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Effects of In-Season Velocity- vs. Percentage-Based Training in Academy Rugby League Players

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23 **ABSTRACT**

24 **Purpose:** To compare the effects of velocity-based training (VBT) versus percentage-based
25 training (PBT) on strength, speed and jump performance in academy rugby league players
26 during a 7-week in-season mesocycle.

27 **Methods:** Twenty-seven rugby league players competing in the Super League U19s
28 Championship were randomised to VBT (n = 12) or PBT (n = 15). Both groups completed a 7-
29 week resistance training intervention (2x/week) that involved the back squat. The PBT group
30 used a fixed load based on a percentage of one repetition maximum (1RM), whereas the VBT
31 group used a modifiable load based on individualised velocity thresholds. Biomechanical and
32 perceptual data were collected during each training session. Back squat 1RM,
33 countermovement jump (CMJ), reactive strength index (RSI), sprint times, and back squat
34 velocity at 40-90% 1RM were assessed pre- and post-training.

35 **Results:** The PBT group showed *likely to most likely* improvements in 1RM strength and RSI,
36 whereas the VBT group showed *likely to very likely* improvements in 1RM strength, CMJ
37 height, and back squat velocity at 40 and 60% 1RM. Sessional velocity and power were *most*
38 *likely* greater during VBT compared with PBT (standardised mean differences [SMDs] = 1.8
39 to 2.4), whilst time under tension and perceptual training stress were *likely* lower (SMDs = 0.49
40 to 0.66). The improvement in back squat velocity at 60% 1RM was *likely* greater following
41 VBT compared with PBT (SMD = 0.50).

42 **Conclusion:** VBT can be implemented during the competitive season, instead of traditional
43 PBT, to improve training stimuli, decrease training stress, and promote velocity-specific
44 adaptations.

45 **Keywords:** Velocity-based training, load-velocity relationship, training load, competitive
46 season, resistance training.

47 INTRODUCTION

48 Resistance training is an integral component of long-term athlete development in rugby league.
49 Regular engagement in resistance training induces marked neurological, musculoskeletal and
50 morphological adaptations that are important for successful rugby league performance.^{1,2}
51 However, acute bouts of resistance exercise can lead to considerable neuromuscular fatigue
52 lasting up to 72 hours.³ This is particularly problematic for rugby league players during the
53 competitive season because excessive fatigue may impair match performance.⁴ Therefore, it is
54 important to carefully regulate training load during this period.

55 The traditional approach to prescribing resistance training load is to use a percentage of one
56 repetition maximum (1RM), known as percentage-based training (PBT). Using this method,
57 the external load is fixed until the 1RM assessment is repeated, usually at the end of a
58 mesocycle. While PBT has been shown to be effective for improving surrogate measures of
59 rugby league performance,⁵⁻⁷ it is not sensitive to the athlete's daily readiness to train. Maximal
60 strength can fluctuate on a day-to-day basis or change throughout the training block.⁸
61 Consequently, prescribing loads based on percentage 1RM can lead to a suboptimal training
62 stimulus.

63 The recent development of portable kinematic devices has enabled practitioners to obtain
64 instantaneous measurements of barbell velocity.⁹ As a result, velocity-based training (VBT)
65 has become a popular method of regulating resistance training load. VBT is characterised by
66 lifting with maximal intended velocity and adjusting training load based on the resultant
67 velocity data. A decline in barbell velocity is representative of neuromuscular fatigue,¹⁰
68 whereas greater velocity attained against a given absolute load may indicate enhanced muscle
69 strength.¹¹ Therefore, VBT can be used to manipulate training load according to the athlete's
70 current physiological state.

71 Whilst several VBT approaches exist, recent research has encouraged the use of individualised
72 load-velocity relationships.¹²⁻¹⁴ This method involves obtaining concentric velocity data across
73 the loading spectrum and establishing velocity thresholds at each relative load, which are then
74 used to modify subsequent training load. Dorrell et al¹⁵ recently reported that six weeks of
75 prescribing training load based on generalised velocity zones led to greater improvements in
76 countermovement jump (CMJ) height than PBT in 16 recreationally-trained men. However,
77 the use of general velocity thresholds does not account for the large inter-individual
78 heterogeneity in load-velocity relationships.¹² In addition, no study has compared VBT to PBT
79 in sportspeople during the competitive season, which is arguably where VBT could have the
80 greatest application. Therefore, the purpose of this study was to compare the effects of VBT
81 versus PBT on strength, speed and jump performance in semi-professional academy rugby
82 league players during the competitive season. Sessional kinematic, kinetic and perceptual data
83 were also compared between-groups.

84 METHODS

85 Participants

86 Academy rugby league players were recruited from one English Super League club during the
87 second half of the competitive season. All players were free from injury, were currently
88 competing in the Super League U19s Championship, and had competed a 12-week pre-season
89 training block prior to entering the study. In addition, all participants had at least two years of
90 resistance training experience as part of a Super League U15-U16s Scholarship squad.
91 Participants were informed of the experimental procedures before giving written informed
92 consent, and parental/guardian consent was obtained for participants aged < 18 years. Ethical

93 approval for the study was granted by the relevant institutional review board in line with the
94 Declaration of Helsinki.

95 **Experimental design**

96 This study used a parallel-group, randomised design. Participants were randomly allocated
97 (1:1) to 7-weeks of either VBT or PBT in block sizes of four using online randomisation
98 software. Both groups completed two resistance training sessions per week that involved the
99 back squat. VBT involved adjusting back squat load using real-time velocity feedback, whereas
100 PBT involved a fixed load based on baseline 1RM. Outcomes of strength, speed and jump
101 performance were assessed at baseline (before randomisation) and post-intervention endpoint.
102 Biomechanical and perceptual data were also collected during each training session.

103 **Procedures**

104 Participants completed performance testing on three separate days, with 24-48 hours recovery
105 between each day. Day 1 involved a CMJ, a drop jump (DJ) and a 30 m linear sprint. Day 2
106 involved a 1RM test, and day 3 involved an assessment of load-velocity relationships. In the
107 following training week, participants were randomly assigned to PBT or VBT and began the
108 7-week training mesocycle. After the completion of the final resistance training session, testing
109 for outcome measures was repeated in the next training week.

110 **Outcome measures**

111 *One repetition maximum*

112 Participants completed 1RM testing in the free-weight back squat using methods described
113 previously.⁹ Briefly, participants performed a standardised warm-up followed by five
114 repetitions at ~50% 1RM, three repetitions at ~70% 1RM, and two repetitions at ~80% 1RM.
115 Thereafter, participants performed 1RM attempts with progressively increased loads.
116 Participants were required to achieve a parallel squat depth (thigh parallel to the floor), which
117 was monitored by a member of the research team. A maximum of five attempts were permitted
118 and the last successful lift was taken as the 1RM.

119 *Individualised load-velocity relationships*

120 A linear position transducer (GymAware PowerTool [GYM], Kinetic Performance
121 Technologies, Canberra, Australia) was used to measure mean velocity (MV) in the free-weight
122 back squat. Following the same standardised warm-up performed in the 1RM assessment,
123 participants completed three repetitions at 40%, three repetitions at 60%, two repetitions at
124 80%, and one repetition at 90% of baseline 1RM. GYM has been shown to obtain reliable
125 measurements of MV at 40-90% 1RM.⁹ Participants were verbally encouraged to complete
126 each repetition with maximal concentric velocity, although objective velocity feedback was
127 not provided. Three minutes of rest was provided between each relative load. Individualised
128 load-velocity relationships were constructed by plotting MV against load and applying a line
129 of best fit.¹³ The MVs corresponding to 60 and 80% 1RM were used to modify training load in
130 the VBT group. At post-intervention, load-velocity relationships were constructed with the
131 same absolute loads used in the baseline assessment.

132 *Sprint performance*

133 Following a dynamic warm-up and one practise 30 m sprint, participants completed two
134 maximal 30 m sprints, with times being recorded at 5, 10, 20 and 30 m intervals using a
135 photocell timing system (Witty Timing System, Microgate, Balzano, Italy). Three minutes rest
136 was provided between efforts. Reliability for each sprint distance was high (coefficient of

137 variations = 2.0 to 4.5%). All sprints took place on the same outdoor 4G artificial turf and
138 began from a standing start. The fastest sprint was used for analysis.

139 ***Jump performance***

140 CMJ and DJ tests were administered indoors using the Optojump photocell system (Optojump,
141 Microgate, Bolzano, Italy), which samples at 1000 Hz and consists of two dual-beam bars (100
142 x 4 x 3 cm) that were placed in parallel approximately 1 m apart.¹⁶ For the CMJ, participants
143 placed their hands on their hips and descended downwards to a self-selected level before
144 jumping upwards for maximum height. For the DJ test, participants stepped off a standardised
145 box (height, 30 cm) with their preferred leg, landed on the floor with both feet, and immediately
146 jumped as high as possible. Participants received instructions to maintain their hands on their
147 hips, to keep their legs as straight as possible on contact with the ground, and to minimise
148 ground contact time. Three CMJS and DJs were performed with the highest jump (cm) and
149 reactive strength index ($RSI = \text{jump height [m]} / \text{contact time [s]}$) used for analysis,
150 respectively. Sixty seconds of rest was provided between each jump. Coefficient of variations
151 for CMJ height and RSI were 2.7% and 8.0%, respectively.

152 ***Exercise responses***

153 Participants completed a perceived wellness questionnaire prior to every resistance training
154 session. The questionnaire included five items (muscle soreness, fatigue, stress, sleep and
155 mood) on a 7-point Likert scale ranging 'very bad' to 'great'. Higher scores indicated better
156 perceived wellness. RPE data were collected after the completion of every set using the OMNI-
157 RES scale.¹⁷ All participants were familiarised with the OMNI-RES during prior training
158 sessions and the scale was always in full view. MV, mean power (MP), TUT, work and barbell
159 load of each back squat repetition were also recorded.

160 ***Training routine***

161 Resistance training sessions were completed on a morning (7 a.m.), with field sessions (rugby
162 league skills and conditioning) taking place in the afternoon of the same day (16:30 p.m.). An
163 additional low-intensity field session ('team run') was performed 24 hours before a competitive
164 match. Furthermore, participants completed a training session that focused on active recovery
165 and general motor ability approximately 48 hours after a match (Figure 1). Each resistance
166 training session began with a standardised warm-up followed by four sets of five free-weight
167 back squat repetitions, separated by 2-3 min inter-set rest periods. The PBT group performed
168 back squats with a fixed load based on their baseline 1RM, whereas the VBT group performed
169 back squats with a modifiable load based on a target velocity threshold established from
170 individualised load-velocity relationships. Both groups received the same encouragement to
171 lift with maximal intended concentric velocity and complete the eccentric phase in a controlled
172 manner, although neither group received instantaneous velocity information to control for the
173 effect of feedback.¹⁸ Following back squats, participants then completed the same four
174 supplementary exercises (Nordic lower/Romanian deadlift, upper-body push, upper-body pull,
175 anti-extension) using body weight or a repetitions in reserve approach to adjust load (Table 1).

176 ***Percentage-based training***

177 In the first weekly session, the PBT group performed back squats with 80% of baseline 1RM,
178 while the second weekly session was performed with 60% 1RM. These loads were chosen
179 because they are regularly prescribed in strength programmes, they target distinct physical
180 qualities on the strength-velocity continuum, and velocity data attained at these loads are
181 reliable.⁹ The barbell load was not adjusted during the 7-week mesocycle.

182 **Velocity-based training**

183 Participants in the VBT group performed one weekly session with a load that corresponded to
184 MV at 80% 1RM established from their individual load-velocity relationship. The second
185 weekly session was completed with a load corresponding to MV at 60% 1RM. The load for the
186 first set of session one and the first set of session two were 80% and 60% 1RM, respectively.
187 Thereafter, if the maximum MV in a set of five repetitions was $\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ outside of the target
188 movement velocity, the barbell load was then adjusted by $\pm 5\%$ 1RM for the subsequent set. A
189 threshold of $\pm 0.06 \text{ m}\cdot\text{s}^{-1}$ was chosen based on the measurement error in MV obtained by GYM⁹
190 and to align with previous research.¹³ Training load was modified based on the maximum MV
191 in a set (rather than mean MV) because load-velocity relationships were constructed with the
192 maximum value.

193 **Data analysis**

194 Exercise responses to back squats at 60% 1RM were analysed separately to responses at 80%
195 1RM. All biomechanical data were collected during the concentric phase. The placement of
196 GYM and the methods used to calculate MV and MP have been described previously.^{9,19,20}
197 Work was determined as the area underneath the force-displacement curve during the
198 concentric phase of each repetition, and TUT represented the time spent during the same
199 period. Data obtained from GYM were transmitted via Bluetooth to a tablet (iPad, Apple Inc.,
200 California, USA) using the GymAware v2.1.1 app and uploaded onto a cloud-based system.
201 Body mass and barbell load were entered into the app prior to each set. MV, TUT, work and
202 barbell load were determined as the average of all repetitions for each individual across the
203 training intervention. Perceived wellness and RPE were also determined as the average of all
204 data collected during the intervention to reduce the number of statistical comparisons made.

205 **Statistical analysis**

206 Data were analysed using Microsoft Excel spreadsheets.²¹ Participants were required to attend
207 $\geq 70\%$ of resistance training sessions to be included in the analyses. A magnitude-based
208 inference (MBI) approach was used to assess the magnitude of effects within- and between-
209 groups, which interprets the mean differences and their corresponding 90% confidence
210 intervals (CIs) in relation to the smallest worthwhile change (SWC).²² The SWC was
211 considered to be 0.2 times the standard deviation (SD) at baseline.²³ Standardised mean
212 differences (SMDs) from pre to post-intervention were calculated using the formula: (mean
213 change/baseline SD), which was divided by $(1-3/(4df-1))$ to adjust for a small sample size.
214 Values of < 0.2 , 0.2 to 0.59 , 0.6 to 1.19 , and 1.2 to 2.0 were considered trivial, small, moderate,
215 and large effects, respectively.²⁴ SMDs in change scores, sessional MV, MP and barbell load
216 were compared between-groups using baseline values as covariates. Covariates were not used
217 to compare RPE, TUT, work nor perceived wellness. Effects that favoured VBT are reported
218 as positive SMDs, whereas effects that favoured PBT are reported as negative SMDs. The
219 qualitative probabilities that the magnitude of effect was greater than the SWC was rated as: $<$
220 0.5% , *most unlikely*; $< 5\%$; *very unlikely*; $< 25\%$, *unlikely*; $25-75\%$, *possibly*; $> 75\%$, *likely*; $>$
221 95% , *very likely*; $> 99.5\%$; *most likely*.²¹ Data are presented as mean \pm SD or SMD \pm 90% CI.

222 **RESULTS**

223 Thirty-two players were initially recruited, although five withdrew due to leaving the club (n
224 = 3) or suffering an injury during a competitive match (n = 2). Therefore, 27 participants
225 completed the intervention (Table 2). Compliance was 86% in the PBT group and 90% in the
226 VBT group.

227 **Exercise responses**

228 Relative to the 60 and 80% 1RM sessions in the PBT group, average loads in the VBT group
229 were 62 and 79% 1RM, respectively. Sessional MV and MP were *most likely* greater during
230 VBT compared with PBT (Figure 2), whilst TUT and perceived training stress were *likely*
231 lower (Figure 3). Compared to the PBT group, VBT elicited *likely* higher RPE at 60% 1RM,
232 but *likely* lower RPE at 80% 1RM (Figure 2).

233 **Performance outcomes**

234 The PBT group showed *likely* to *most likely* improvements in 1RM strength and RSI, whereas
235 the VBT group showed *likely* to *very likely* improvements in 1RM strength, CMJ height, and
236 back squat MV at 40 and 60% 1RM (Table 3). The improvement in back squat MV at 60%
237 1RM was *likely* greater following VBT compared with PBT (SMD = 0.50). Both groups
238 showed reductions in sprint performance (Table 3), although the change in 10 m sprint time
239 *possibly* favoured the PBT group (SMD = -0.21 ± 0.40). All other SMDs in change scores
240 between-groups were *likely trivial* or *unclear* (Figure 4).

241 **DISCUSSION**

242 The main finding was that VBT promoted greater sessional MV and MP compared with
243 conventional PBT, whilst TUT and perceived stress were lower. The improvement in back
244 squat velocity attained against 60% 1RM was also greater following VBT compared with PBT.
245 Therefore, VBT could be implemented during the competitive season to increase back squat
246 repetition velocity, minimise lower-body mechanical stress, and promote velocity-specific
247 adaptations.

248 Sessional MV and MP were *most likely* greater during back squats in the VBT group compared
249 with PBT group (SMDs: 1.8 to 2.4). In addition, concentric TUT and perceived training stress
250 were *likely* reduced in the VBT group, whilst differences in concentric work were *unclear*. This
251 finding agrees with previous research showing that, at the cross-sectional level, prescribing
252 training load based on individualised load-velocity profiles yielded greater MV (SMD = 1.05),
253 similar total work, and less TUT compared with PBT during five sets of five back squats.¹³
254 Others have also shown that limiting velocity loss during a set leads to higher MV during 6-8
255 weeks of back squat training in resistance-trained males²⁵ and professional soccer players.²⁶
256 Hence, our findings extend those of previous studies by showing that VBT enhances lower-
257 body training stimuli whilst minimising training stress during a competitive rugby league
258 mesocycle.

259 The improvement in back squat velocity at 60% 1RM was *likely* greater following VBT
260 compared with PBT (SMD = 0.50). The uncertainty of the SMD (90% CI: -0.16 to 1.16) shows
261 that differences compatible with the data range from a trivial effect to a moderate effect
262 favouring VBT. Hence, adjusting training load based on velocity feedback, rather than a
263 percentage of 1RM, has negligible negative effects but potentially moderate benefits on back
264 squat velocity at 60% 1RM. This favourable shift in the load-velocity relationship ostensibly
265 resulted from the higher training velocities elicited by VBT and represents an improvement in
266 explosive strength. Explosive strength is the ability to maximise force in minimal time, and is
267 often a key objective of strength and conditioning programmes because many rugby league
268 actions require force to be applied quickly. However, it is unknown whether this adaptation is
269 exclusive to the back squat or whether it could also transfer to enhanced rugby league match-
270 play.

271 Both groups comparatively improved 1RM strength. In addition, although the difference in
272 CMJ height favoured VBT (0.28 ± 0.61), the effect estimate was small and the precision of the
273 estimate was low, leading to an *unclear* difference between groups. Thus, VBT did not provide
274 additional benefit over PBT for these outcomes, which can be explained by training specificity.
275 Back squats at 60 and 80% 1RM are performed at moderate to slow velocities, respectively,
276 and training with these loads will produce the greatest gains in strength at moderate to slow
277 velocities.²⁷ As a result, the higher sessional MV elicited by VBT at 60 and 80% 1RM is
278 unlikely to lead to further improvements in 1RM strength or jumping performance, which
279 represent two extremes of the load-velocity continuum. These results suggest that either PBT
280 or VBT can be utilised when maximal lower-body strength or explosive jump performance is
281 the primary training objective.

282 Sprint performance decreased in both groups, which may have been because the 7-week
283 mesocycle did not include any linear sprint training nor horizontally-loaded resistance
284 exercises. Previous research has shown that sprint performance does not improve during a
285 rugby league season despite regular speed training.²⁸ Sprint times have also been shown to
286 worsen in international rugby union forwards during the second half of the competitive season,
287 which was attributed to accumulated match fatigue.²⁹ Thus, a lack of specific training could
288 have combined with residual fatigue to impair sprint performance. Surprisingly, the change
289 score in 10 m sprint time *possibly* favoured PBT (SMD = -0.21 ± 0.40). However, this finding
290 was presumably due to chance variation and/or noise given the 90% CI touched the upper
291 boundary of the SWC and the direction of SMDs in 5, 20 and 30 m sprint times actually
292 favoured the VBT group (Figure 4).

293 An interesting finding was that VBT elicited *likely* higher RPE at 60% 1RM (SMD: 0.65), but
294 *likely* lower RPE at 80% 1RM (SMD: -0.67). The higher RPE at 60% 1RM may be related to
295 *possibly* greater barbell load (SMD: 0.35) given the direct relation between RPE and load,³⁰
296 although unclear differences were found in concentric work. Relative to the 60 and 80% 1RM
297 sessions in the PBT group, the average loads in the VBT group were 62 and 79% 1RM,
298 respectively. Hence, players in the VBT group increased sessional MV more when lifting 60%
299 1RM than 80% 1RM, which led to barbell load being increased across the mesocycle. This is
300 supported by the finding that adaptations in the load-velocity relationship induced by VBT
301 were specific to 60% 1RM. Consequently, using VBT methods at 60% 1RM may lead to
302 greater loads and RPE compared with PBT, whilst VBT at 80% 1RM appears to maintain
303 barbell load but reduce RPE.

304 There are some limitations to this study. Training load was only manipulated in the back squat,
305 however, this aligns with previous VBT papers^{25,26} and using velocity thresholds to adjust load
306 in other lower-body exercises included in the training routine (Nordic lowers/unilateral
307 Romanian deadlift) was not appropriate because maximising concentric velocity is not the main
308 training objective for these exercises. Another limitation is that training load was not adjusted
309 in the PBT group, whilst the VBT group continually modified load. Furthermore, although
310 participants were randomised and completed the same training regimen, it cannot be guaranteed
311 that on-field player loads were the same between groups, which could have influenced training
312 adaptations. Finally, the magnitudes of effects were interpreted in relation to the SWC (baseline
313 SD x 0.2). Whilst this distribution-based statistic is widely used throughout the literature, it
314 does not consider whether the magnitude of effect is important for rugby league performance.

315 PRACTICAL APPLICATIONS

316 This study suggests that adjusting resistance training load based on individual velocity
317 thresholds is a superior alternative to conventional percentage-based approaches during the

318 competitive rugby league season. VBT promoted faster back squat repetition velocities,
319 minimised mechanical stress, and improved lower-limb explosive strength. However, it should
320 be considered that VBT requires the use of relatively expensive devices, additional time to set
321 up equipment and potentially more staff to competently monitor sessional velocity. Coaching
322 staff must judge whether the benefits of VBT outweigh the increased financial and time burden
323 compared with PBT.

324 **CONCLUSIONS**

325 VBT was associated with greater sessional velocity and power, as well as lower TUT and
326 perceived training stress, throughout a 7-week mesocycle compared with PBT. VBT also led
327 to a greater improvement in back squat velocity attained against 60% 1RM compared with
328 PBT. Therefore, this study is the first to show that VBT can be implemented during the
329 competitive rugby league season, instead of traditional PBT, to improve lower-body training
330 stimuli, decrease unnecessary training stress, and promote velocity-specific adaptations.

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333 **REFERENCES**

334 1. Folland JP, Williams AG. The adaptations to strength training : morphological and
 335 neurological contributions to increased strength. *Sports medicine (Auckland, NZ)*.
 336 2007;37(2):145-168.

337 2. de Souza EO, Tricoli V, Paulo AC, et al. Multivariate analysis in the maximum strength
 338 performance. *Int J Sports Med*. 2012;33(12):970-974.

339 3. Thomas K, Brownstein CG, Dent J, Parker P, Goodall S, Howatson G. Neuromuscular
 340 Fatigue and Recovery after Heavy Resistance, Jump, and Sprint Training. *Medicine and
 341 science in sports and exercise*. 2018.

342 4. Gabbett TJ. Influence of Fatigue on Tackling Ability in Rugby League Players: Role
 343 of Muscular Strength, Endurance, and Aerobic Qualities. *PLoS One*.
 344 2016;11(10):e0163161.

345 5. Comfort P, Haigh A, Matthews MJ. Are changes in maximal squat strength during
 346 preseason training reflected in changes in sprint performance in rugby league players?
 347 *J Strength Cond Res*. 2012;26(3):772-776.

348 6. Speranza MJ, Gabbett TJ, Johnston RD, Sheppard JM. Effect of Strength and Power
 349 Training on Tackling Ability in Semiprofessional Rugby League Players. *J Strength
 350 Cond Res*. 2016;30(2):336-343.

351 7. Coutts AJ, Murphy AJ, Dascombe BJ. Effect of direct supervision of a strength coach
 352 on measures of muscular strength and power in young rugby league players. *J Strength
 353 Cond Res*. 2004;18(2):316-323.

354 8. Dankel SJ, Counts BR, Barnett BE, Buckner SL, Abe T, Loenneke JP. Muscle
 355 adaptations following 21 consecutive days of strength test familiarization compared
 356 with traditional training. *Muscle & nerve*. 2017;56(2):307-314.

357 9. Orange ST, Metcalfe JW, Marshall P, Vince RV, Madden LA, Liefieith A. The Test-
 358 retest Reliability of a Commercial Linear Position Transducer (GymAware PowerTool)
 359 to Measure Velocity and Power in the Back Squat and Bench Press. *The Journal of
 360 Strength & Conditioning Research*. Published Online: June 25, 2018 (doi:
 361 10.1519/JSC.0000000000002715).

362 10. Sanchez-Medina L, Gonzalez-Badillo JJ. Velocity loss as an indicator of
 363 neuromuscular fatigue during resistance training. *Medicine and science in sports and
 364 exercise*. 2011;43(9):1725-1734.

365 11. Sánchez-Medina L, Pallarés JG, Pérez CE, Morán-Navarro R, González-Badillo JJ.
 366 Estimation of relative load from bar velocity in the full back squat exercise. *Sports
 367 Medicine International Open*. 2017;1(02):E80-E88.

368 12. Banyard HG, Nosaka K, Vernon AD, Haff GG. The Reliability of Individualized Load-
 369 Velocity Profiles. *International journal of sports physiology and performance*. 2017;1-
 370 22.

371 13. Banyard HG, Tufano JJ, Delgado J, Thompson SW, Nosaka K. Comparison of
 372 Velocity-Based and Traditional 1RM-Percent-Based Prescription on Acute Kinetic and
 373 Kinematic Variables. *International journal of sports physiology and performance*.
 374 2018;1-28.

375 14. Torrejon A, Balsalobre-Fernandez C, Haff GG, Garcia-Ramos A. The load-velocity
 376 profile differs more between men and women than between individuals with different
 377 strength levels. *Sports Biomech*. 2018;1-11.

378 15. Dorrell HF, Smith MF, Gee TI. Comparison of Velocity-Based and Traditional
 379 Percentage-Based Loading Methods on Maximal Strength and Power Adaptations. *J
 380 Strength Cond Res*. Published Online: February 18, 2019 (doi:
 381 10.1519/JSC.0000000000003089).

- 382 16. Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffiuletti NA.
383 Validity and reliability of Optojump photoelectric cells for estimating vertical jump
384 height. *J Strength Cond Res.* 2011;25(2):556-560.
- 385 17. Robertson RJ, Goss FL, Rutkowski J, et al. Concurrent validation of the OMNI
386 perceived exertion scale for resistance exercise. *Medicine and science in sports and*
387 *exercise.* 2003;35(2):333-341.
- 388 18. Weakley JJ, Wilson KM, Till K, et al. Visual feedback attenuates mean concentric
389 barbell velocity loss, and improves motivation, competitiveness, and perceived
390 workload in male adolescent athletes. *J Strength Cond Res.* Published Online: July 12,
391 2017 (doi: 10.1519/JSC.0000000000002133).
- 392 19. Orange ST, Metcalfe JW, Liefeyth A, et al. Validity and reliability of a wearable inertial
393 sensor to measure velocity and power in the back squat and bench press. *The Journal*
394 *of Strength & Conditioning Research.* Published Online: May 8, 2018 (doi:
395 10.1519/JSC.0000000000002574).
- 396 20. Banyard HG, Nosaka K, Sato K, Haff GG. Validity of various methods for determining
397 velocity, force and power in the back squat. *International journal of sports physiology*
398 *and performance.* 2017:1-25.
- 399 21. Hopkins WG. Spreadsheets for analysis of controlled trials, crossovers and time series.
400 *Sportscience.* 2017;21:1-4.
- 401 22. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes.
402 *International journal of sports physiology and performance.* 2006;1(1):50-57.
- 403 23. Hopkins WG. How to interpret changes in an athletic performance test. *Sportscience.*
404 2004;8(1):1-7.
- 405 24. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies
406 in sports medicine and exercise science. *Medicine and science in sports and exercise.*
407 2009;41(1):3-13.
- 408 25. Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, et al. Effects of velocity loss
409 during resistance training on athletic performance, strength gains and muscle
410 adaptations. *Scandinavian journal of medicine & science in sports.* 2017;27(7):724-
411 735.
- 412 26. Pareja-Blanco F, Sanchez-Medina L, Suarez-Arrones L, Gonzalez-Badillo JJ. Effects
413 of Velocity Loss During Resistance Training on Performance in Professional Soccer
414 Players. *International journal of sports physiology and performance.* 2017;12(4):512-
415 519.
- 416 27. Balshaw TG, Massey GJ, Maden-Wilkinson TM, Tillin NA, Folland JP. Training-
417 specific functional, neural, and hypertrophic adaptations to explosive- vs. sustained-
418 contraction strength training. *J Appl Physiol (1985).* 2016;120(11):1364-1373.
- 419 28. Gabbett TJ. Changes in physiological and anthropometric characteristics of rugby
420 league players during a competitive season. *Journal of Strength and Conditioning*
421 *Research.* 2005;19(2):400-408.
- 422 29. Holmyard DJ, Hazeldine RJ. Seasonal variations in the anthropometric and
423 physiological characteristics of international rugby union players. In: Reilly T, Clarys
424 J, Stibbe A, eds. *Science and Football II: Proceedings of the second World Congress*
425 *of Science and Football.* London, UK: E and FN Spon; 1993:21-26.
- 426 30. Lagally KM, Robertson RJ. Construct validity of the OMNI resistance exercise scale.
427 *J Strength Cond Res.* 2006;20(2):252-256.

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429 **Table and Figure captions**

430 **Table 1.** Summary of resistance training sessions during the 7-week mesocycle

431 **Table 2.** Baseline characteristics (mean \pm SD)

432 **Table 3.** Mean \pm SD at pre- and post-intervention, within-group change scores in standardised
433 units (Δ SMD \pm 90% CI) and qualitative inferences

434 **Figure 1.** Weekly in-season training schedule during the 7-week mesocycle. GMA = general
435 motor ability; RT = resistance training.

436 **Figure 2.** Sessional mean velocity (MV, panel A), mean power (MP, panel B), time under
437 tension (TUT, panel C), work (panel D), barbell load (BL, panel E), and rating of perceived
438 exertion (RPE, panel F) at 60% and 80% of one repetition maximum (1RM) in percentage-
439 based training (PBT) and velocity-based training (VBT) groups. Data are presented as mean \pm
440 SD (TUT, work, RPE) or adjusted mean \pm SEE (MV, MP and BL), along with standardised
441 mean differences (SMDs) and the corresponding 90% confidence interval.

442 **Figure 3.** Mean perceived wellness scores in percentage-based training (PBT) and velocity-
443 based training (VBT) groups. * VBT had a *likely* beneficial effect on perceived stress
444 (standardised mean difference = 0.66 ± 0.66). All other differences between groups were
445 *unclear*. Data are presented as mean \pm SD.

446 **Figure 4.** Standardised mean differences (SMDs) between change scores and their
447 corresponding 90% confidence intervals. Area shaded in grey represents a trivial SMD. 1RM
448 = one repetition maximum; PBT = percentage-based training; CMJ = countermovement jump;
449 MV = mean velocity; RSI = reactive strength index; VBT = velocity-based training.