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# Wales Anaerobic Test: Reliability and Fitness Profiles of International Rugby Union Players

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1 **Title:** The Wales Anaerobic Test (WAT): Reliability and fitness profiles of international Rugby  
2 Union players

3

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17

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4 **ABSTRACT**

5 **In order to** provide strength and conditioning coaches a practical and evidence-based test for  
6 repeated-sprint ability in rugby union players, **this study assessed** the relative and absolute test-  
7 retest reliability of the Wales Anaerobic Test (WAT) and its position-specific association with  
8 other fitness performance indices. Thirty-four players (forwards: n = 19; backs: n = 15) of the  
9 Welsh rugby union male senior national team performed the WAT (10 × 50-m distance, 25-30  
10 s of passive recovery) twice within 4 days. Time for each repetition was recorded, with the best  
11 (WAT<sub>Best</sub>) and total time (WAT<sub>TT</sub>) retained for analysis. Relative (intra-class correlation  
12 coefficient, ICC) and absolute (standard error of measurement, SEM) reliability of the WAT  
13 indices were quantified. Further, association (Pearson’s product–moment correlations and  
14 stepwise backward elimination procedure) with other fitness performance indices [10-m and  
15 40-m sprinting times, 30-15 intermittent fitness test (30-15<sub>IFT</sub>) and Yo-Yo intermittent recovery  
16 test level 2 (YYIR2)] was investigated. Pooled values revealed “*moderate*” to “*high*” ICCs  
17 for WAT<sub>Best</sub> (ICC = 0.89, P = 0.626) and WAT<sub>TT</sub> (ICC = 0.95, P = 0.342). Good test sensitivity  
18 was reported for forwards and backs’ WAT<sub>TT</sub> (P > 0.101). Both WAT<sub>Best</sub> and WAT<sub>TT</sub> correlated  
19 with 10-m and 40-m sprinting times ( $r > 0.69$ , P < 0.001) as well as with 30-15<sub>IFT</sub> ( $r < -0.77$ , P  
20 < 0.001) and YYIR2 ( $r < -0.68$ , P < 0.001) for pooled values. The WAT proved to be a reliable  
21 and sensitive test to assess the rugby union specific repeated-sprint ability related fitness of  
22 international players.

23  
24 **Keywords:** High-intensity running; Repeated-sprint ability; Anaerobic capacity; aerobic  
25 power; Team sports.

26

## 27 INTRODUCTION

28 Rugby union is an intermittent team sport that requires many different physical qualities during  
29 a match (13, 31). This sport requires a sufficient aerobic capacity which can be seen with  
30 players running up to 6000 m for backs and 5200 m for forwards (31), while exhibiting high  
31 levels of repeated high-intensity activities such as accelerations, decelerations, sprinting (3, 12,  
32 14, 31), and also combative movements such as tackling, rucking and mauling (13, 32). Further,  
33 repeated-sprint ability (RSA) has been described as a very important determinant of the match  
34 result (12, 13, 35) and may contribute to ensuring that players are able to repeat specific  
35 activities such as rucks, mauls and getting to breakdowns quicker than their opponents.  
36 Therefore, evaluating and monitoring RSA-related qualities of rugby union players would be  
37 relevant for coaches and background staffs, not only to assist the development of strength and  
38 conditioning programs but also to differentiate playing positions and standards (3).

39  
40 By definition, RSA has been described as short “all-out” sprinting efforts of <10 s with brief  
41 recovery times <60 s (17). Due to its “all-out” nature, developing RSA is complex. Both  
42 neuromuscular (neural drive or motor unit recruitment) and metabolic (aerobic capacity,  
43 phosphocreatine resynthesis, hydrogen buffering) components are thought to contribute to  
44 RSA performance (17, 18, 36). Further, RSA-induced fatigue development has been shown to  
45 be task dependent, with exercise mode, specificity, effort duration, recovery time and type  
46 (passive or active) impacting the physiological response (4, 17). Therefore, evaluating RSA for  
47 rugby union would require the incorporation of rugby union-specific movements.

48  
49 Several field tests [*e.g.*, 30-15 intermittent fitness test (30-15<sub>IFT</sub>) (25), Yo-Yo intermittent  
50 recovery test level 1 (YYIR1) or 5-m multiple shuttle test (5-m MST) (33)] have been used  
51 extensively to evaluate the fitness standards of rugby union players. While these field tests are

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52 reliable, they may not evaluate or capture the specific high-intensity actions of the sport. Only  
53 few studies have looked at specific tests in rugby union. Reportedly, Austin et al. (1) considered  
54 a 3 repeated high-intensity exercise tests for rugby league and rugby union players, and Smart  
55 et al. (35) used the rugby-specific repeated-speed test (RS2). To the best of the authors'  
56 knowledge, apart from the RS2 implemented exclusively in New Zealand, the other specific  
57 tests are not widely used in professional rugby union. In a recent review of strength and  
58 conditioning practices in both the northern and southern hemisphere in rugby union (26), the  
59 Wales Anaerobic Test (WAT) was referred as a rugby-specific fitness test and has been used  
60 both as an assessment and training tool for the development of repeated high-intensity effort  
61 ability by the Welsh Rugby Union for the senior international team, national age grade and  
62 regional club players as well as with the British and Irish Lions team in 2013. According to  
63 Nicholas et al. (19), the WAT (*i.e.*, 10 × 10-15 s efforts over a 50-m distance, interspersed by  
64 25-30 s of passive recovery) would be representative of rugby union match time motion  
65 analysis (*i.e.*, 5-15 s of intensive efforts interspersed by <40 s of recovery). Because RSA test  
66 alone may underestimate the repeated high-intensity demands of rugby union (19), using tests  
67 that replicates/mimics rugby union locomotor demands appears relevant to provide useful  
68 information for strength and conditioning coaches and background staffs. Despite the interest  
69 of this novel test and its growing popularity in the rugby community, no study has examined  
70 the construct validity of the WAT and its associations with other fitness qualities such as  
71 maximal sprinting velocity or aerobic capacity.

72  
73 Therefore, the aims of this study were twofold: (i) to assess the relative and absolute test-retest  
74 reliability of the WAT in elite rugby union players, and (9) to investigate its position-specific  
75 association and criterion validity with other fitness performance indices. We hypothesized that

1 76 the WAT would be a reliable test and would be associated with field-based tests. We also  
2 77 expected a position-specific dependency among reliability and correlations/predictions.  
3

4 78

## 7 79 **METHODS**

### 10 80 *Experimental approach to the problem*

11 81 This study was completed in two phases. First, the test-retest reliability of the WAT was  
12 82 determined by having players perform the WAT twice within 4 days, at the same time of day.  
13 83 Relative and absolute reliability was examined using intra-class correlation coefficient (ICC)  
14 84 and standard error of measurement, coefficients of variation (CV) and 95% limit of agreement  
15 85 (LOA), respectively. Second, their position-specific association with other fitness performance  
16 86 indices was investigated using Pearson's product-moment correlations and multiple linear  
17 87 regression models.  
18

19 88

### 31 89 *Subjects*

32 90 Thirty-four international-level players (forwards:  $n = 19$ ,  $28.8 \pm 3.5$  yr,  $190.6 \pm 6.7$  cm,  $115.2$   
33 91  $\pm 5.6$  kg; backs:  $n = 15$ ,  $26.3 \pm 2.6$  yr,  $183.5 \pm 7.4$  cm,  $90.5 \pm 8.8$  kg) belonging to the Welsh  
34 92 rugby union senior male national team participated in the study as part of their normal national  
35 93 squad training schedule in preparation for the Six Nations rugby union tournament. All  
36 94 players were informed of all procedures and gave their written and informed consent for data  
37 95 collection. The study was approved by the local ethics committee and carried out in  
38 96 accordance with procedural requirements (19) and the declaration of Helsinki.  
39

40 97

### 53 98 *Procedures*

54 99 The present study was performed in 4 sessions. Data were first gathered on the absolute and  
55 100 relative reliability of the WAT where each player performed the WAT twice at the same time  
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101 of day (14:00-16.00 h) to minimize the effects of diurnal variation, with a maximum of 4 days  
102 between the tests. On a separate occasion (within 2 weeks), straight-line 40-m sprint was  
103 performed and followed after 1 h of rest by the 30-15<sub>IFT</sub> or YYIR test level 2 (YYIR2) in a  
104 randomized and counter-balanced order. The remaining test (30-15IFT or YYIR2) was  
105 conducted in the next days with at least 48 h apart. All players were familiarized and habituated  
106 to the test protocol, arising as a condition of their duties. All tests were performed at the Welsh  
107 rugby union national center of excellence on a 4-G artificial grass surface in-doors (ambient  
108 temperature 22-25°C, relative humidity 50-60%). Players were instructed to wear the same  
109 footwear for all sessions and were allowed to complete a 15-min standardized warm-up of low-  
110 intensity running drills interspersed with eight dynamic stretch routines and strides followed  
111 by two submaximal sprints efforts, with 3 min passive rest before beginning assessment. Being  
112 in supervised training camp, sleep, diet (caffeine-free beverage >3 h before testing) and training  
113 load (avoiding strenuous session in the preceding 24 h) were carefully controlled.

114

#### 115 *Wales Anaerobic Test (WAT)*

116 The WAT protocol consisted of 1 set of 10 repetitions over 50 m, completed maximally on a  
117 rolling clock of every 40 s (exercise:recovery ratio of 1:3-5 with efforts ranging 10-15 s and  
118 recovery periods of 25-30 s), thereby mimicking rugby union match activity (29). Players  
119 completed the WAT in lanes, with each individual lane marked by 4 cones set out as follows  
120 (figure 1): cone 1 positioned 2 m behind the starting line. On the master whistle, players  
121 completed an “up-down” between cones 1 and 2 with their chest on the ground while being  
122 required to touch the *gluteal* muscles with each hand before getting up. The players then  
123 completed a figure of eight around cones 2 and 3, and once they came around cone 2, they  
124 sprinted forth (up to cone 4) and back (cone 2) at which the time was recorded for the completed  
125 repetition.



126 For each test, the best time ( $WAT_{Best}$ , always the first repetition) was determined and  
127 subsequent repetition time added up to give a total time score ( $WAT_{TT}$ ). Video recordings  
128 obtained by means of a Sony HD camera (HDR-HC9E) were analyzed using Dartfish 5.0  
129 (Dartfish, Fribourg, Switzerland) to calculate sprint times (from start from foot lift-off to finish  
130 line).

\*\*\* Figure 1 about here \*\*\*

### *Straight-sprinting test*

135 Players were asked to run a maximal, straight-line 40-m sprint. Dual-beam electronic timing  
136 gates (Swift, Wireless Speedlight Timing System, Queensland, Australia) were used to record  
137 split time at 10-m and overall 40-m sprint time to the nearest 0.01 s. The start commenced from  
138 a standing static position with their preferred front foot 0.5 m behind the first timing gate and  
139 were instructed to sprint as fast as possible over the 40-m distance. The height of the photocells  
140 was adjusted according to the height of the participant's hip (sprinting order were defined a-  
141 priori to avoid **photocells' over-manipulation**). Two trials with 3 min of passive recovery were  
142 completed, and the best performance was kept for analysis.

### *30-15<sub>IFT</sub>*

145 The test consisted of 30-s shuttle runs over 40 m, interspersed with 15 s of passive recovery  
146 and was performed as previously described (8). The starting speed was set at  $8 \text{ km}\cdot\text{h}^{-1}$  for the  
147 first 30-s run and was increased by  $0.5 \text{ km}\cdot\text{h}^{-1}$  every 45-s stage thereafter. The speed of the test  
148 was controlled by an audible signal (via a portable audio player with loudspeaker adjusted so  
149 all players could clearly hear the instructions) that beeped at appropriate intervals, whereby  
150 players were to be within a 3-m tolerance zone at either end or the middle of the 40-m shuttle.

151 Players were instructed to complete as many stages as possible, with the test ended when they  
152 could no longer maintain the imposed running speed or when they failed to reach the tolerance  
153 zone on 3 consecutive occasions. The last completed stage was noted as  $V_{IFT}$  (8).

154

#### 155 *Yo-Yo Intermittent Recovery Test Level 2*

156 As previously described (27), the YYIR2 is an incremental running test to exhaustion which  
157 consists of 2 repeated 20-m runs back and forth between the starting, turning and finishing  
158 lines, at progressively increased speeds (starting at 13 km.h<sup>-1</sup>), interspersed by 10-s active  
159 recovery (2 × 3.5 m jogging) periods and controlled by audio beeps through a portable audio  
160 player with loudspeaker. When a player twice failed to reach the finishing line before the next  
161 audio cue, the distance covered was recorded as the final test result and converted to the  
162 corresponding stage speed level. The YYIR2 has been reported as reproducible (2).

163

#### 164 ***Statistical analysis***

165 Data analyses were performed using Sigmaplot 11.0 software (Systat Software, Inc., San Jose,  
166 CA, USA) and a predesigned spreadsheet for reliability analysis (22). Normality of the data  
167 was confirmed using the Kolmogorov-Smirnov test. The relative and absolute reliability of the  
168 WAT indices were quantified. To determine relative reliability, the ICC was calculated. ICCs  
169 >0.90 were considered as “*high*”, 0.80 to 0.90 as “*moderate*”, and <0.80 as “*low*” (37). To  
170 test the absolute reliability, the standard error of measurement (34), the CVs (21) and 95%  
171 LOA were calculated. The level of agreement between repeated trials (test-retest) was  
172 quantified using the 95% LOA method originally described by Bland and Altman (5) . The  
173 differences between trials were drawn in relation to the mean values and 95% of the differences  
174 were expected to lie between the two LOA that were the mean difference ± 2 SD of the  
175 differences, expressed as bias ×÷ random error. In complement, the smallest worthwhile change

176 (SWC) was determined by rearrangement of Cohen' *d* effect size calculation, where the SWC  
177 effect (0.2) was multiplied by the between-subject SD. By comparing SWC with SEM, test  
178 sensitivity was determined, using the thresholds proposed by Lexell and Downham (28), When  
179 SEM was  $\leq$  SWC, the test's capacity to detect change was considered "good", when SEM was  
180 equal to SWC it was considered "satisfactory", and when SEM was  $\geq$  SWC the test was rated  
181 as "marginal". To investigate systematic bias, a paired sample *t*-test was conducted to test the  
182 hypothesis that the sample means of test and retest values did not differ. The effect size of the  
183 difference (*d*) for WAT was determined as: (mean value of trial 2 – mean value of trial 1) /  
184 pooled SD. The modified scale by Hopkins ([www.sportsci.org/resource/stats](http://www.sportsci.org/resource/stats)) was used for the  
185 interpretation of *d*:  $< 0.2$ , "trivial";  $0.2 - < 0.6$ , "small";  $0.6-1.2$ ; "moderate; and  $> 1.2$ ,  
186 "large".

187  
188 Pearson's product-moment correlations were used to examine the relationships among the  
189 various fitness tests. The magnitude of effects was interpreted according to Hopkins et al. (23)  
190 as follows:  $\leq 0.1$ , "trivial";  $> 0.1-0.3$ , "small";  $> 0.3-0.5$ , "moderate";  $> 0.5-0.7$ , "large";  
191  $> 0.7-0.9$ , "very large"; and  $> 0.9-1.0$ , "almost perfect". Furthermore, multiple linear  
192 regression models (stepwise backward elimination procedure) with WAT<sub>Best</sub> or WAT<sub>TT</sub> as the  
193 dependent variables were used to determine the most relevant position-dependent fitness  
194 factors contributing to WAT performance. The  $r^2$  values derived from the multiple linear  
195 regression models were converted to *r* values for relationship's magnitude interpretation.

## 197 RESULTS

### 198 *Reliability*

199 Summary results for WAT test and retest are shown in Table 1. Except for backs, residual data  
200 for WAT<sub>Best</sub> test and retest were normally distributed. The relative and absolute reliabilities for

201 forwards and backs were “*low*” with larger SEMs than their respective SWCs, indicating that  
202 both were of “*marginal*” value. However, pooled values satisfied the ICC criterion with  
203 “*moderate*” relative reliability, confirmed by larger SWC vs. SEM. The bias  $\times$  random error  
204 between the two trials for WAT<sub>Best</sub> were  $0.07 \times \pm 0.10$  s,  $-0.02 \times \pm 0.14$  s and  $0.19 \times \pm 0.14$  s for  
205 pooled, forwards and backs, respectively (Table 1 and Figure 2A, B and C).

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207  
208 \*\*\* Table 1 about here \*\*\*

209  
210 Residual data for WAT<sub>TT</sub> test and retest were normally distributed ( $P = 0.101-0.387$ ), with no  
211 significant test-retest bias for pooled, forwards and backs values. The relative reliability was  
212 considered “*high*” for pooled and forwards and “*moderate*” for backs. However, all SEMs  
213 were lower than their respective SWCs, indicating that all were of “*good*” value for test  
214 sensitivity. The bias  $\times$  random error between the two trials for WAT<sub>TT</sub> were  $-1.34 \times \pm 0.73$  s, -  
215  $1.67 \times \pm 1.17$  s and  $-0.92 \times \pm 0.84$  s for pooled, forwards and backs, respectively (Table 1 and  
216 Figure 2D, E and F).

217  
218 \*\*\* Figure 2 about here \*\*\*

### 219 220 221 ***Correlations and multiple regression analysis***

222 Figures 3, 4, 5 and 6 present the relationships between WAT with the different standard fitness  
223 performance indices. WAT<sub>Best</sub> was significantly correlated with 10 m and 40 m sprinting times  
224 for forwards ( $r = 0.46$ , “*moderate*”,  $P = 0.046$ ;  $r = 0.54$ , “*large*”,  $P = 0.018$ , respectively),  
225 backs ( $r = 0.54$ , “*large*”,  $P = 0.038$ ;  $r = 0.52$ , “*large*”,  $P = 0.047$ ) and pooled sample ( $r = 0.75$ ,

226 “*very large*”,  $P < 0.001$ ;  $r = 0.73$ , “*very large*”,  $P < 0.001$ ) (Figure 3). Correlations were also  
227 found between  $WAT_{TT}$  and 10 m and 40 m sprinting times for forwards ( $r = 0.53$ , “*large*”,  $P$   
228  $= 0.020$ ;  $r = 0.51$ , “*large*”,  $P = 0.026$ ) and pooled sample ( $r = 0.73$ , “*very large*”,  $P < 0.001$ ;  $r$   
229  $= 0.69$ , “*large*”,  $P < 0.001$ ) but not for backs ( $r = 0.28$ , “*small*”,  $P = 0.319$ ;  $r = 0.37$ ,  
230 “*moderate*”,  $P = 0.171$ ) (Figure 4).

231  
232 \*\*\* Figures 3 and 4 about here \*\*\*

233  
234 “*Large-to-very large*” relationships were observed between  $WAT_{Best}$  and  $WAT_{TT}$  with 30-  
235 15<sub>IFT</sub> ( $r = -0.80$ , “*very large*”,  $P < 0.001$ ;  $r = -0.77$ , “*very large*”,  $P < 0.001$ ) and YYIR2 ( $r = -$   
236  $0.70$ , “*large*”,  $P < 0.001$ ;  $r = -0.68$ , “*large*”,  $P < 0.001$ ) performance for pooled values. Backs  
237 showed significant correlations between  $WAT_{Best}$  and  $WAT_{TT}$  with 30-15<sub>IFT</sub>, and only  $WAT_{TT}$   
238 with YYIR2 (Figures 5 and 6).

239  
240 \*\*\* Figures 5 and 6 about here \*\*\*

241  
242 The stepwise multiple regression analysis (Table 2) showed that a combination of 40-m  
243 sprinting time and 30-15<sub>IFT</sub> performance explained ~76 % of the variance in  $WAT_{Best}$  for  
244 pooled sample (model 1,  $r = 0.87$ ,  $r^2 = 0.76$ , “*very large*”,  $P < 0.001$ ). Interestingly, selected  
245 determinants changed depending with position: 40-m sprinting time for forwards (model 2,  $r =$   
246  $0.54$ ,  $r^2 = 0.29$ , “*large*”,  $P = 0.018$ ); 10-m sprinting time and 30-15<sub>IFT</sub> performance for backs  
247 (model 3,  $r = 0.76$ ,  $r^2 = 0.58$ , “*very large*”,  $P = 0.005$ ).

248  
249 With  $WAT_{TT}$  as dependent variable, 10-m sprinting time ( $P = 0.002$ ) and 30-15<sub>IFT</sub> performance  
250 ( $P < 0.001$ ) account for the greater proportion of total variance for overall (model 4,  $r = 0.84$ ,

251  $r^2 = 0.70$ , “*very large*”,  $P < 0.001$ ) (Table 2). However, 40-m sprinting time appears as the sole  
252 determinants for forwards (model 5,  $r = 0.51$ ,  $r^2 = 0.26$ , “*large*”,  $P = 0.026$ ), whereas 30-15<sub>IFT</sub>  
253 performance was the one retained for backs (model 6,  $r = 0.61$ ,  $r^2 = 0.37$ , “*large*”,  $P = 0.016$ ).

254

255 \*\*\* Table 2 about here \*\*\*

256

## 257 DISCUSSION

258 The main purpose of this study was to determine the relative and absolute reliability of the

259 WAT in international rugby union players and to investigate its position-specific association

260 and criterion validity with other fitness performance indices. Our findings indicated that the

261 WAT is a reliable and sensitive tool to assess the rugby union specific RSA-related fitness of

262 international players. Results also showed that  $WAT_{TT}$  is a more reliable measure (“*moderate*”

263 to “*high*” ICCs) than  $WAT_{Best}$  (“*low*” ICCs). Furthermore, the WAT correlated with several

264 other fitness indices such as sprint times and team-sport aerobic fitness field-based tests.

265 Interestingly, both Pearson’s product–moment correlations and multiple linear regression

266 models (stepwise backward elimination procedure) indicated position-specific dependence.

267 Although correlation does not imply causality, this may provide some practical insights for

268 coaches and background staffs.

269

270 In the present study, ICCs for  $WAT_{Best}$  and  $WAT_{TT}$  were “*moderate*” to “*high*” for pooled and

271 forwards, and deemed “*acceptable*” for backs. Since it is affected by sample heterogeneity (5),

272 ICC cannot be used as the sole statistical measure of reliability. Consequently, it is

273 recommended that absolute measures of reliability, such as CV and LOA would also be

274 determined in conjunction with the ICC (24). As checked by Bland and Altman plots, test-

275 retest reliability and measurement errors were comparable between the samples. In these

1 276 analyses, both bias and random error were found to be low. However, both pooled and forwards  
2 277 values showed larger CVs than backs, which may be due to the large variability in  
3  
4 278 anthropometrical characteristics and body composition (20) as well as position-specific  
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7 279 demand (3) generally observed between playing positions We conclude that the WAT could be  
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10 280 used with international rugby union players with a higher reliability for backs. To be interpreted  
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12 281 as genuine and not consequential to random performance fluctuation or “noise” (21), a training-  
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14 282 induced change need to exceed 2.81% and 1.81% / 3.50% and 1.74% for  $WAT_{Best}$  and  $WAT_{TT}$   
15  
16  
17 283 in forwards and backs, respectively. In the particular context of international rugby union  
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19 284 competition where RSA requirements significantly increase from professional club to senior  
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22 285 international games (3), the WAT would be relevant in the selection process and competition  
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24 286 preparation.

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29 288 One may also assume that  $WAT_{Best}$  was less reliable than  $WAT_{TT}$ . A close examination of the  
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31 289 likelihood that the true values of estimated differences in WAT outcome would be substantial  
32  
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34 290 (*i.e.*, larger than the SWC) showed that the SWC for pooled, forwards and backs were greater  
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36 291 than their SEMs for  $WAT_{TT}$  only, indicating that this variable only has a good ability to detect  
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39 292 real changes in WAT in international rugby union players. A possible explanation for such  
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41 293 differences may relate to the nature of the WAT involving a higher mechanical stress and  
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44 294 energy expenditure compared to straight-RSA test that did not require repeated accelerations  
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46 295 and change of directions (15). Interestingly, irrespective of playing positions, ICCs and CV for  
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49 296  $WAT_{TT}$  were similar to those of Austin et al. (1) who tested the reliability and sensitivity of a  
50  
51 297 repeated high-intensity exercise performance in rugby league and rugby union players. While  
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53  
54 298 we have focused on directly measured variables, the calculation of sprint decrement or fatigue  
55  
56 299 index would not have led to a higher reliability. In fact, because they incorporate direct

1 300 **measures**, sprint decrements indices have been reported to be less reliable (11-43%) than direct  
2 301 measures (2-8%) (1).

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4 302  
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6  
7 303 Assessing the relationship between the WAT performance and other fitness field-based test is  
8  
9 304 also informative about its criterion-validity. Here, we have observed several significant  
10  
11 305 associations between the WAT variables and sprinting times and 30-15<sub>IFT</sub> and/or YYIR2. In  
12  
13 306 agreement with previous rugby league and rugby union (1, 38) or Australian football (30)  
14  
15 307 studies having investigated relationship between RSA or repeated high-intensity exercise,  
16  
17 308 WAT<sub>Best</sub> and WAT<sub>TT</sub> significantly correlated with sprinting ability, collectively suggesting that  
18  
19 309 fastest players are also those who perform best in RSA efforts. However, WAT<sub>TT</sub> appears to  
20  
21 310 be position-dependent suggesting a greater emphasis on acceleration for the forwards. As  
22  
23 311 previously demonstrated in international soccer (7), different proportional muscle and skeletal  
24  
25 312 structure between forwards and backs (20) may **contribute** in the prevalence of neuromuscular  
26  
27 313 qualities to determine RSA. This may also explain the difference between forwards and backs  
28  
29 314 regarding the relationships between WAT variables and team-sport aerobic tests. Accordingly,  
30  
31 315 Darrall-Jones et al. (11) demonstrated that body mass negatively impacts 10-m sprint velocity  
32  
33 316 ( $r = -0.34$  to  $-0.46$ ) as well as 30-15 IFT ( $r = -0.59$  to  $-0.79$ ) and YYIR1 ( $r = -0.65$  to  $-0.74$ ) in  
34  
35 317 English academy rugby union players. The forwards higher body mass may detrimentally affect  
36  
37 318 the constant change of direction over a short distance during the 30-15<sub>IFT</sub> (10) as well as during  
38  
39 319 the YYIR2.

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44 321 In the present study, multiple regression analysis showed that 70-76% of the WAT performance  
45  
46 322 can be explained by both sprinting and 30-15<sub>IFT</sub> performance, with a greater emphasis on  
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48 323 sprinting ability for forwards vs. aerobic fitness for backs. As for RSA (6, 16), WAT  
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50 324 performance may integrate various physiological systems (e.g., neuromuscular,  
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1 325 cardiovascular) and metabolic pathways (*e.g.*, anaerobic, aerobic), with most of the energy  
2 326 required being derived from phosphocreatine hydrolysis and anaerobic glycolysis (although  
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4 327 their magnitudes are reduced over repetitions). Besides, a higher aerobic contribution is likely  
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7 328 to improve between-efforts recovery through a higher tolerance and removal of metabolic by-  
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9  
10 329 products (lactate, hydrogen ions) (6). Thus, while it is possible that WAT variables allow the  
11  
12 330 evaluation of international rugby union players' fitness in an integrated way, this **also suggests**  
13  
14 331 that different position-dependent fitness determinants are at play. According to the  
15  
16 332 aforementioned variability in anthropometrics and body composition among rugby union  
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18 333 players (11, 20) as well as position-specific match demands (3), this has implications for  
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20 334 strength and conditioning coaches and sport science staffs and how they may program training  
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22 335 to positively influence RSA/WAT performance in rugby union players depending on their  
23  
24 336 position. Therefore, specific training could be implemented to reinforce forwards and backs'  
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26 337 strengths (based on their respective WAT fitness determinants) or inversely to develop their  
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28 338 weaknesses. **Future position-specific training studies using WAT must be conducted to validate**  
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31  
32 339 **this contention.**  
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36 340  
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38 341 A possible limitation of the present study is the lack of metabolic/physiological measurements.  
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40 342 Inclusion of such measures would provide a better understanding of the specific requirements  
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42 343 of the WAT. Further, our findings have been limited to a group of international rugby union  
43  
44 344 players. More data is needed to confirm that the WAT protocol is appropriate for assessing the  
45  
46 345 performance of players of different levels of training, age groups and even gender. Because  
47  
48 346 other team sports such as rugby league and Australian football have similar physical demands,  
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50 347 further research of the applicability of the WAT in those sports is also warranted.  
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## 58 349 **PRACTICAL APPLICATIONS**

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1 350 The WAT proved to be a reliable test, in particular when expressed as  $WAT_{TT}$ . This easy-to-  
2 351 perform test may be considered by strength and conditioning coaches and sport science staffs  
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4 352 for inclusion in a testing battery as an accurate rugby union-specific fitness assessment and for  
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6  
7 353 **probable** prescription of position-specific training protocols. Based on position-specific WAT  
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9 354 fitness determinants, tailored training program prescription may be an asset for performance  
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11 355 optimization. In addition, the WAT performance reported here may be used as normative  
12  
13 356 benchmarks for goal setting, players evaluation/selection in rugby union.  
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27  
28 362 for their help. The results of this study do not constitute endorsement by the National Strength  
29  
30 363 and Conditioning Association.  
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459 **Figure legend**

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2 460 Figure 1. Visual representation of the Welsh Anaerobic Test (WAT).  
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7 462 Figure 2. Bland and Altman plots for the Welsh Anaerobic Test (WAT) test-retest. A) Pooled  
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9 463 values (n = 34), B) backs (n = 16), C) forwards (n = 19) for Welsh Anaerobic Test best time  
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11 464 ( $WAT_{Best}$ ); D) Pooled values (n = 34), E) backs (n = 16), F) forwards (n = 19) for Welsh  
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13 465 Anaerobic Test total time ( $WAT_{TT}$ ). Solid line – bias; dashed lines – 95% limits of agreement  
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15 466 (LOA).  
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19 467  
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21 468 Figure 3. Zero-order correlations between the Welsh Anaerobic Test best time ( $WAT_{Best}$ ) and  
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23 469 sprinting times (left panel, 10-m distance; right panel, 40-m distance). Black dots are forwards,  
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25 470 gray dots are backs, and thick and bold lines are pooled values. Dotted lines are 95% confidence  
26  
27 471 interval.  
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31 472  
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33 473 Figure 4. Zero-order correlations between the Welsh Anaerobic Test total time ( $WAT_{TT}$ ) and  
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35 474 sprinting times (left panel, 10-m distance; right panel, 40-m distance). Black dots are forwards,  
36  
37 475 gray dots are backs, and thick and bold lines are pooled values. Dotted lines are 95% confidence  
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39 476 interval.  
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45 478 Figure 5. Zero-order correlations between the Welsh Anaerobic Test best time ( $WAT_{Best}$ ) and  
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47 479 team sport-specific aerobic performances (left panel, 30-15<sub>IFT</sub>; right panel, YYIR2). Black dots  
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49 480 are forwards, gray dots are backs, and thick and bold lines are pooled values. Dotted lines are  
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51 481 95% confidence interval.  
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483 Figure 6. Zero-order correlations between the Welsh Anaerobic Test total time (WAT<sub>TT</sub>) and  
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2 484 team sport-specific aerobic performances (left panel, 30-15<sub>IFT</sub>; right panel, YYIR2). Black dots  
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5 485 are forwards, gray dots are backs, and thick and bold lines are pooled values. Dotted lines are  
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7 486 95% confidence interval.  
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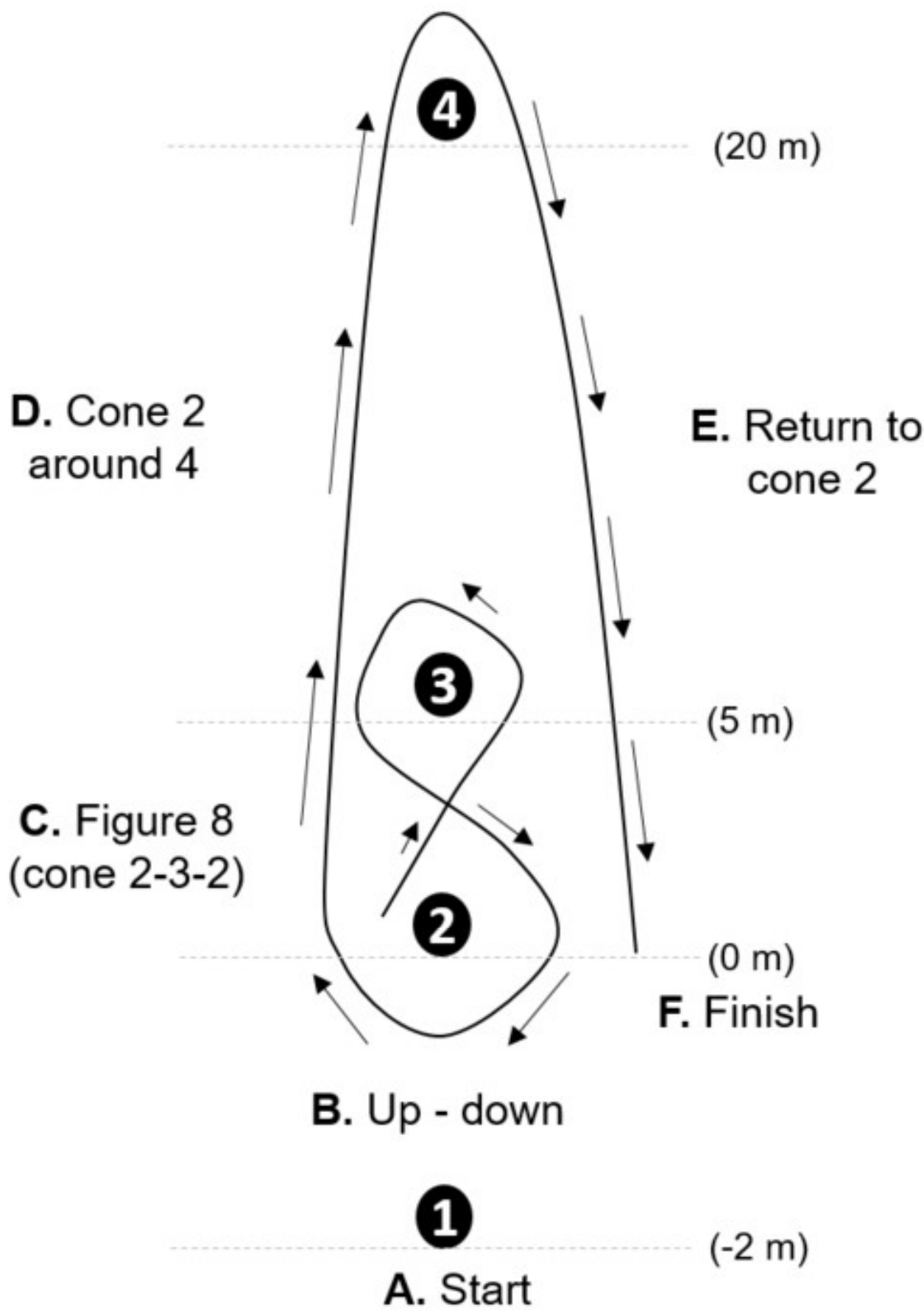
Table 1. Parameters of reliability analysis for the WAT indices.

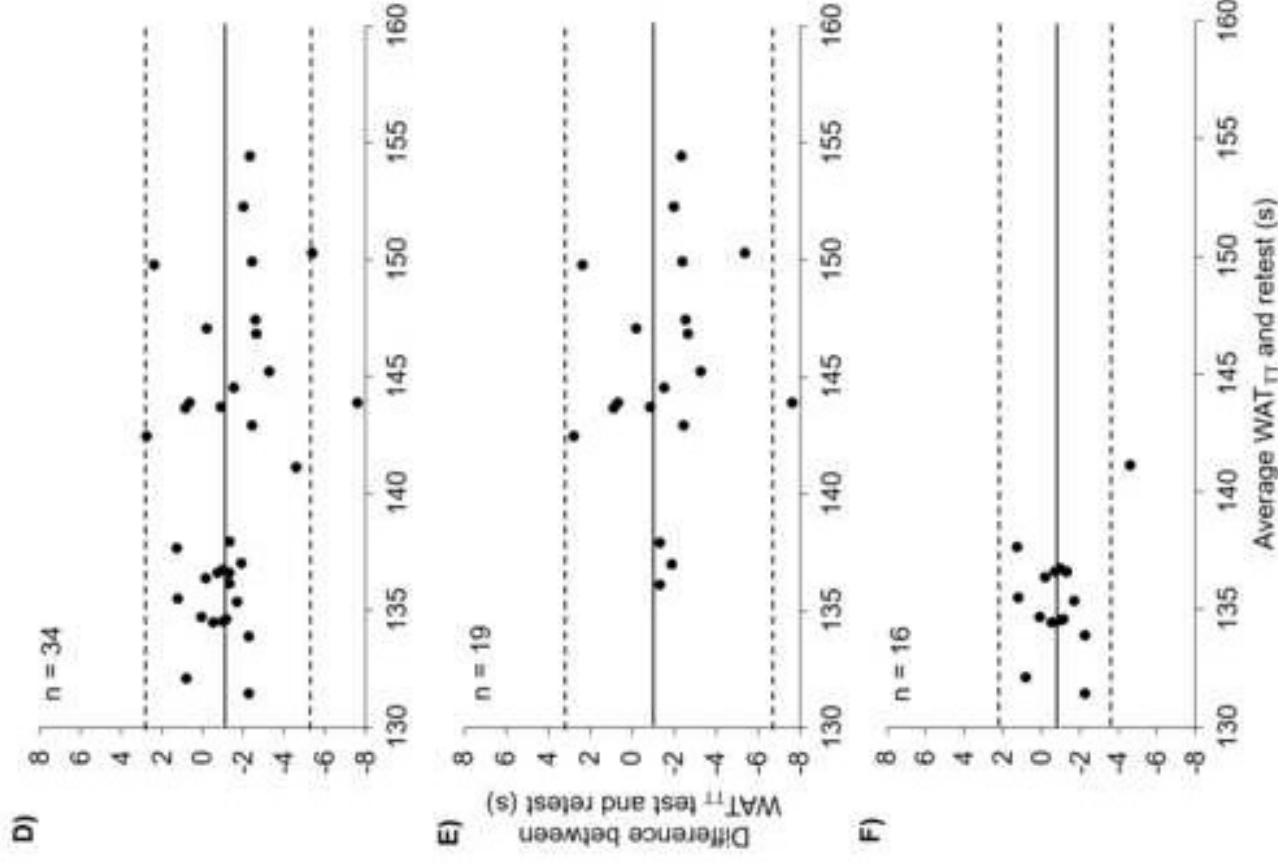
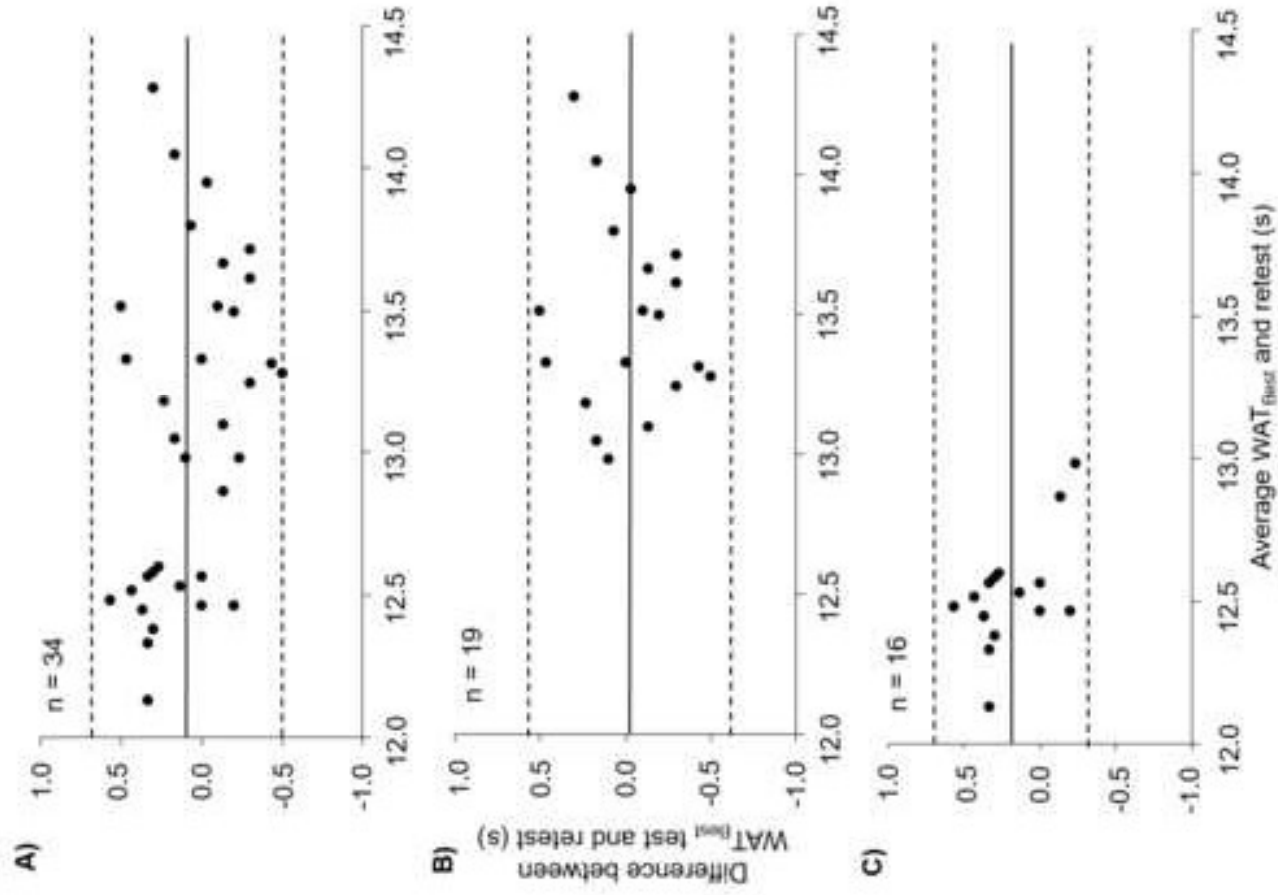
Test	Retest	P-Value	d	ICC (95% CI)	CV (%)	Bias	95% LOA	SEM	SWC
<b>WAT<sub>Best</sub></b>									
Pooled (n = 34)	13.10±0.54	0.626	0.12	0.89 (0.79-0.94)	4.47	1.01	1.28	0.05	0.11
Forwards (n = 19)	13.49±0.40	0.854	0.06	0.74 (0.44-0.89)	2.81	1.01	1.40	0.07	0.06
Backs (n = 16)	12.62±0.17	0.038	0.75	0.49 (-0.01-0.79)	1.81	1.02	1.47	0.06	0.03
<b>WAT<sub>Tt</sub></b>									
Pooled (n = 34)	140.26±6.16 s	0.342	0.21	0.95 (0.90-0.97)	4.54	1.01	1.28	0.36	1.25
Forwards (n = 19)	144.42±4.94 s	0.319	0.33	0.90 (0.76-0.96)	3.50	1.01	1.40	0.56	0.96
Backs (n = 16)	135.00±2.21 s	0.263	0.40	0.83 (0.57-0.94)	1.74	1.02	1.47	0.37	0.44

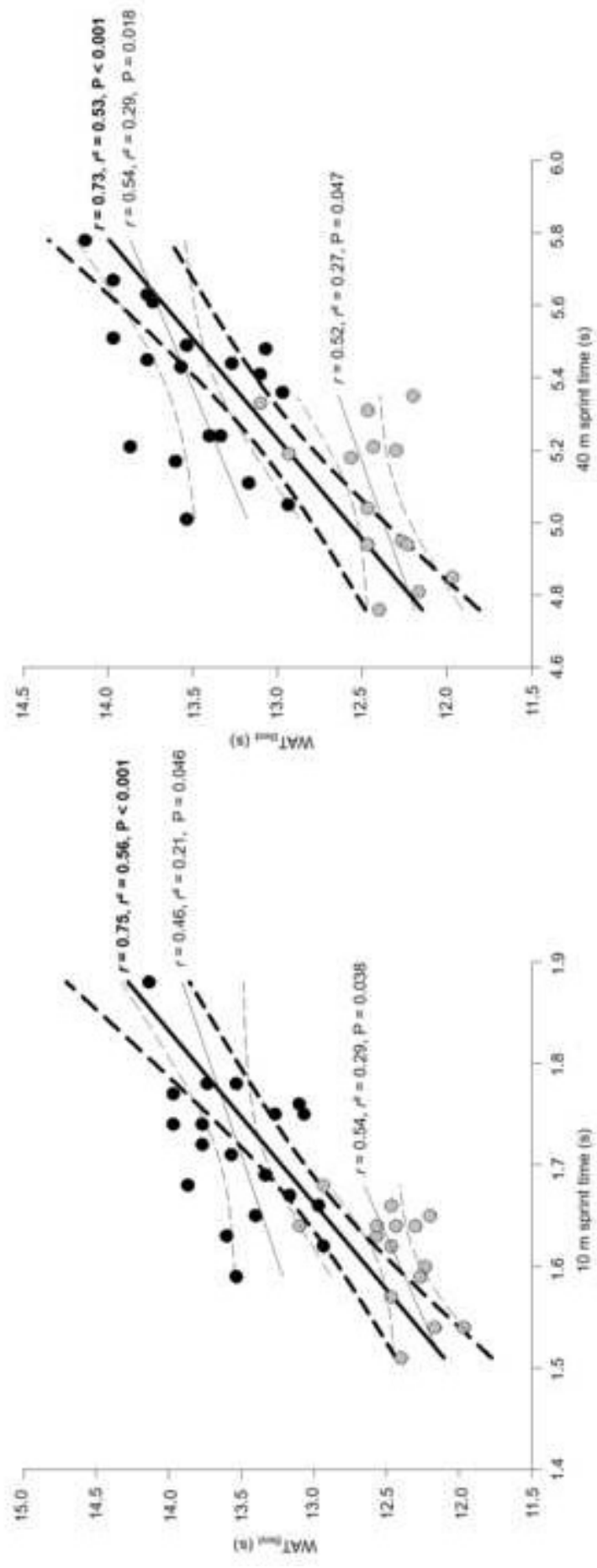
d: Cohen' d; ICC: intra class correlation coefficient; CV: coefficient of variation; LOA: limit of agreement; SEM: standard error of measurement; SWC: smallest worthwhile change.

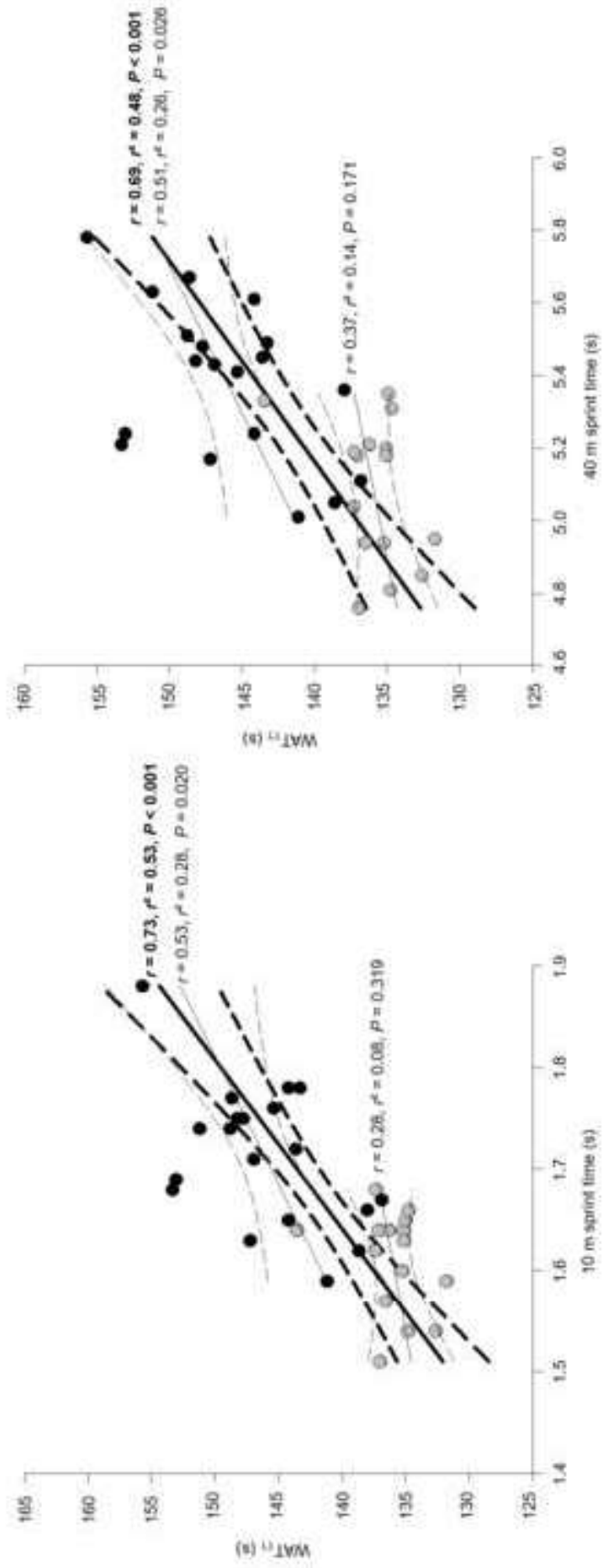
Table 2. Determinants of Welsh Anaerobic Test best (WAT<sub>Best</sub>) and total time (WAT<sub>TT</sub>) performance.

<b>Variables</b>	<b>Coefficient</b>	<b>P</b>	<b>r<sup>2</sup></b>	<b>r</b>
<b>Stepwise multiple regression - WAT<sub>Best</sub></b>				
Model 1 – Overall				
Intercept	12.84	< 0.001	0.76	0.87
30-15	-0.28	< 0.001		
40 m	1.05	< 0.001		
Model 2 – Forwards				
Intercept	8.68	0.018	0.29	0.54
40 m	0.90	0.018		
Model 3 – Backs				
Intercept	12.242	0.005	0.58	0.76
30-15	-0.215	0.014		
10 m	2.777	0.025		
<b>Stepwise multiple regressions – WAT<sub>TT</sub></b>				
Model 4 – Overall				
Intercept	134.73	< 0.001	0.70	0.84
30-15	-2.71	< 0.001		
10 m	34.72	0.002		
Model 5 – Forwards				
Intercept	79.76	0.026	0.26	0.51
40 m	12.32	0.026		
Model 6 – Backs				
Intercept	179.997	0.016	0.37	0.61
30-15	-2.211	0.016		









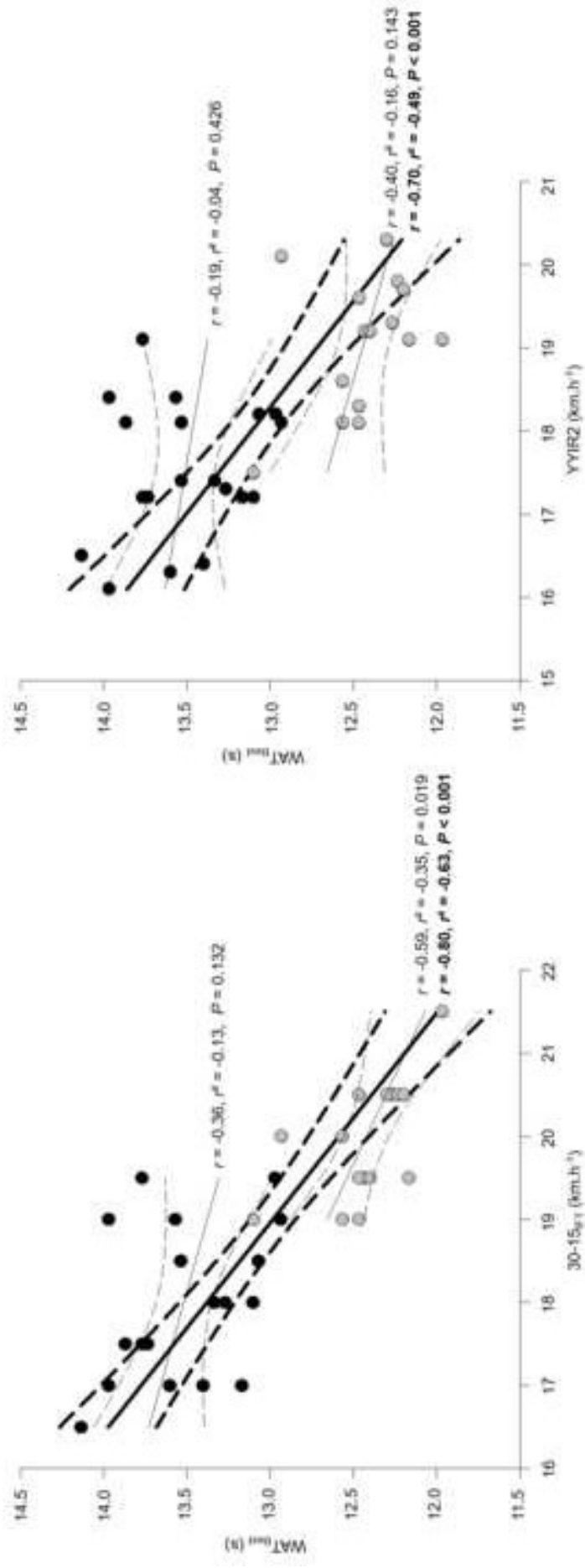




Figure 6

