 The theoretical optimal force-velocity curve (S_{fvopt} , normalised to body mass, in N.s.kg⁻¹.m⁻¹)
 217 posited to maximise jump performance was produced using P_{max} and h_{po} . Individual FV_{imb} (in %) were
 218 then computed using Equation 4 where 100% represents an optimal F-V profile (Samozino et al.,
 219 2012):

220 Eq'n 4: $FV_{imb} = 100. \cdot \left| 1 - \frac{S_{fv}}{S_{fvopt}} \right|$

221

222 *Training intervention*

223 Upon completion of pre-intervention testing, athletes were strength-matched using their 3RM
 224 squat and alternately assigned to one of two groups; the optimised (OP; $n = 15$) experimental group,
 225 or the non-optimised (GP; $n = 14$) control group. All participants completed a 5-week general-
 226 preparatory cycle of training, which is a common periodization strategy adopted by RL clubs,
 227 emphasising strength and hypertrophy with an intensity relative volume (IRV = sets x repetitions x
 228 intensity) of approximately 350 units per week (de Lacey et al., 2014; McMaster et al., 2013).
 229 Training programmes for the OP group were assigned based on the percentage difference in profile
 230 from optimal, with the categories defined by Jimenez-Reyes et al (2017) outlined in Table 1. The GP
 231 group consisted of two low-force deficient (60-90%), and 12 high-force deficient players (<60%) and
 232 received a standard 8-week strength-power programme. The OP group contained four low-force
 233 (60-90%), six high-force (<60%), three low-velocity (>110-140%), and two high-velocity (>140%)
 234 deficient players (Table 1). Each received an 8-week training programme, adjusted to their individual
 235 FV_{imb} , as outlined in Table 1. During the intervention, all programmes were matched for training
 236 volume. Intensity varied based on the FV_{imb} and individual load prescription. Session rate of
 237 perceived exertion (RPE) scores for breathlessness and leg fatigue were collected immediately

238 following all training sessions both on- and off-field to account for individual training loads across
 239 all groups throughout the study.

240 **Table 1.** Force-velocity imbalance and weekly training prescription (adapted from Jimenez-Reyes,
 241 Samozino, Brughelli, & Morin, 2017).

FV_{imb} catagories	Ratio of optimal threshold (%)	Exercise	Training intensity	
				242
High force deficit	<60	Squat	≥80% 1RM	
		Box Squat	≥80% 1RM	243
		TBD	≥80% 1RM	
		Clean Pull	80% 1RM	244
		Squat Jump	70% 1RM	
		Jump Shrug	65% 1RM	245
Low force deficit	60-90	Squat	≥80% 1RM	
		Box Squat	≥80% 1RM	246
		Clean Pull	80% 1RM	
		Squat Jump	70% 1RM	247
		Jump Shrug	65% 1RM	
		Squat Jump	20-30% 1RM	248
Balanced	>90-110	Squat	≥80% 1RM	
		Clean Pull	80% 1RM	249
		Jump Shrug	65% 1RM	
		Squat Jump	20-30% 1RM	250
		CMJ	10% BWT	
		Depth Jump	BWT	251
Low velocity deficit	>110-140	Jump Shrug	65% 1RM	
		Squat Jump	20-30% 1RM	252
		CMJ	10% BWT	
		Squat Jump	BWT	253
		Depth Jump	BWT	
		Accelerated Band Jump	<BWT	254
High velocity deficit	>140	Jump Shrug	65% 1RM	
		CMJ	10% BWT	255
		Squat Jump	BWT	
		CMJ	BWT	256
		Depth Jump	BWT	
		Accelerated Band Jump	<BWT	257

258 Notes: 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.

259 Considering the sensitivity of the force-velocity curve to training type (de Lacey et al., 2014; Jimenez-
 260 Reyes et al., 2017), and the specificity of adaptation to contraction velocity (Cormie et al., 2011),
 261 force-oriented programmes focused on compound exercises at high loads, >80% 1RM, at resultantly
 262 low contraction velocities (Baker and Newton, 2006; McMaster et al., 2013). Velocity-oriented
 263 programmes focused on the movement of body mass and/or low external loads at high contraction
 264 velocities (Cormie et al., 2007). Loaded power movements were prescribed according to their
 265 optimal load, ranging between 20-70% 1RM (Baker, Nance, & Moore, 2001; McBride et al., 2002;
 266 McMaster et al., 2013). As optimal load varies extensively, an extensive review paper was utilised
 267 to guide programming (Cormie et al., 2010). Programmes comprised three sessions per week, which
 268 is suggested to elicit the greatest improvements in strength and power (McMaster et al., 2013), with
 269 two lower-body lifts included in each session (Table 2). Lower body lifts were conducted first in the
 270 session, whilst all other lower body strength-power exercises outside the experimental training
 271 were excluded. All remaining weight-room programme elements were standardised across both
 272 groups. Player's on-field training was maintained, including linear and multidirectional speed,
 273 running conditioning, and rugby technical skills. On-field skills and games could not be quantified
 274 due to a lack of GPS; however, speed training volumes and intensities were identical for both groups,
 275 whilst running conditioning was prescribed based on the athlete's maximal aerobic speed (MAS).
 276 Consequently, though the volume and intensity of each session were matched across groups, the
 277 exact distance of each repetition varied based on the individuals MAS score.

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	2kg MB
4b	SA DB Row	3	6 each side	RPE 7
5	Trunk Rotation Circuit	2-3	6-8 each	RPE 7

278 Note: Exercise 1 and 2 were variable based on an athletes force-velocity profile, exercises 3-5 were
 279 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.

280 **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	2kg MB
3b	SA DB Row	3	6 each side	RPE 7
4	Trunk Rotation Circuit	2-3	6-8 each	RPE 7

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

284 *Statistics*

285 All data were tested for normality using the Shapiro-Wilks test and checked for homogeneity of
286 variance using Levene’s test. A one-way ANCOVA was used with baseline test results (pre-measures)
287 as a covariate to determine the change in $F0$, $v0$, S_{fv} , 3RM squat, 10- and 20-m sprint, SJ height, peak
288 power, and FV_{imb} (dependent variables) between the OP and GP training groups (independent
289 variables). The magnitude of difference between-groups was interpreted using Cohen’s effect size
290 (ES; Cohen, 1988) calculated using Microsoft Excel (2016). Following the ranges set by Rhea (2004)
291 for highly trained subjects (≥ 5 -years training experience), ES were set as trivial (<0.25), small (0.25-
292 0.50), moderate (0.50-1.0), or large (>1.0). Smallest worthwhile change (SWC) was computed by
293 multiplying the between subject SD with the classification level. Confidence intervals were
294 calculated at 95% for the between difference score and statistical significance was set at $P < 0.05$.
295 An independent samples t-test revealed there were no significant 3RM squat differences between
296 groups prior to the intervention (OP: 151.17 ± 22.95 kg, GP: 156.43 ± 25.07 kg, $P = 0.56$). All statistical
297 analysis was performed using SPSS Statistics 24 (IBM, USA).

300 RESULTS

301 There were no differences between-groups for MAS running volume (OP: $26,854.53 \pm 1,875.04\text{m}$,
 302 GP: $27,035.71 \pm 1,873.09\text{m}$, $t_{(27)} = -0.26$, $P = 0.79$). There were no differences between-groups for
 303 “breathlessness” RPE (OP: $2416.84 \pm 211.18\text{ AU}$, GP: $2414.63 \pm 208.76\text{ AU}$, $t_{(14)} = 0.01$, $P = 0.49$), or
 304 “leg-fatigue” RPE (OP: $2422.88 \pm 226.54\text{ AU}$, GP: $2440.75 \pm 242.42\text{ AU}$, $t_{(14)} = -0.14$, $P = 0.44$) across
 305 the training period.

306

307 Result for F_0 , v_0 and S_{fv} are present in Table 4. Group effects were found for F_0 ($F_{(1,26)} = 8.50$, $P =$
 308 0.007), with higher values in the OP group (95% CI $[0.80, 4.66]$, $P = 0.007$, Table 4). There was a
 309 group effect for v_0 ($F_{(1,26)} = 5.35$, $P = 0.029$), with higher values for the GP group (95% CI $[0.46, 0.78]$,
 310 $P = 0.029$, Table 4). There was a group effect for S_{fv} ($F_{(1,26)} = 6.96$, $P = 0.014$), with a larger score for
 311 the OP group (95% CI $[0.36, 2.92]$, $P = 0.014$, Table 4). The averaged R^2 of the force-velocity
 312 relationship were 0.95 (pre-intervention), 0.97 (post-intervention), and 0.89 (pre-intervention), and
 313 0.95 (post-intervention) for OP and GP respectively.

314

315

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

	Group	Pre-Intervention	Post-Intervention	ES (CI)
F_0 ($\text{N}\cdot\text{kg}^{-1}$)	OP	46.63 ± 13.95	$47.01 \pm 11.38^*$	0.03 (-0.63, 0.57)
	GP	34.65 ± 3.62	34.62 ± 3.59	0.01 (-0.61, 0.63)
v_0 ($\text{m}\cdot\text{s}^{-1}$)	OP	4.02 ± 1.9	4.14 ± 1.81	0.06 (-0.66, 0.54)
	GP	5.02 ± 1.46	$5.54 \pm 1.64^*$	0.33 (-0.95, 0.30)
S_{fv} ($\text{N}\cdot\text{s}/\text{m}/\text{kg}$)	OP	-14.42 ± 9.66	$-13.76 \pm 7.38^*$	0.09 (-0.68, 0.53)
	GP	-6.20 ± 3.04	-5.83 ± 2.91	0.12 (-0.72, 0.50)

316

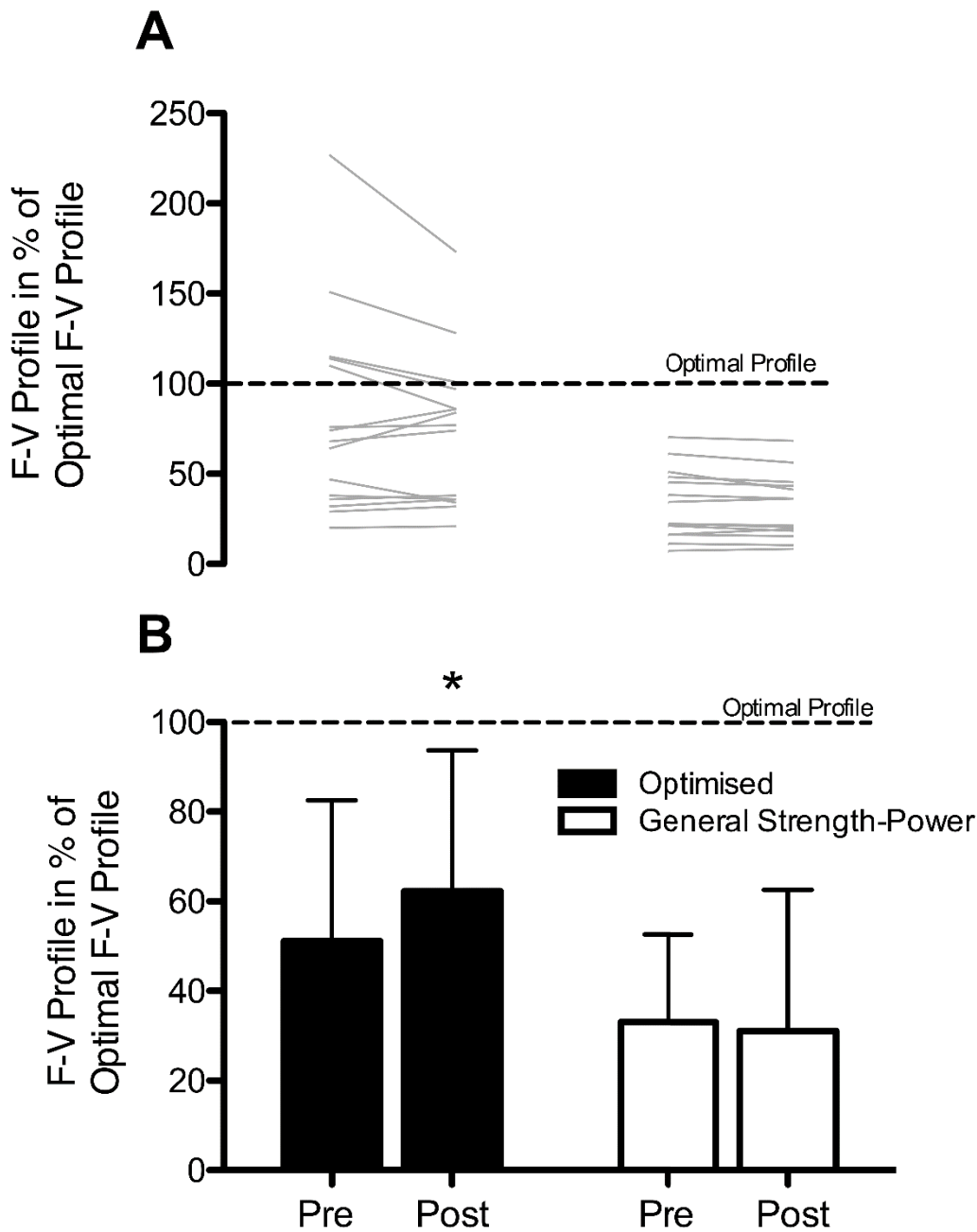
317

Note: ES = effect size, CI = confidence interval, F_0 = theoretical maximal force, v_0 = theoretical maximal velocity, S_{fv} = force-velocity curve, * = significant difference post intervention, $p < 0.05$.

318

319 Individual changes for FV_{imb} and mean F-V deficit changes are presented in Figure 1. Group effects
 320 were found for F-V deficit improvement ($F_{(1,26)} = 9.17$, $P = 0.005$), with lower scores in the OP group

321 compared to the GP post-intervention (95% CI [4.59, 24.01], $P = 0.001$, Figure 1). Pre-post effect
 322 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]).
 323

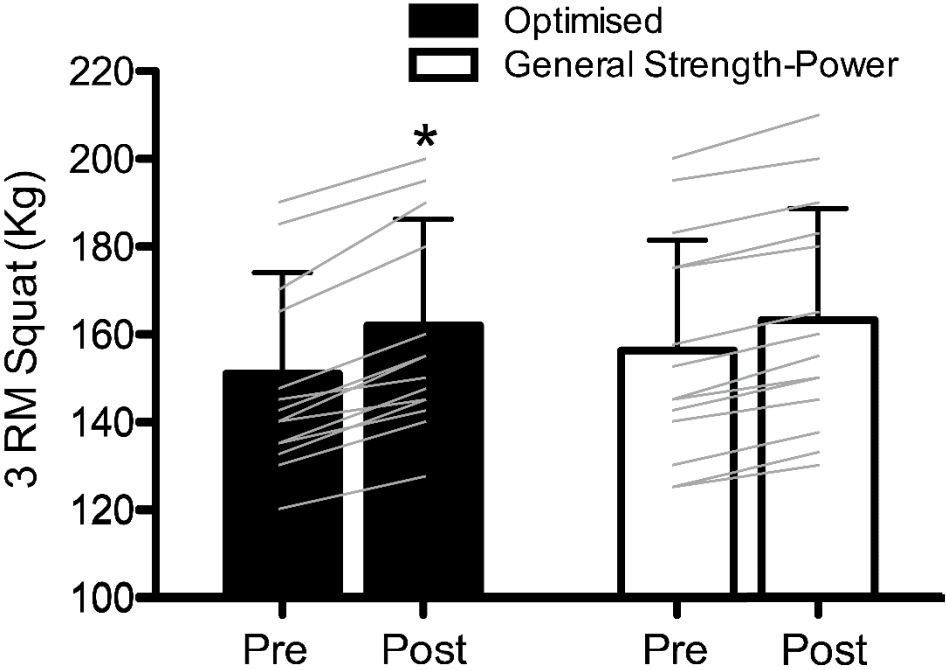


324 **Figure 1. (A)** Individual pre-post changes in FV_{imb} . **(B)** Mean changes in F-V profile as a
 325 percentage of optimal F-V profile. * = significant differences post-intervention, $p < 0.05$.

326
 327 Changes in 3RM squat across the training programme are presented in Figure 2. There was a group
 328 effect ($F_{(1,26)} = 12.72$, $P = 0.001$), with greater values in the OP group post-intervention (95% CI [1.76,

329 6.56] $P = 0.001$, Figure 2). Pre-post effect sizes for the OP group versus the GP group were 0.47 (CI
 330 [-1.05, 0.16]) vs 0.26 (CI [-0.89, 0.36]).

331



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

334

335 The results for peak power are presented in Figure 3. Group effects were found ($F_{(1,26)} = 48.89$, $P =$
 336 0.001), with higher values for the OP group post-intervention (95% CI [175.65, 321.92], $P = 0.001$,
 337 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]).

338

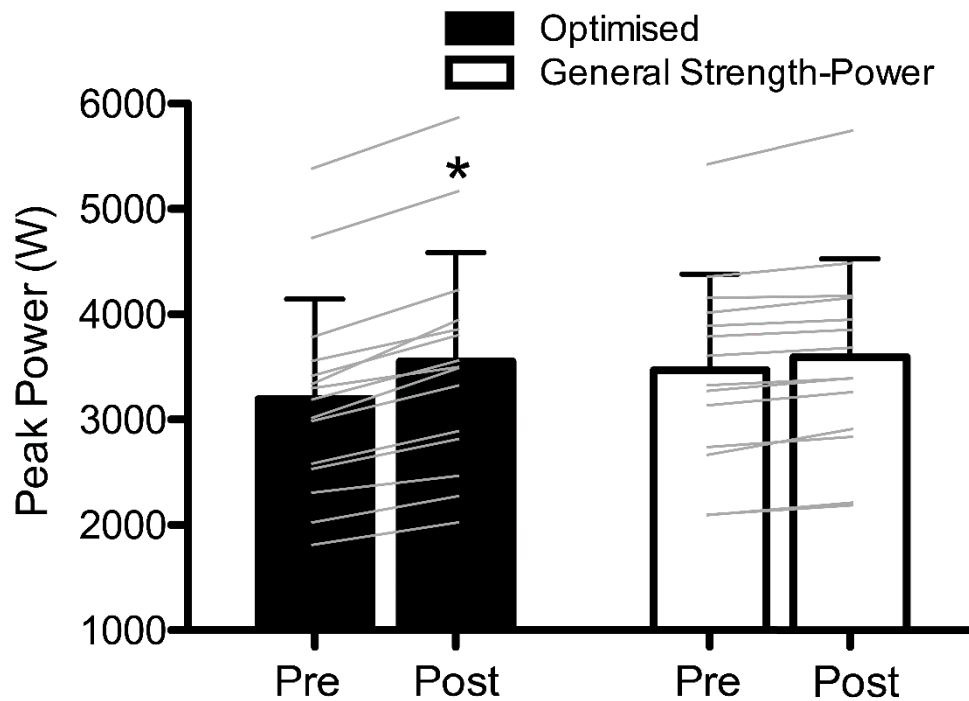


Figure 3. Mean changes in peak power with individual pre-post changes. * = significant differences post-intervention, $p < 0.05$.

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]).

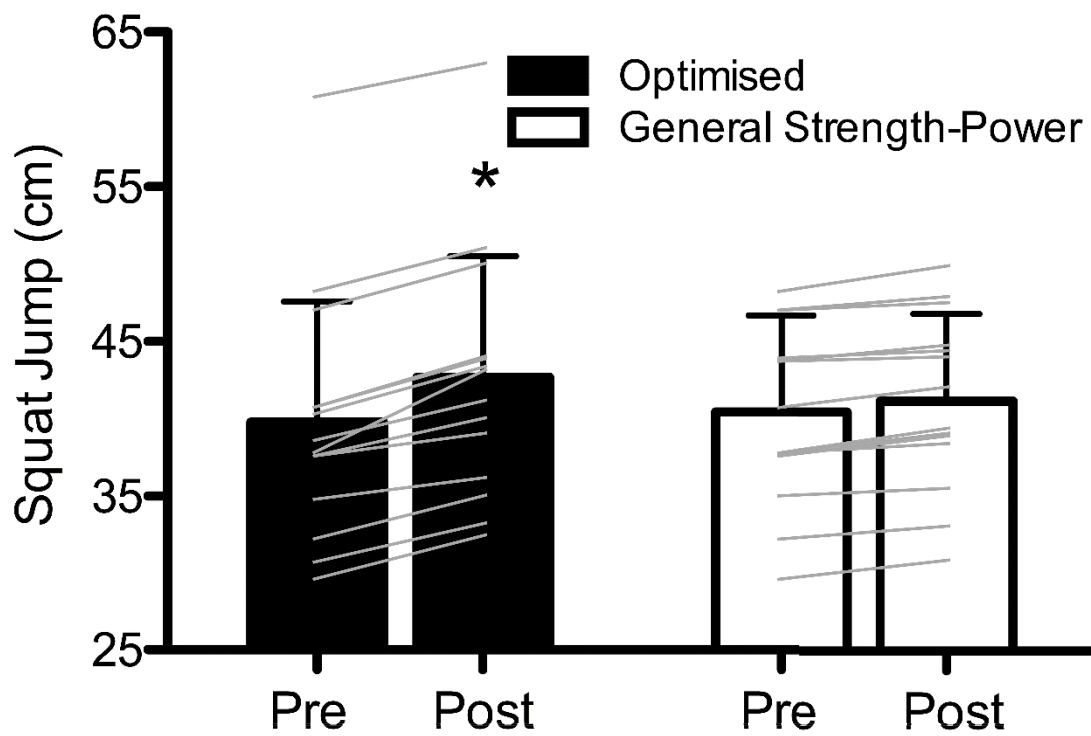


Figure 4. Mean changes in squat jump with individual pre-post changes. * = significant differences post-intervention, $p < 0.05$.

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, $F_{(1,26)} = 0.17$, $P = 0.68$).

360 DISCUSSION

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

369

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

386

387 Greater improvements in maximal strength were shown for the OP training group. Maximal strength
388 improvements have been reported in elite rugby union (Hansen et al., 2011), with one study (Baker
389 and Newton, 2006) demonstrating maximal strength improvements using traditional training
390 methods across a similar time period to the current study. The differing distributions of F-V deficit

391 between groups were a result of matching according to 3RM scores based on the standard training
392 period prior to the intervention. Whilst the authors feel this does not challenge the results, other
393 researchers may consider matching groups based off F-V deficits. Interestingly, as 10 players from
394 the OP training group, and 14 from the GP training group were velocity biased, this finding shows F-
395 V optimised training may be a more effective method for improving strength than traditional
396 training methods where a force deficiency exists. However, these adaptations may have been
397 assisted by the previously mentioned peaking effect from the initial 5-week preparatory cycle
398 (Morin et al., 2020). This delay in adaptation may also explain the increases in 3RM scores for
399 athletes across both training groups. Similarly, the OP training group demonstrated greater
400 improvements in peak-power compared with the GP training group. This is consistent with the
401 reported improvements in peak power following a F-V optimised training programme (Jimenez-
402 Reyes et al., 2017), with the current study now providing support in elite professional RL athletes.
403 While increased maximal strength has been reported following 8-week pre-season programmes of
404 traditional strength-power and cluster training (Hansen et al., 2011), these changes occurred
405 without increases in vertical power (Hansen et al., 2011). Given the importance of both maximal
406 strength and power production in RL (Baker and Newton, 2008), these findings collectively infer that
407 the specific nature of F-V informed prescription is more effective method for targeting
408 neuromuscular deficiencies. As concomitant improvements in power with maximal strength are
409 typically more apparent among novice athletes (Argus et al., 2012; Baker & Newton, 2006; McBride
410 et al., 2002), the development of power in elite athletes requires greater focus on contraction
411 velocity specificity and optimal load prescription (Cormie et al., 2010, 2011; McBride et al., 2002). It
412 seems the use of F-V optimised training may be an effective method to discern the optimal load
413 prescription for a RL player's deficiency, thereby targeting the contraction velocities most in need
414 of development.

415

416 Large differences were also found post-intervention between groups for the unloaded SJ. This aligns
417 with existing research demonstrating improvements in F-V deficit concurrently with increases in SJ
418 height (Jimenez-Reyes et al., 2017). As greater changes were also found for maximal strength and
419 peak-power, this finding is intuitive due to the force-producing strategy necessary for success in the
420 SJ. In addition, training prescription for the OP was derived from each athletes FV_{imb} to shift them
421 toward an optimal profile, which is computed to maximise jumping performance. Consequently, it
422 is unsurprising differences between groups were present for jumping performance. In this

423 investigation, athletes were required to perform a 1 s pause at the end of the eccentric phase of the
424 movement, which limits the involvement of the stretch-shortening cycle and emphasises concentric
425 rate of force development (Harmen et al., 1990; Jimenez-Reyes et al., 2014). Performance is
426 therefore dependent on the application of the highest magnitude of force in the short time available
427 before toe-off throughout a concentric contraction regime. As maximal strength has increased
428 alongside peak power, the OP group appear to be able to apply more force within the time available
429 during the SJ, therefore improving jump height to a greater degree. Furthermore, the current study
430 provides stronger evidence that the F-V relationship can be shifted towards the force side in order
431 to optimise power output and improve strength concomitantly. Both the OP and GP training groups
432 consisted predominantly of velocity biased athletes at baseline, which may suggest RL players can
433 be characterised this way most commonly. Additionally, the higher values for F_0 and S_{fv} post-
434 intervention in the OP group support the effectiveness of a F-V optimised programme in shifting an
435 athlete's profile more optimally. Conversely, as the GP group was entirely velocity biased and
436 presented higher scores in v_0 , it seems a general programme may serve to increase an athletes
437 existing imbalance. Consequently, the larger changes in maximal strength, peak power, and SJ
438 suggest that a F-V optimised programme offers the most efficient approach for eliciting change over
439 an 8-week period.

440

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

455 issues other than force production may be the limiting factor in sprinting performance. As the
456 athletes in this study are high level professionals, this may explain the lack of transfer to 10- and 20-
457 m sprint performance.

458

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

471

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

486

487 **CONCLUSION**

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

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