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54 **ABSTRACT**

55

56 Objectives: The main objective of this study was to determine the concurrent validity between a  
57 hand-held (HHD) and mounted hand-held dynamometer (MHHD) for assessing isometric neck  
58 strength.

59 Design: Observational design.

60 Setting: UK-based semiprofessional rugby club

61 Participants: Nineteen semi-professional rugby players (age =  $26 \pm 5$  years, stature =  $186.5 \pm 6.5$   
62 cm, body mass =  $98.7 \pm 12.8$  kg).

63 Main outcome measures: Concurrent validity (i.e., limits of agreement, correlation) between  
64 HHD and MHHD, the intrarater reliability (intra-class correlation, ICC) and comparison between  
65 playing positions.

66 Results: Absolute peak and mean peak force were systematically lower when using the HHD  
67 compared to MHHD, with the mean bias ranging from -1.8 to -3.8 kgf ( $P < 0.05$ ). Differences  
68 were not evident for flexion when applying the correction equations (-0.5 to 2.1 kgf,  $P > 0.05$ ) but  
69 remained for extension. Correlations between methods were large-to-very large; the ICCs for both  
70 methods were good (ICC = 0.72-0.89), with no difference between positions ( $P > 0.05$ ).

71 Conclusion: The concurrent validity of HHD was considered acceptable when compared to the  
72 MHHD and the correction equation was applied. Both methods are reliable and useful for  
73 assessing neck strength in rugby players, though, caution is needed when determining strength  
74 during neck extension.

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87 Keywords: rugby, concussion playing position, physiotherapy, injury, rehabilitation

88 **1. Introduction**

89 Rugby union is a high-intensity intermittent game involving large impact forces (~4-5 kN)  
90 between players that may account for a large number of the reported injuries (99.1 per 1000  
91 match-hours).<sup>1,31</sup> Within rugby union, tackle-related injuries account for approximately 23-53%  
92 of injuries,<sup>3</sup> with ~33% of injuries located at the head and neck.<sup>26</sup> An injury surveillance study, in  
93 English rugby union, reported that 17% of all injures involved the head,<sup>29</sup> resulting in a significant  
94 proportion diagnosed as concussion.<sup>12</sup> A systematic review and meta-analysis, including 37  
95 studies focused on sub-elite populations, found a higher incidence of concussion (2.1 per 1000  
96 match-hours) with the authors concluding that future research should focus on prevention,  
97 management and understanding the long-term outcomes of concussive head injuries.<sup>12</sup>  
98 Concussive head injuries have been linked with both long-term cognitive and motor performance  
99 deficits in retired professional athletes,<sup>25</sup> and may lead to a significant health and socio-economic  
100 burden to individuals once retired<sup>24</sup> as well as potential legal implications. Such reports highlight  
101 the importance of conducting research that focuses on reducing the incidence of concussion and  
102 ultimately improving long-term safety of players in rugby union.

103

104 Injury prevention strategies should be a key focus for medical practitioners and strength and  
105 conditioning coaches working in rugby, with the aim of reducing concussion risk. One strategy  
106 receiving attention is neck strengthening, as research has reported an association with reduced  
107 risk of concussion and reported neck injuries.<sup>4,11,34</sup> In a cohort study conducted in professional  
108 rugby, Naish et al.<sup>27</sup> reported an improvement in neck strength and reduced cervical spine injuries  
109 during matches, following a 13-week neck-specific strengthening programme in professional  
110 male rugby union players. Similarly, Hislop et al.<sup>16</sup> demonstrated that an injury prevention  
111 programme, over a 4-month period including specific neck strengthening components, was  
112 effective at reducing concussion incidence in amateur rugby union players (risk ratio = 0.71).  
113 Whilst such findings are promising, it is essential for researchers and practitioners to be able to  
114 accurately measure neck strength to determine the efficacy of such programmes, establish

115 normative data and identify a minimal threshold of acceptable neck strength<sup>23</sup> with respect to  
116 playing position.

117

118 Isokinetic dynamometry is largely considered the criterion method to measure neck strength,<sup>32</sup>  
119 though the cost, time and accessibility within a sport and clinical setting remain an issue.<sup>19</sup> As  
120 such, there is a need for a portable and cost-effective measurement tool that is both reliable and  
121 valid. Hand-held dynamometry (HHD) is one such measurement tool that could potentially be  
122 used to objectively measure neck strength given its application when assessing upper and lower  
123 limbs.<sup>23,32</sup> Stark et al.<sup>32</sup> conducted a systematic review, concluding that HHD is both reliable and  
124 valid when compared to isokinetic dynamometry for measuring muscle strength in both upper  
125 and lower limbs. However, the studies included were somewhat dated and did not use the HHD  
126 and isokinetic dynamometry for measuring neck strength.<sup>32</sup> To date, few studies have assessed  
127 the neck strength of rugby players with two studies using the criterion method<sup>8,28</sup> and two using  
128 a dynamometer.<sup>13,14</sup> Two of these studies considered playing position when assessing neck  
129 strength, with the results indicating lower mean values for backs when compared to forwards  
130 across cervical spine movements including, flexion, extension and side flexions.<sup>14,28</sup> As such it  
131 may appear that assessment of neck strength can discriminate between playing positions, thus  
132 offering some insight into the sensitivity of the HHD.

133

134 Although HHDs are commonly used in physiotherapy, there are some issues surrounding the  
135 ‘make’ condition. This refers to the force that is applied to the HHD being equal and opposite to  
136 the force generated by muscle contraction.<sup>30</sup> Whilst using a HHD is suggested to be reliable in  
137 healthy populations,<sup>23,36</sup> there are questions over the validity of this measurement tool. Kolber  
138 and Cleland<sup>22</sup> conducted a literature review of HHD testing and found that the strength of the  
139 tester and the lack of adequate device stabilisation reduced the reliability and validity of the tool.  
140 This issue may be overcome in the sporting environment with a pragmatic approach of mounting  
141 the device to a fixed point. This would potentially avoid the issues of adequate stabilisation and

142 the strength of the tester would no longer be a factor. Currently, there is no evidence on the level  
143 of concurrent validity between a HHD and a mounted HHD (MHHD) measure neck strength. In  
144 the absence of the available criterion method, it is important to establish the concurrent validity  
145 between the HHD and a 'new' criterion using a MHHD as well as assess the ability of it to  
146 discriminant between playing position and possess within-session reliability.

147

148 The aims of the study were to 1). determine the concurrent validity between a HHD and MHHD  
149 when used to measure isometric neck strength in semi-professional rugby players, 2). generate a  
150 correction equation to address any potential systematic biases between HHD and MHHD, 3).  
151 determine the intrarater reliability and 4). determine if both dynamometers can discriminate  
152 between playing positions.

153

## 154 **2. Methods**

### 155 *2.1 Participants*

156 Semi-professional rugby players from a single rugby union club in the Northwest of England were  
157 recruited for this study. To address the objectives of this study, a required sample of 19-25 was  
158 needed based on the work of De Vet et al.<sup>6</sup> and when using the expected mean difference (~2.0  
159 kgf) and standard deviation of the difference (~2.8 kgf) based on Katoh et al.<sup>20</sup> Further, to make  
160 between-group comparison, a required sample of between 9 and 20 was required based on the  
161 standardised mean difference (0.66 to 1.26) using the work of Geary et al.<sup>14</sup> when inserted into  
162 G\*Power.<sup>9</sup> The club had a total of 26 players registered at the time of the study, however seven  
163 were unable to participate due to club commitments, resulting in a sample of nineteen players  
164 (age =  $26 \pm 5$  years, stature =  $186.4 \pm 6.5$  cm, body mass =  $98.7 \pm 12.8$  kg, neck circumference =  
165  $39 \pm 2$  cm) and sufficient power for most aspects of this study. The sample included 10 forwards  
166 and 9 backs, all of whom were free of any cervical spine injury and were cleared to participate  
167 by the club's medical team. Written consent was provided by all participants and the procedures  
168 were approved by the ethics committee at Manchester Metropolitan University (No. 9818).

169

## 170 *2.2 Study Procedure*

171 All data was collected across two days within the first two weeks of pre-season and with 72 hours  
172 of rest between trials. On arrival, measures of body mass (Seca 875, Seca ltd., Hamburg,  
173 Germany), stature (Seca 213 height-measure, Seca ltd, Hamburg, Germany) and neck  
174 circumference (EMI Body Retractable Tape Measure 400W, Elite Medical Instruments,  
175 California, USA) were recorded along with the participants age and playing position  
176 (forward/back). All assessments were preceded by a standardised warm-up, consisting of five  
177 repetitions of active cervical spine movement, flexion, extension and side flexion and one  
178 maximal isometric contraction in each direction.

179

180 During the two assessment days, participants completed 3 maximal isometric contractions in the  
181 same order: forward flexion, extension, right and left side flexion. The use of the HHD or MHHD  
182 (Micro FET2, Hoggan, Utah, USA; sample rate 50 samples/s) was randomised, by an independent  
183 researcher not involved with the procedure, using the RAND function in Microsoft Excel. During  
184 the procedure, participants were seated upright with their back against the chair, feet flat on the  
185 floor and hands rested on the upper thigh with palms facing upward. Participants were provided  
186 with a full explanation and demonstration of the testing procedure, then asked to perform the  
187 maximal contraction in each direction, each followed by a 2-minute passive recovery. The  
188 instruction provided for each direction was to ask the participant to perform a maximal contraction  
189 of cervical flexion, extension and side flexion of the head against the force applied for 3 seconds.  
190 E.g., “You will attempt to produce this movement (flexion, extension or side flexion) against my  
191 resistance as hard as you can for 3 seconds”

192

## 193 *2.3 Hand-held dynamometer*

194 A HHD (Micro FET2, Hoggan, Utah, USA) was used to measure mean peak and absolute peak  
195 isometric neck strength (kgf) in flexion, extension and side flexions, in a seated push test. The

196 HHD was placed in contact with the participant's head and the researcher provided a fixed  
197 counter-pressure. The same researcher, throughout the data collection, is a physiotherapist with  
198 extensive experience of using HHD in clinical and sporting practice. The standardised approach  
199 adopted ensured the HHD pad was positioned: on the centre of the forehead for forward flexion;  
200 superior to the external occipital protuberance during extension; and above the ear on the lateral  
201 aspect of the head during the right and left side flexion, for all participants. The researcher  
202 positioned with locked arms, in a step-standing position in front, behind and at the side of the  
203 participant during flexion, extension and side flexion, respectively. Participants were required to  
204 generate their maximum voluntary contraction against the researcher's force. The procedures  
205 used were in accordance with Krause et al.<sup>23</sup>

206

#### 207 *2.4 Mounted Hand-held Dynamometer*

208 During the mounted push test procedure, the HHD (Micro FET2, Hoggan, Utah, USA) was  
209 attached to a head harness using heavy duty Velcro. The harness (AQF Head Harness, AQF  
210 Sports, Luton, England) was adjusted to fit the participants' head. Markers were placed on the  
211 harness to standardise the procedures; superior to the bridge of the nose on the anterior aspect;  
212 superior to the C2 spinous process posteriorly; and on the most superior aspect of the ear helix  
213 apex laterally. During the procedure, participants were required to generate a maximum voluntary  
214 contraction against a fixed point.

215



216

217 Figure 1. Mounted (left) and Hand-held (right) methods.



218

## 219 2.5 Statistical Analysis

220 Descriptive statistics were presented as the mean  $\pm$  standard deviation (SD). The Shapiro-Wilk  
221 test was used to assess normality and a Pearson's correlation ( $r$  value) to visually check for  
222 heteroscedastic errors and the relationship between methods using the following descriptive  
223 thresholds:  $<0.10$ , trivial;  $0.11-0.30$ , small;  $0.31-0.50$ , moderate;  $0.51-0.70$ , large;  $0.71-0.90$ , very  
224 large;  $>0.90$ , nearly perfect.<sup>17</sup> A two-tailed paired sample  $t$ -test was used to assess the difference  
225 in mean peak and absolute peak force values between methods. The mean peak was the average  
226 peak force over the 3 contractions, whereas the absolute peak was the highest force achieved  
227 across the 3 contractions. To assess concurrent validity, the mean bias and 95% limits of  
228 agreement (LOA) were determined with the between-method SD multiplied by 1.96.<sup>2</sup> In the  
229 instance of a significant mean bias, correction equations were determined through linear  
230 regression analysis. A 50/50 split of the sample was used to cross-validate the correction  
231 equations and establish the degree of shrinkage in the  $R^2$  value. To determine the intrarater  
232 reliability, intra-class correlations (ICC) were calculated using a one-way-random model and  
233 interpreted as: excellent  $>0.90$ , good  $0.70-0.90$ , fair  $0.40-0.70$ , and poor  $<0.40$ .<sup>5</sup> To determine the  
234 between-position differences, an independent  $t$ -test and effect sizes were calculated for mean peak  
235 and absolute peak force. Statistical analysis was performed SPSS statistical software (IBM SPSS  
236 Statistics for Windows, Version 26.0, Armonk, NY, USA) and significance achieved at 0.05.

237

## 238 3. Results

239 Between-method comparisons for mean peak and absolute peak force demonstrated a  
240 systematically lower score achieved when using the HHD versus the MHHD (all  $P \leq 0.001$ ), with  
241 the mean bias ranging from  $-1.8$  to  $-3.8$  kgf (Table 1). There was large to very large correlations  
242 between the HHD and MHHD for mean peak and absolute peak force ( $r = 0.66$  to  $0.80$ ,  $P < 0.001$   
243 to  $0.002$ ).

Table 1. Isometric neck strength using the hand-held and mounted dynamometer and between-method comparisons.

Direction of force applied	Hand-held dynamometer	Mounted dynamometer	Between-method comparisons					Pearson's correlation	
			Mean Bias	Lower 95% LOA	Upper 95% LOA	<i>t</i>	<i>P</i>	<i>r</i>	<i>P</i>
Absolute peak flexion (kgf)	16.2 ± 2.1	18.0 ± 3.1	-1.8	-5.8	2.2	-3.81	0.001	0.77	<0.001
Absolute peak extension (kgf)	21.8 ± 4.3	25.6 ± 4.8	-3.8	-11.0	3.4	-4.50	<0.001	0.68	0.001
Absolute peak RSF (kgf)	16.3 ± 2.7	18.5 ± 2.6	-2.3	-6.7	2.2	-4.35	<0.001	0.80	<0.001
Absolute peak LSF (kgf)	16.6 ± 3.8	19.3 ± 3.6	-2.7	-8.2	2.8	-4.17	0.001	0.71	0.001
Mean peak flexion (kgf)	15.0 ± 2.8	17.1 ± 2.8	-2.1	-6.8	2.6	-3.77	0.001	0.66	0.002
Mean peak extension (kgf)	20.6 ± 4.0	23.5 ± 4.3	-2.9	-8.6	2.8	-4.32	<0.001	0.76	<0.001
Mean peak RSF (kgf)	15.4 ± 2.5	17.3 ± 2.3	-1.9	-5.5	1.7	-4.63	<0.001	0.72	0.001
Mean peak LSF (kgf)	15.5 ± 3.3	18.3 ± 3.3	-2.8	-7.5	2.0	-4.93	<0.001	0.72	<0.001

Note: RSF = right side flexion; LSF = left side flexion; kgf = kilograms of force; LOA = limits of agreement.

Table 2. Parameters of the cross-validation prediction model using the hand-held dynamometer to estimate peak force derived from the wall-mounted dynamometer across isometric contractions (~50% of sample)

Predictor variable	Unstandardized coefficient		Standardized Coefficient		Adjusted R <sup>2</sup>
	B	Standard error	Beta	t	
Constant	-1.865	3.740		-0.499	
HHD absolute peak flexion (kgf)	1.203	0.222	0.898	5.413	0.78
Constant	-2.266	3.932		-0.576	
HHD absolute peak extension (kgf)	1.202	0.169	0.937	7.110	0.86
Constant	5.997	2.627		2.283	
HHD absolute peak right side flexion (kgf)	0.769	0.164	0.871	4.679	0.72
Constant	4.410	3.105		1.421	
HHD absolute peak left side flexion (kgf)	0.903	0.195	0.868	4.633	0.72
Constant	6.066	1.848		3.282	
HHD mean peak flexion (kgf)	0.690	0.128	0.897	5.370	0.78
Constant	11.007	3.651		3.014	
HHD mean peak extension (kgf)	0.669	0.160	0.845	4.173	0.67
Constant	3.519	2.441		1.442	
HHD mean peak right side flexion (kgf)	0.884	0.157	0.905	5.625	0.79
Constant	5.224	2.874		1.818	
HHD mean peak left side flexion (kgf)	0.823	0.181	0.864	4.539	0.71

Note: HHD = hand-held dynamometer. kgf = kilograms of force.

The regression analysis based on the cross-validation sample of 50% (Table 2) indicated that the mean peak and absolute peak force derived from the HHD explained between 67 and 86% of the variance in the dependent variable (MHHD), yielding 8 directional-specific equations. Cross-validation analysis revealed no significant difference ( $P = 0.094$  to  $0.655$ ) between the corrected HHD and MHHD for force with the mean biased reduced to  $-0.5$  to  $2.1$  kgf (Table 3). The change in  $R^2$  represents a shrinkage of between 6 and 27% with highest values reported for extension. The overall regression model (Table 4) revealed that the mean and absolute peak force, when using the equations for HHD, explained between 75 and 87% of the variance of the dependent variable (MHHD). The final correction equations for mean peak force were; flexion (force =  $(0.826 \cdot \text{HHD peak force}) + 4.097$ ), extension (force =  $(1.122 \cdot \text{HHD peak force}) + -0.013$ ), RSF (force =  $(0.855 \cdot \text{HHD peak force}) + 4.161$ ) and LSF (force =  $(0.815 \cdot \text{HHD peak force}) + 5.047$ ). The correction equations for absolute peak force were; flexion (force =  $(1.176 \cdot \text{HHD peak force}) - 1.465$ ), extension (force =  $(0.958 \cdot \text{HHD peak force}) + 3.474$ ), RSF (force =  $(0.844 \cdot \text{HHD peak force}) + 4.405$ ) and LSF (force =  $(0.658 \cdot \text{HHD peak force}) + 7.770$ ) were derived.

Table 3. Cross-Validation of corrected and wall-mounted dynamometer (~50% sample)

Direction of force is applied	Corrected hand-held dynamometer	Mounted dynamometer	Between-method comparisons					Adjusted R <sup>2</sup>
			Mean Bias	Lower 95% LOA	Upper 95% LOA	<i>t</i>	<i>P</i>	
Absolute peak flexion (kgf)	17.5 ± 2.0	17.7 ± 2.4	-0.2	-2.6	2.2	-0.462	0.655	0.71
Absolute peak extension (kgf)	24.6 ± 4.0	25.9 ± 3.9	-2.1	-6.0	1.8	-1.555	0.154	0.59
Absolute peak RSF (kgf)	18.8 ± 2.7	18.6 ± 2.7	0.2	-3.7	4.1	0.370	0.720	0.63
Absolute peak LSF (kgf)	20.8 ± 3.6	20.1 ± 3.5	0.8	-4.4	5.9	1.150	0.280	0.66
Mean peak flexion (kgf)	17.1 ± 1.3	17.5 ± 2.9	-0.4	-4.9	4.1	-0.740	0.478	0.85
Mean peak extension (kgf)	23.7 ± 2.3	21.8 ± 4.5	1.5	-4.9	8.0	1.875	0.094	0.74
Mean peak RSF (kgf)	17.1 ± 2.4	17.6 ± 2.5	-0.5	-4.5	3.5	-0.931	0.376	0.58
Mean peak LSF (kgf)	18.1 ± 1.7	18.0 ± 1.7	0.5	-2.4	3.3	1.316	0.221	0.55

Note: RSF = right side flexion; LSF = left side flexion; kgf = kilograms of force; LOA = limits of agreement.

Table 4. Overall parameters of the cross-validation prediction model using the hand-held dynamometer to estimate peak force derived from the wall-mounted dynamometer (100% sample).

Predictor variable	Unstandardised coefficient		Standardised Coefficient		Adjusted R <sup>2</sup>
	<i>B</i>	Standard error	Beta	<i>t</i>	
Constant	-1.465	2.097		-0.699	
HHD absolute peak flexion (kgf)	1.176	0.128	0.912	9.185	0.82
Constant	3.474	2.419		1.436	
HHD absolute peak extension (kgf)	0.958	0.109	0.905	8.781	0.81
Constant	4.405	1.427		3.087	
HHD absolute peak right side flexion (kgf)	0.844	0.087	0.921	9.737	0.84
Constant	7.770	1.464		5.306	
HHD absolute peak left side flexion (kgf)	0.658	0.086	0.880	7.646	0.76
Constant	4.097	1.478		2.772	
HHD mean peak flexion (kgf)	0.826	0.097	0.901	8.549	0.80
Constant	-0.013	2.106		-0.006	
HHD mean peak extension (kgf)	1.122	0.100	0.938	11.191	0.87
Constant	4.161	1.381		3.014	
HHD mean peak right side flexion (kgf)	0.855	0.089	0.919	9.625	0.84
Constant	5.047	1.760		2.868	
HHD mean peak left side flexion (kgf)	0.815	0.111	0.872	7.330	0.75

Note: HHD = hand-held dynamometer. kgf = kilograms of force.

The within-session, ICC was considered good for flexion (0.90), extension (0.90), RSF (0.77) and LSF (0.78) when using the HHD. Similarly, the ICC was considered good for flexion (0.86), extension (0.79), RSF (0.77) and LSF (0.92) when using the MHHD.

There was no significant difference in mean peak force or absolute peak force between forwards and backs across all directions (Figure 1).

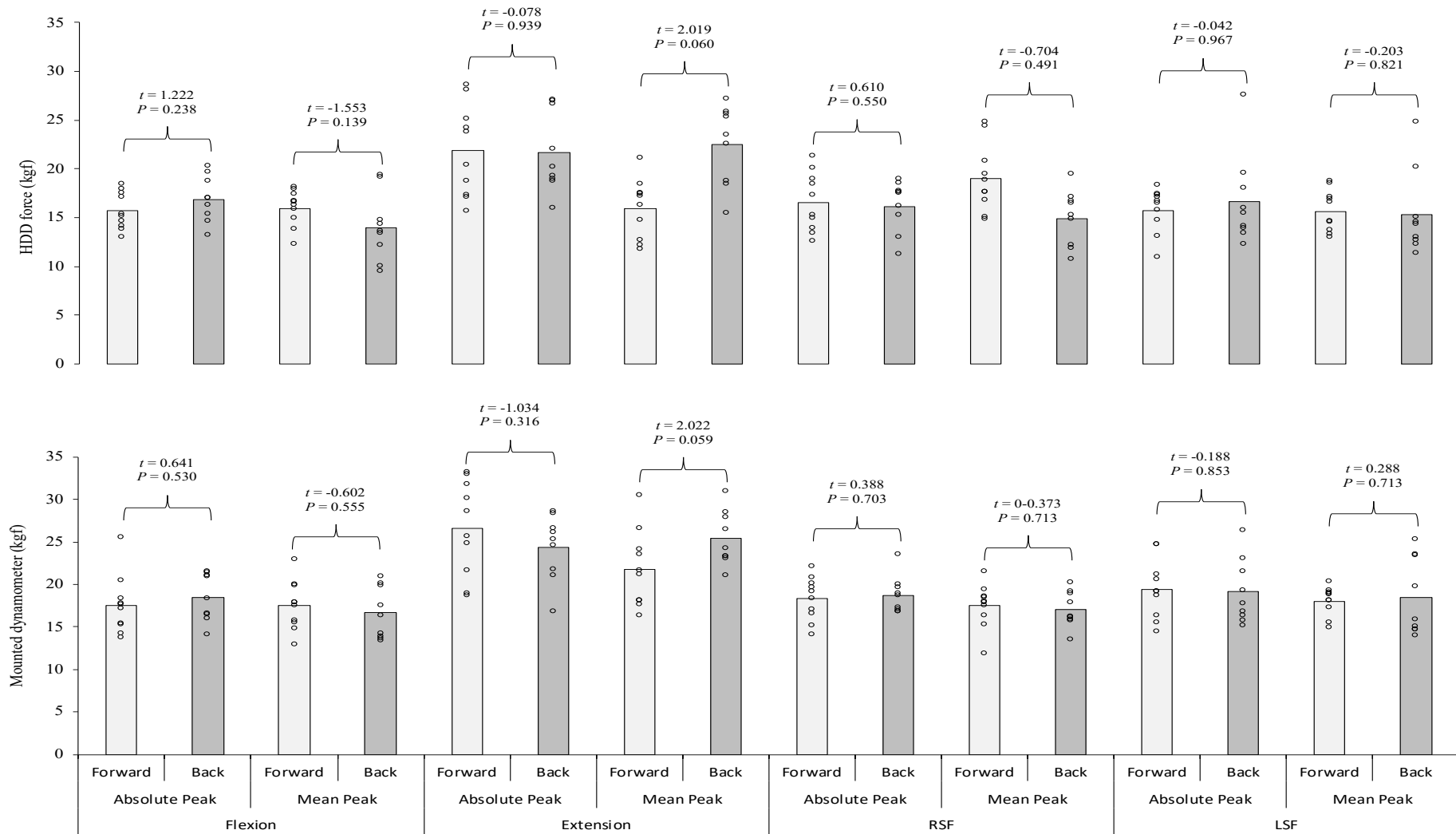


Figure 1. Between-position differences in neck flexion and extension presented as absolute and mean peak force using the HDD and MHDD.



#### **4. Discussion**

This study sought to determine concurrent validity between an HHD and a MHHD as well as report the reliability and potential playing position differences in neck strength. The principle finding in this study was that HHD systematically underestimated force when compared to a MHHD. However, the large to very large correlations allowed for the mean difference between methods to be corrected and reduced substantially with narrower limits of agreement. This study also demonstrated good intrarater reliability but no difference in neck strength between playing position, suggesting both methods are unable to differentiate between forwards and backs.

The HHD is a practical method frequently used in practice, albeit our results highlight a systematic underestimation in force during flexion, side-flexion and extension when using the HHD compared to MHHD. The underestimation in neck strength when measured using the HHD was expected given the potential inability of the assessor to resist the force generated,<sup>10</sup> or the inhibition on the part of the participant, as they may have perceived the ability to be able to overcome the assessor's force, particularly within resistance-trained athletes. Such findings may also explain the greater mean bias observed for neck extension where greater force is typically generated.<sup>13,14</sup> It is also likely that participants are able to generate greater force using the MHHD compared to the HHD, due to a higher degree of confidence with the added stability of the fixed point. The slight methodological differences might also explain the results, whereby participants pushed against a counter-balance force applied by the researcher when using the HHD compared to force being actively generated against the fixed point when using the MHHD. Regardless, our results provide evidence to suggest that the HHD and MHHD cannot be used interchangeably, and that practitioners seeking to determine 'maximal' force, should use a fixed-point. Use of a MHHD should be favored when trying to determine mean peak and absolute peak force, though this may restrict where such assessments can take place. The support for the use for MHHD is supported by research demonstrating a strong agreement between a MHHD and criterion method such as isokinetic dynamometry.<sup>21,33</sup>

The 95% LOA calculated for flexion, side-flexion and extension were wide for most measures in the initial comparisons between methods. For example, an absolute peak force of 20 kgf during extension on the MHHD could, in the worst-case scenario, result in a score of between 9 and 23.5 kgf on the HHD. Similarly, when considering a mean peak force for flexion of 20 kgf measured on the MHHD, the score on the HHD could be, in the worst-case scenario, between 13.2 and 22.6 kgf. This margin of error is unlikely to be acceptable within clinical and sporting practice. To provide some context, the minimal detectable change previously observed for a HHD when assessing neck strength is approximately 2.1 to 3.8 kgf.<sup>35</sup> This detectable change is smaller than the mean bias observed in this study, meaning a change is unlikely to be detected when the HHD and MHHD are used interchangeably and that some rehabilitation programmes may be deemed ineffective or that a reduction in strength of less than 2.1 kgf is not considered meaningful. However, we provide correction equations that adjust for the mean bias and narrows the 95% LOA to enable medical and sport science personnel to use the HHD and obtain accurate values and evaluate training or detraining adaptations using either tool. This is importance given it may not always be possible to mount the HHD, such as during a field assessment or clinical setting. In calculating the regression equations, we observed a smaller shrinkage in the  $R^2$  of all measures of flexion (~6%), compared to the larger value for extension ( $R^2 = 27\%$ ). This shrinkage is much larger than that previously reported when assessing the criterion validity of a portable isometric mid-thigh pull dynamometer, though this was a whole-body assessment.<sup>7</sup> That said, the overall mean bias was reduced and equal to, or lower than, the minimal detectable changes previously noted.<sup>35</sup> This suggests that the HHD and MHHD can be used interchangeably when the correction equations are applied. When considering the 95% LOA for the same variables noted earlier, narrower limits were observed, with the scores on the HHD ranging from 14.0 to 21.8 kgf for extension and 15.9 to 24.1 kgf for flexion when compared to the MHHD, respectively. Practitioners using the HHD to measure neck strength should consider correcting their scores using the equations to better reflect peak force and ensure the data is comparable to a MHHD approach. However, a MHHD should be used when assessing neck strength in extension.

Both the HHD and MHHD demonstrated good within-session reliability, which concur with the work of Garvey et al.<sup>14</sup> where ICC's of 0.80 to 0.85 were observed for flexion, side-flexion and extension in rugby union athletes. These values are, however, slightly lower than previous studies that have investigated the reliability of a MHHD to measure peak isometric lower-limb strength (ICC  $\geq$  0.90, excellent).<sup>18,21,33</sup> The intrarater reliability observed may be somewhat lower in this study due to difficulty in standardising the measurement position, joint angle and measurement site, though attempts to address this were taken, by having anatomical reference points and standardised markers on the head harness. Overall, our results support the notion that HHD and MHHD are reliable methods when assessing neck strength in rugby union players enabling practitioners to assess the changes in strength as a result of rehabilitation programmes.

The final objective of this study was to determine any potential playing position differences, with results revealing no differences in neck strength between forwards and backs in flexion, side-flexion and extension using either device. It could be argued, both testing methods lack sensitivity to detect a playing position difference, although the participants used were semi-professional and carried out limited position-specific strength training. In support of this, clear differences have been observed in neck extension and total isometric strength in elite-level rugby union academy athletes where specialized training is likely to be implemented. No significant difference was observed for flexion in the study by Geary et al.<sup>14</sup>

Whilst no difference was observed in this study, there is evidence that improving neck strength is beneficial<sup>16,27</sup> and should be a focus for practitioners. Hamilton et al.<sup>15</sup> suggested that an objective measure of neck strength is needed with a lowest acceptable value derived, particularly for those in the front row. Whilst this is beyond the scope of this study, the results confirm that the HHD when corrected or the MHHD can be used to support practitioners when determining the lowest acceptable strength in each direction with rugby union players.

This study provides useful insight for medical and sport practitioners working in rugby. However, it is not without its limitations. Due to player availability and the single club approach, we were unable to collect data on the between-session reliability or the within-session reliability with reference to two broad playing positions. The relatively small sample also results in a lack of statistical power when interpreting the concurrent validity (LoA) as well as positional differences in extension. Therefore, caution is needed by the reader when interpreting our conclusion for the lack of agreement between the HHD and MHHD when uncorrected and for the lack of difference between positions in extension. The lack of information on between-session reliability such as the typical error does limit our understanding when using the methods to assess training-related improvement or recovery of neck strength. It is important to note that both dynamometers were explicitly used with a small sample of semi-professional rugby union players, and hence, the measurement properties discussed might not be suitable when extrapolated to other sports or playing standards. Finally, we have undertaken a comparison of the same device with two assessment methods and therefore, neither method fully reflects the criterion method previously noted, albeit the practicalities associated with isokinetic dynamometer limit its use in sport and alternative methods like those used in this study provide a more feasible approach.

## **Conclusion**

When choosing a suitable method to assess neck strength in rugby union, it is important to balance the practicality and logistics associated with each method as well as the psychometric properties such as validity against a feasible criterion as well as the reliability. The results of this study support the use of a MHHD where possible to achieve a more reflective assessment of peak strength. However, when this method is not possible, a HHD can be used and the correction equations applied. The reliability for both methods was good and neither method discriminated between semi-profession rugby union forwards and backs.

### **Highlights**

- Neck strength when measured using the HHD and corrected using the regression equations is a valid measure against a MHHD and can be used by practitioners working in rugby union
- Caution is needed when measuring neck strength in extension and a MHHD should be used.
- Both methods are reliable when measuring neck strength in flexion, side-flexion and extension.
- There was no difference between semi-professional forwards and backs.

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