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1 **Title: Criterion and construct validity of an isometric mid-**
2 **thigh pull dynamometer for assessing whole body strength**
3 **in professional rugby league players**

4

5 **Short Title:** Validity of an isometric mid-thigh pull
6 dynamometer

7

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21

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26 **ABSTRACT**

27 **Purpose:** The purpose of this study was to examine the
28 criterion and construct validity of an isometric mid-thigh pull
29 dynamometer to assess whole body strength in professional
30 rugby league players.

31 **Methods:** Fifty-six male rugby league players, (33 senior and
32 23 youth professional players) performed four isometric mid-
33 thigh pull efforts (i.e. two on the dynamometer and two on the
34 force platform) in a randomised and counterbalanced order.

35 **Results:** Isometric peak force was underestimated ($P < 0.05$)
36 using the dynamometer compared to the force platform (95%
37 LoA: -213.5 ± 342.6 N). Linear regression showed that peak
38 force derived from the dynamometer explained 85% (adjusted
39 $R^2 = 0.85$, SEE = 173 N) of the variance in the dependent
40 variable, with the following prediction equation derived:
41 predicted peak force = $[1.046 * \text{dynamometer peak force}] +$
42 117.594 . Cross-validation revealed a non-significant bias
43 ($P > 0.05$) between the predicted and peak force from the force
44 platform, and an adjusted R^2 (79.6%), that represented
45 shrinkage of 0.4% relative to the cross-validation model (80%).
46 Peak force was greater for the senior compared to youth
47 professionals using the dynamometer (2261.2 ± 222 cf. 1725.1
48 ± 298.0 N, respectively; $P < 0.05$).

49 **Conclusion:** The isometric mid-thigh pull assessed using a
50 dynamometer underestimates criterion peak force but is capable

51 of distinguishing muscle function characteristics between
52 professional rugby league players of different standards.

53

54

55 **Keywords:** Peak force, measurement error, talent

56 identification, collision sport, evaluation.

57 **INTRODUCTION**

58 Maximum muscle strength is an important physical quality for
59 rugby league that is related to fundamental performance
60 characteristics (e.g. sprint performance, tackling ability)^{1,2,3} and
61 is associated with a lower risk of injury.⁴ Maximal strength is
62 also known to differentiate between playing standard,⁵⁻⁷
63 meaning it has importance as part of talent identification.
64 Practitioners must therefore be able to accurately assess a rugby
65 league player's whole body maximal strength.

66

67 The assessment of maximal strength using isoinertial measures
68 (e.g. 1RM squat) is traditionally used in rugby league,^{1,6,8,9} but
69 can be influenced by individual technique and experience.¹⁰
70 Isoinertial dynamometry is also associated with an increased
71 risk of injury,¹¹ while testing with large squads can be time
72 consuming. Taken together, the shortcomings of isoinertial
73 dynamometry suggest that practitioners must think carefully
74 about the selection of a valid, safe and time-efficient measure
75 of maximal strength.

76

77 The use of the isometric mid-thigh pull offers a method of
78 maximal strength assessment that meets the aforementioned
79 criteria.¹²⁻¹⁴ The mid-thigh pull requires participants to stand on
80 a force platform with an immovable bar positioned to
81 correspond with the second-pull clean position, just below the

82 crease of the hip.¹⁵ Participants are then instructed to pull as
83 fast and hard as possible, enabling various kinetic measures to
84 be quantified from ground reaction forces.^{16,17} With good
85 reliability^{15,18,19} and strong relationships with dynamic actions
86 such as sprinting and jumping,^{3,17} the isometric mid-thigh pull
87 presents a useful method for assessing whole-body maximum
88 strength. However, the utility of the method is likely to be
89 limited by the availability of a force platform.¹⁷

90

91 The development of a custom-built isometric mid-thigh pull
92 dynamometer offers a more cost effective method for the safe
93 and time-efficient measure of maximal strength. However, for
94 practitioners it is important to understand the validity of any
95 new device against the criterion method,²⁰ whilst it must be
96 capable of differentiating between those of different training
97 status (i.e. construct validity).²¹ In a recent study by James et
98 al.,¹⁹ isometric mid-thigh pull performance measured using a
99 strain gauge had good reliability (coefficient of variation =
100 3.1%) but poor criterion validity when compared against the
101 same exercise conducted on a force platform. In this study,
102 validity was assessed using a relatively small sample size of
103 recreationally active participants (n = 15) and no attempt was
104 made to understand the ability of the simplified apparatus to
105 differentiate peak force capabilities between athletes of
106 different training status (i.e. construct validity). Accordingly,

107 the purpose of this study was twofold: 1) to compare the peak
108 forces obtained in a group of professional rugby league players
109 during the isometric mid-thigh pull between a custom built
110 dynamometer and a force platform (i.e. criterion validity); and
111 2) to establish the utility of the isometric mid-thigh pull to
112 differentiate muscle strength characteristics between rugby
113 league players of different standards (i.e. construct validity).

114

115 **METHODS**

116 **Participants and design**

117 With institutional ethics approval and participant consent, 56
118 male rugby league players were recruited from two professional
119 clubs and classified as senior professional (n = 33, age $25.3 \pm$
120 3.4 years, stature 183.9 ± 6.8 cm, body mass 97.9 ± 9.5 kg) and
121 youth professional (n = 23, age 18.3 ± 1.4 years, stature $179.2 \pm$
122 5.2 cm, body mass 86.2 ± 8.2 kg) players. Senior players had
123 completed at least one season training for, and competing in,
124 the Super League competition. Youth consisted of players who
125 were currently playing at Academy level or who had in the last
126 three months graduated to the first team. Data were collected in
127 the pre-season period with all players having at least two years
128 of systematic resistance training experience that involved lower
129 body maximum lifts. After habituation, each player completed
130 two isometric mid-thigh pull strength assessments on the
131 dynamometer and force platform in a randomised cross-over

132 design with a five-minute passive recovery between each effort.

133 All testing was carried out indoors on a hard, non-slip surface.

134

135 **Methods**

136 All participants completed a standardised warm up before the

137 mid-thigh pull that comprised of five minutes of dynamic

138 stretching along with two isometric efforts at 50% and 75% of

139 maximal effort.²² For both measurements, participants were

140 positioned similar to the second pull phase of the power clean,

141 with the bar located mid-way between the knees and hips,

142 knees flexed at ~140 degrees and shoulders over the bar.²³

143 Based on previous literature, participants were given a 3 second

144 countdown and instructed to pull as fast and hard as possible

145 for 5 seconds, placing emphasis on the rate of force

146 development, which is reported to aid maximal force

147 development.²⁴

148

149 *Dynamometer:* A custom-built isometric mid-thigh pull

150 dynamometer was designed and built to include a T.K.K.5402

151 dynamometer (Takei Scientific Instruments Co. Ltd, Niigata,

152 Japan) sampling at 122 Hz. Briefly, this consisted of a wooden

153 platform (80 x 50 cm) with rubber foot grips (31 x 20 cm),

154 placed shoulder width apart and chain (51 cm) from the

155 dynamometer to a latissimus pulldown bar (120 cm; Decathlon,

156 United Kingdom; see Figure 1b). The chain length was adjusted

157 to allow participants to achieve the position described above.
158 Before pulling, participants applied minimal pre-tension to the
159 chain to avoid any jerking action on initiating the lift. The
160 highest peak force (kgf) from the two attempts was then
161 multiplied by 9.81 (to represent the value in Newtons) and
162 subsequently used for analysis.

163

164 *Force Platform:* The isometric mid-thigh pull was performed
165 using a commercially available portable force platform (HUR
166 Labs, FP4, Tampere, Finland) with a sampling rate of 1200 Hz.
167 The force plate was seated in a customized fixed rack, which
168 enabled adjustments in bar height by 3 cm increments (Figure
169 1a). Where necessary, smaller adjustments in bar height were
170 made by placing 1 cm wooden boards on the force platform. In
171 such instances the force platform was then re-calibrated before
172 any measurement was performed. Each participant's best trial
173 from two attempts, as determined by the highest peak force
174 (PF) in Newtons (N), was used for analysis.²²

175

176 *** INSERT FIGURE 1 HERE***

177

178 Statistical Analyses

179 Data were initially checked for normality via the Shapiro-Wilk
180 statistic ($P > 0.05$) before using Pearson product-moment
181 correlations (r -value) to check for heteroscedastic errors and

182 assess the relationship between methods. Paired sample *t*-tests
183 were used to calculate differences (biases) between means of
184 measurement methods (criterion validity) and followed up
185 using 95% limits of agreement (95% LoA)²⁵ to quantify the
186 within-subject variation (random error). **Effect sizes (ES) and**
187 **90% confidence intervals [lower bound – upper bound]** were
188 also used to quantify the magnitude of the effect between
189 methods and groups using the following criteria: 0.2, 0.6 and
190 1.2 for small, moderate and large effects, respectively.²⁶ Linear
191 regression analysis was used to determine a prediction equation
192 for peak force along with the typical regression statistics (R^2
193 and SEE). Using an 80/20% split of the sample,²⁷ we cross-
194 validated the prediction equation and sought to establish that
195 there was minimal shrinkage in the R^2 value relative to the
196 model. This being the case, the full predictive model can be
197 presented. To determine the sensitivity of the IMTP against an
198 analytical goal, an independent *t*-test was used to assess
199 between-group differences in peak force (construct validity)
200 and normalised peak force using ratio (PF/BM) and allometric
201 (PF/BM^{*b*}) scaling, where PF represents peak force, BM is body
202 mass in kilograms and *b* is a power exponent.²⁸ Within-session
203 reliability was determined using coefficient of variation (CV)
204 and intraclass correlation coefficient (ICC). Data are reported
205 as mean and standard deviation(s) and analysed using SPSS for

206 Windows (Version 23.0, 2015) and a predesigned
207 spreadsheet.²⁹

208

209 **RESULTS**

210 Within-session reliability revealed CVs of 8.3% and 9.2%, and
211 ICCs of 0.913 and 0.912 for the dynamometer and force
212 platform, respectively.

213 Isometric peak force was significantly underestimated
214 ($P < 0.001$, $ES = -0.53 [-0.85 - -0.21]$) using the dynamometer
215 compared to the force platform, with 95% of the differences
216 ranging between -556.1 and 130.1 N. However, there was a
217 strong, significant relationship for peak force between the
218 dynamometer and force platform ($r = 0.92$, $P < 0.001$) (Table 1,
219 Figure 2).

220 ***INSERT TABLE 1 HERE***

221 *** INSERT FIGURE 2 HERE***

222 The regression analysis based upon the cross-validation sample
223 (Table 2) revealed that peak force derived from the
224 dynamometer explained 80% (adjusted $R^2 = 0.80$) of the
225 variance in the dependent variable, yielding the equation:
226 predicted peak force = (1.046 * dynamometer peak force) +
227 117.594. Cross-validation analysis revealed no significant
228 difference ($P = 0.724$, $ES = 0.05 [-0.26 - 0.36]$) between the
229 predicted and observed peak force from the force platform, and

230 an adjusted R^2 (79.6%) that represented a shrinkage of 0.4%
231 relative to the cross-validation model (80%, Table 3).
232 Therefore, the predictive power of the model was not
233 substantially changed when applied to a different sample.

234 ***INSERT TABLE 2 HERE***

235 ***INSERT TABLE 3 HERE***

236 The overall regression model (Table 4) revealed that peak force
237 measured on the dynamometer explained 84.2% of the variance
238 in the dependent variable (SEE = 173 N). The equation was:
239 peak force (N) = (1.089*dynamometer peak force) + 31.95.

240 ***INSERT TABLE 4 HERE***

241 Peak force was greater for the senior compared to youth
242 professionals using both the force plate (2532.7 ± 242.5 cf.
243 1855.3 ± 325.1 N, respectively; $t = 8.93$, $P < 0.001$, ES = 2.36
244 [1.96 - 2.76] and the modified dynamometer (2261.2 ± 222.0
245 cf. 1725.1 ± 298.0 N, respectively; $t = 7.66$, $P < 0.001$, ES =
246 2.04 [1.66 - 2.42]. Due to the large difference in body mass (ES
247 1.32 [0.98 - 1.66], peak force data were scaled to account
248 for this difference. Senior players generated significantly
249 greater force compared to youth with both ratio (26.07 ± 3.08
250 cf. 21.58 ± 3.71 N/kg, $t = 4.936$, $P < 0.001$, ES = 1.32 [0.98 -
251 1.66] and allometric scaling (23.44 ± 2.63 cf. 19.46 ± 3.35
252 N/kg^{1.02}, $t = 4.828$, $P < 0.001$, ES = 1.32 [0.98 - 1.66] applied.
253 Similarly, peak force was greater for the senior players
254 compared to youth on the dynamometer for ratio (23.25 ± 2.63

255 cf. 20.04 ± 3.25 N/kg, $t = 4.069$, $P < 0.001$, **ES = 1.09 [0.76 –**
256 **1.42]** and allometrically (21.88 ± 2.50 cf. 18.89 ± 3.07 N/kg^{1.01},
257 $t = 4.01$, $P < 0.001$, **ES = 1.07 [0.74 – 1.40]** scaled values.

258

259 **DISCUSSION**

260 This study sought to compare the peak force obtained during
261 the isometric mid-thigh pull performed on a customised
262 dynamometer and a force platform in a group of professional
263 rugby league players (i.e. criterion validity). Additionally,
264 comparisons between two playing standards (senior and junior
265 professionals) were made to determine the construct validity of
266 the isometric mid-thigh pull for use with rugby league players.
267 The principle finding of this study was that the isometric mid-
268 thigh pull performed on a custom-built dynamometer
269 underestimated peak force from a force platform as evidenced
270 by the significant difference and small effect size. However,
271 there was a strong relative agreement between both
272 measurement methods. As such, a regression equation was
273 developed that could correct this ‘average’ underestimation.
274 Finally, the modified dynamometer was able to differentiate
275 peak force between playing standards suggesting it possesses
276 appropriate construct validity in the measurement of muscle
277 function characteristics of senior and youth professional rugby
278 league players.

279

280 There was poor agreement between peak force measurements
281 during an isometric mid-thigh pull on the modified
282 dynamometer and the force platform. The mean difference in
283 peak force achieved between the two methods indicated that the
284 modified dynamometer was, on average, -213.5 N lower
285 compared to the force platform. This is consistent with the
286 systematic bias (-229.1 N) between similar apparatus reported
287 by James et al.¹⁹ When the 95% LoA were considered, a player
288 with a peak force of 2000 N measured during an isometric mid-
289 thigh pull using a force platform could, in the worst-case
290 scenario, achieve a value between 1444 and 2129 N using the
291 modified dynamometer. To provide context, this potential error
292 (~685 N) is larger than improvements in peak force derived
293 from an isometric mid-thigh pull after a nine-week maximal
294 strength or power training programme (431-608 N³⁰). This
295 means it would be difficult to detect meaningful changes in
296 mid-thigh pull performance when using the modified
297 dynamometer and, therefore, when small-to-moderate changes
298 are expected, practitioners might consider using a regression
299 equation or force platform.

300

301 The underestimation in peak force observed in the present
302 study might be explained by the more open-chain design of the
303 modified dynamometer compared to that of the force platform.
304 During the force platform trials, peak ground reaction force was

305 measured through the feet in contact with the force platform
306 and force applied vertically in a single plane. In contrast, the
307 modified dynamometer required participants to ‘pull’ vertically
308 on a bar anchored centrally, which due to its design had a large
309 degree of anterior-posterior and medio-lateral movement. It is
310 possible that this movement allowed participants lean back into
311 the pull, resulting in force being applied outside of the vertical
312 axis.¹⁹ It is also possible that the superior sampling frequency
313 of the force platform compared to the modified dynamometer
314 (1200 cf. 122 Hz, respectively) influenced the precision of the
315 peak force measurements.¹⁵

316

317 To correct for the underestimation of peak force using the
318 modified dynamometer, we have developed a regression
319 equation that reduces the difference from the force platform to
320 within mean values of ~4.6 N. Therefore, when a comparison
321 between methods is necessary, this equation can be applied to
322 data collected from the modified dynamometer when using a
323 similar sample to that used in this study. However, practitioners
324 should note that there might be some error in this estimate of
325 ~173 N in individual cases, owing to some of the variance in
326 force platform performance not being explained by
327 performance using the modified dynamometer.

328

329 In this study, players of a higher standard, who are deemed to

330 be stronger from more extensive resistance training exposure,⁶
331 performed better on the isometric mid-thigh pull using both
332 methods. More specifically, peak force measured on the
333 modified dynamometer for senior professional rugby league
334 players was 31% higher than that of youth professionals,
335 similar to the difference of ~36% according to the force
336 platform. Furthermore, our results indicated that this large
337 difference in peak force was irrespective of differences in body
338 mass. After applying both ratio and allometric scaling, the
339 results indicated that senior players outperformed youth players
340 regardless of body mass, suggesting training history is an
341 important factor when assessing peak force. As such, the
342 modified dynamometer mid-thigh pull is sufficiently sensitive
343 to be used to classify the strength capabilities of professional
344 rugby league players of different standards and training
345 histories.

346 **Practical Applications**

347 A criterion measure of peak force during an isometric mid-
348 thigh pull cannot be measured from a modified dynamometer.
349 This notwithstanding, the dynamometer is capable of
350 distinguishing differences in muscle function between more
351 and less experienced rugby league players. For those
352 practitioners who require more accurate measures of peak force
353 from isometric-mid thigh pull, they might choose to use the
354 regression equation provided. It is important to note that the

355 prediction equation for peak force is specific to rugby league
356 players and caution should be taken when applying this to other
357 populations. Strength and conditioning coaches who wish to
358 measure maximal strength when profiling rugby players might
359 adopt this safe, cost-effective and valid apparatus.

360

361 **Conclusion**

362 The current study investigated the criterion and construct
363 validity of a modified dynamometer for the assessment of
364 isometric mid-thigh pull strength. Where practitioners are
365 required to profile players (i.e. talent identification), the use of
366 a modified dynamometer can be used to differentiate between
367 academy and first-grade professional rugby league players.
368 Additionally, the regression equation provided can allow
369 practitioners to detect training-induced changes in whole-body
370 strength, albeit they should be cognisant that small changes are
371 likely to go undetected, and in such cases, a force platform
372 should be used.

373 **References**

374

- 375 1. Comfort P, Haigh A, Matthews MJ. Are changes in
376 maximal squat strength during preseason training
377 reflected in changes in sprint performance in rugby
378 league players? *J Strength Cond Res.* 2012;26(3):772-
379 776.
- 380 2. Speranza MJ, Gabbett TJ, Johnston RD, Sheppard JM.
381 Muscular strength and power correlates of tackling
382 ability in semiprofessional rugby league players. *J*
383 *Strength Cond Res.* 2015;29(8):2071-2078.
- 384 3. Suchomel TJ, Nimphius S, Stone MH. The importance
385 of muscular strength in athletic performance. *Sports*
386 *Med.* 2016;46(10):1419-1449.
- 387 4. Gabbett TJ, Ullah S, Finch CF. Identifying risk factors
388 for contact injury in professional rugby league players--
389 application of a frailty model for recurrent injury. *J Sci*
390 *Med Sport.* 2012;15(6):496-504.
- 391 5. Baker DG Newton RU. Comparison of lower body
392 strength, power, acceleration, speed, agility, and sprint
393 momentum to describe and compare playing rank
394 among professional rugby league players. *J Strength*
395 *Cond Res.* 2008;22(1):153-158.
- 396 6. Till K, Jones B, Geeson-Brown T. Do physical qualities
397 influence the attainment of professional status within
398 elite 16-19 year old rugby league players? *J Sci Med*
399 *Sport.* 2016;19(7):585-589.
- 400 7. Darrall-Jones JD, Jones B, Till K. Anthropometric and
401 physical profiles of english academy rugby union
402 players. *J Strength Cond Res.* 2015;29(8):2086-2096.
- 403 8. Baker DG, Newton RU. Comparison of lower body
404 strength, power, acceleration, speed, agility, and sprint
405 momentum to describe and compare playing rank
406 among professional rugby league players. *J Strength*
407 *Cond Res.* 2008;22(1):153-158.
- 408 9. Meylan CM, Cronin JB, Oliver JL, Hughes MM,
409 Jidovtseff B, Pinder S. The reliability of isoinertial
410 force-velocity-power profiling and maximal strength
411 assessment in youth. *Sports Biomech.* 2015;14(1):68-
412 80.
- 413 10. Abernethy P, Wilson G, Logan P. Strength and power
414 assessment. Issues, controversies and challenges. *Sports*
415 *Med.* 1995;19(6):401-417.
- 416 11. Myer GD, Quatman CE, Khoury J, Wall EJ, Hewett TE.
417 Youth versus adult "weightlifting" injuries presenting to
418 united states emergency rooms: Accidental versus
419 nonaccidental injury mechanisms. *J Strength Cond Res.*
420 2009;23(7):2054-2060.

- 421 12. McGuigan MR, Winchester JB. The relationship
422 between isometric and dynamic strength in college
423 football players. *J Sports Sci Med*. 2008;7(1):101-105.
- 424 13. McGuigan MR, Newton MJ, Winchester JB, Nelson
425 AG. Relationship between isometric and dynamic
426 strength in recreationally trained men. *J Strength Cond
427 Res*. 2010;24(9):2570-2573.
- 428 14. Crewther BT, Kilduff LP, Cook CJ, Cunningham DJ,
429 Bunce P, Bracken RM, Gaviglio CM. Relationships
430 between salivary free testosterone and the expression of
431 force and power in elite athletes. *J Sports Med Phys
432 Fitness*. 2012;52(2):221-227.
- 433 15. Dos'Santos T, Jones PA, Kelly J, McMahan JJ, Comfort
434 P, Thomas C. Effect of sampling frequency on isometric
435 midhigh-pull kinetics. *Int J Sports Physiol and
436 Perform*. 2016;11(2):255-260.
- 437 16. West DJ, Owen NJ, Jones MR, Bracken RM, Cook CJ,
438 Cunningham DJ, Shearer DA, Finn CV, Newton RU,
439 Crewther BT, Kilduff LP. Relationships between force-
440 time characteristics of the isometric midhigh pull and
441 dynamic performance in professional rugby league
442 players. *J Strength Cond Res*. 2011;25(11):3070-3075.
- 443 17. McMaster DT, Gill N, Cronin J, McGuigan M. A brief
444 review of strength and ballistic assessment
445 methodologies in sport. *Sports Med*. 2014;44(5):603-
446 623.
- 447 18. De Witt JK, English KL, Crowell JB, Kalogera KL,
448 Guilliams ME, Nieschwitz BE, Hanson AM, Ploutz-
449 Snyder LL. Isometric mid-thigh pull reliability and
450 relationship to deadlift 1RM. *J Strength Cond Res*.
451 2016.
- 452 19. James LP, Roberst LA, Haff GG, Kelly VG, Beckman
453 EM. The validity and reliability of a portable isometric
454 mid-thigh clean pull. *J Strength Cond Res*. 2015; 31(5):
455 1378-1386.
- 456 20. Haugen T, Buchheit M. Sprint running performance
457 monitoring: Methodological and practical
458 considerations. *Sports Med*. 2016;46(5):641-656.
- 459 21. Baumgarter TA Jackson AS. *Measurment for
460 evaluation in physical education and exercise science*.
461 Dubuque, US: Wm C Brown Company Publishers;
462 1987.
- 463 22. Dos'Santos T, Thomas C, Comfort P, McMahan JJ,
464 Jones PA, Oakley NP, Young AL. Between-session
465 reliability of isometric mid-thigh pull kinetics and
466 maximal power clean performance in male youth soccer
467 players. *J Strength Cond Res*. 2017.
- 468 23. Thomas C, Jones PA, Rothwell J, Chiang CY, Comfort
469 P. An investigation into the relationship between
470 maximum isometric strength and vertical jump

- 471 performance. *J Strength Cond Res.* 2015;29(8):2176-
472 2185.
- 473 24. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey
474 M, Lamont H, Hornsby G, Haff G, Stone M.
475 Relationships of isometric mid-thigh pull variables to
476 weightlifting performance. *J Sports Med Phys Fitness.*
477 2013;53(5):573-581.
- 478 25. Bland MJ, Altman DG. Statistic methods for measuring
479 agreement of clinical measurement. *The Lancet*
480 1986;327(8476):307-310.
- 481 26. Hopkins WG, Marshall SW, Batterham AM, Hanin J.
482 Progressive statistics for studies in sports medicine and
483 exercise science. *Med Sci Sport Exerc.* 2009;41(1):3-12.
- 484 27. Field A. *Discovering statistics using ibm spss statistics:
485 And sex and drugs and rock 'n' roll.* 4th ed. London,
486 UK: Sage Publications; 2013.
- 487 28. Crewther BT, Gill N, Weatherby RP, Lowe T. A
488 comparison of ratio and allometric scaling methods for
489 normalizing power and strength in elite rugby union
490 players. *J Sport Sci.* 2009;27(14):1575-1580.
- 491 29. Hopkins WG. Spreadsheets for analysis of controlled
492 trials with adjustment for a subject characteristic.
493 *Sportscience.* 2006;10:46-50.
- 494 30. Harris GR, Stone MH, O'Bryant HS, Proulx CM,
495 Johnson RL. Short-term performance effects on high
496 power, high force, or combined weight-training
497 methods. *J Strength Cond Res.* 2000;14(1):14-20.
498

1 Table 1. Concurrent validity of the dynamometer against the force platform for measuring peak force.

	Dynamometer peak force (N)	Force platform peak force (N)	95% LoA	CV%	Pearson's <i>r</i> value
Peak force (N)	2041.0 ± 367.5*	2254.5 ± 435.5	-213.5 ± 342.6	19.3	0.92

2 *Note: * = significantly lower (P<0.05) than peak force derived from force platform. LoA = limits of agreement. CV% = coefficient of variation.*

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1 Table 2. Overall parameters of the cross-validation prediction model using the dynamometer to estimate peak force (N) derived from the force
 2 platform ($n = 45$).

Predictor Variable	Unstandardized coefficient		Standardized coefficient	
	B	Standard Error	Beta	<i>t</i> -value
Constant	117.594	161.600		0.0728
Dynamometer peak force (N)	1.046	0.079	0.897	13.302**

3 *Note: Adjusted $R^2 = 0.800$; ** = $P < 0.001$.*

1 Table 3. Cross-validation of predicted and observed force platform peak force ($n = 11$)

	Predicted Peak Force	Force platform peak force (N)	95% LoA	CV%	Adjusted R^2
Peak force (N)	2344.3 ± 319.6	2362.8 ± 388.0	-4.60 ± 352.56	14.73	0.796

2 *Note: predicted force platform peak force = (1.046 * Dynamometer peak force) + 117.594.*

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1 Table 4. Overall parameters for the prediction model using peak force derived from the dynamometer (N) to estimate force platform peak force
 2 (N) (n = 56).

Predictor Variable	Unstandardized coefficient		Standardized coefficient	
	B	Standard Error	Beta	t-value
Constant	31.950	131.816		0.242
Dynamometer Peak Force (N)	1.089	0.064	0.919	17.127**

3 *Note: Adjusted R² = 0.842; ** = P<0.001.*

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1 Figure 1. Isometric mid-thigh pull performed on the force platform (A) and modified
2 dynamometer (B).

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4 Figure 2. Relationship between the dynamometer and force platform for measuring peak
5 force.

