Manuscript Title: The concurrent validity and intrarater reliability of a hand-held dynamometer for the assessment of neck strength in semi-professional rugby union players

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ABSTRACT

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

Design: Observational design.

Setting: UK-based semiprofessional rugby club

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

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

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

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

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

1. Introduction

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

Injury prevention strategies should be a key focus for medical practitioners and strength and conditioning coaches working in rugby, with the aim of reducing concussion risk. One strategy receiving attention is neck strengthening, as research has reported an association with reduced risk of concussion and reported neck injuries.[4,11,34] In a cohort study conducted in professional rugby, Naish et al.[27] reported an improvement in neck strength and reduced cervical spine injuries during matches, following a 13-week neck-specific strengthening programme in professional male rugby union players. Similarly, Hislop et al.[16] demonstrated that an injury prevention programme, over a 4-month period including specific neck strengthening components, was effective at reducing concussion incidence in amateur rugby union players (risk ratio = 0.71). Whilst such findings are promising, it is essential for researchers and practitioners to be able to accurately measure neck strength to determine the efficacy of such programmes, establish normative data and identify a minimal threshold of acceptable neck strength[23] with respective to playing position.

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

Although HHDs are commonly used in physiotherapy, there are some issues surrounding the ‘make’ condition. This refers to the force that is applied to the HHD being equal and opposite to the force generated by muscle contraction.[30] Whilst using a HHD is suggested to be reliable in healthy populations,[23,36] there are questions over the validity of this measurement tool. Kolber and Cleland[22] conducted a literature review of HHD testing and found that the strength of the tester and the lack of adequate device stabilisation reduced the reliability and validity of the tool. This issue may be overcome in the sporting environment with a pragmatic approach of mounting the device to a fixed point. This would potentially avoid the issues of adequate stabilisation and the strength of the tester would no longer be a factor. Currently, there is no evidence on the level of concurrent validity between a HHD and a mounted HHD (MHHD) measure neck strength. In the absence of the available criterion method, it is important to establish the concurrent validity between the HHD and a 'new' criterion using a MHHD as well as assess the ability of it to discriminant between playing position and possess within-session reliability.

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

2. Methods

2.1 Participants

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

2.2 Study Procedure

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

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

2.3 Hand-held dynamometer

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

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

2.4 Mounted Hand-held Dynamometer

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

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

2.5 Statistical Analysis

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

3. Results

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

	Unstandardized coefficient		Standardized Coefficient		
Predictor variable	*B*	Standard error	Beta	*t*	Adjusted R^2
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*HHD peak force) + 4.097), extension (force = (1.122*HHD peak force) + -0.013), RSF (force = (0.855*HHD peak force) + 4.161) and LSF (force = (0.815*HHD peak force) + 5.047). The correction equations for absolute peak force were; flexion (force = (1.176*HHD peak force) - 1.465), extension (force = (0.958*HHD peak force) + 3.474), RSF (force = (0.844*HHD peak force) + 4.405) and LSF (force = (0.658*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^2
			Mean Bias	Lower 95% LOA	Upper 95% LOA	*t*	*P*	
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 *B*	Unstandardised coefficient Standard error	Standardised Coefficient Beta	Standardised Coefficient *t*	Adjusted R^2
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).

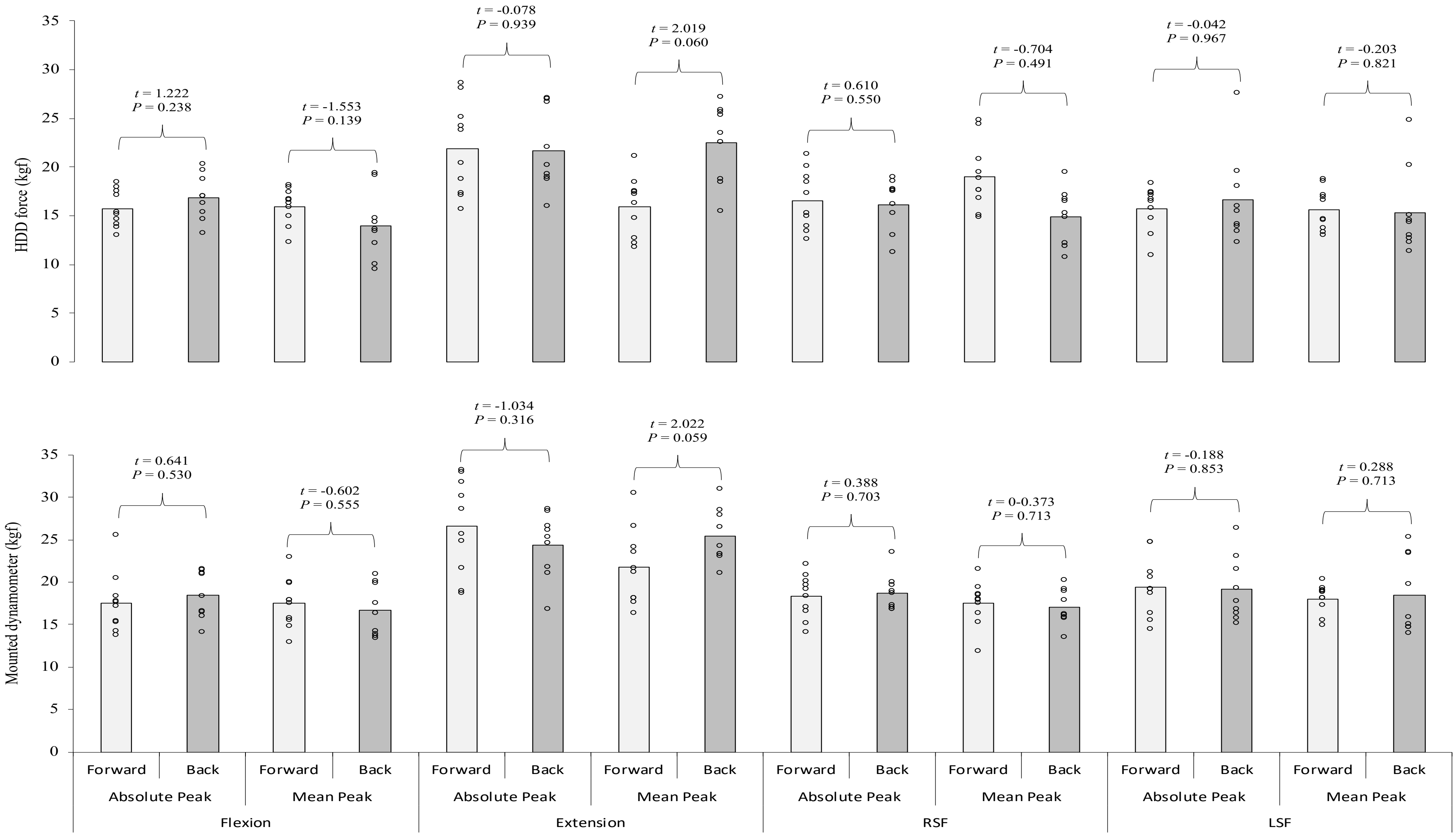

Figure 1. Between-position differences in neck flexion and extension presented as absolute and mean peak force using the HHD and MHHD.

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,[10] 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.[13,14] 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.[21,33]

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.[35] 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.[7] That said, the overall mean bias was reduced and equal to, or lower than, the minimal detectable changes previously noted.[35] 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.[14] 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 ≥ 0.90, excellent).[18,21,33] 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 in likely to be implemented. No significant difference was observed for flexion in the study by Geary et al.[14]

Whilst no difference was observed in this study, there is evidence that improving neck strength is beneficial[16,27] and should be a focus for practitioners. Hamilton et al.[15] 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.

References

1. Bitchell CL, Mathema P, Moore IS. Four-year match injury surveillance in male Welsh professional Rugby Union teams.' *Phys Ther Sport*. 2020;42:26-32.
2. Bland JM, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986;1(8476):307-310.
3. Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, Hendricks S. Tackle technique and tackle-related injuries in high-level South African Rugby Union under-18 players: real-match video analysis. *Br J Sports Med.* 2016;50(15):932-938.
4. Collins CL, Fletcher EN, Fields SK, Kluchurosky L, Rohrkemper MK, Comstock RD, Cantu RC. Neck Strength: A protective factor reducing risk for concussion in high school sports. *J Prim Prev.* 2014;35(5):309-319.
5. Coppieters M, Stappaerts K, Janssens K, Jull G. Reliability of detecting 'onset of pain' and 'submaximal pain' during neural provocation testing of the upper quadrant. *Physiother Res Int*. 2002;7(3):146-156.
6. De Vet, H. C. W., Terwee, C. B. Mokkink, L. B. and Knol, D. L. (2011) 'Measurement in Medicine: a practical guide. Cambridge University Press, Cambridge, UK.
7. Dobbin N, Hunwicks R, Jones B, Till K, Highton J, Twist C. Criterion and construct validity of an isometric midthigh-pull dynamometer for assessing whole-body strength in professional rugby league players. *Int J Sports Physiol Perform.* 2018;13(2): 235-239.
8. Du Toit DE, Buys, FJ, Venter DJL. and Olivier PE. Isokinetic evaluation of neck strength.' *SA J Sports Med*. 2004;15(3): 3-10.
9. Faul, F., Erdfelder, E., Lang, A. G. and Buchner, A. (2007) G*Power 3: a flexible statistical power analysis program for the social, behaviour, and biomedical sciences. *Behaviour Research Methods,* 39 175-191.
10. Gagnon D, Nadeau S, Gravel D, Robert J, Bélanger D, Hilsenrath M. Reliability and validity of static knee strength measurements obtained with a chair-fixed dynamometer in subjects with hip or knee arthroplasty. *Arch Phys Med Rehabil.* 2005;86(10):1998-2000.
11. Gaines A, Cripps A. Effectiveness of neck strengthening exercises on reducing brain injury. *J Sports Med Allied Health Sci.* 2017;3(1):1.
12. Gardner AJ, Iverson GL, Williams WH, Baker S. and Stanwell P. 'A systematic review and meta-analysis of concussion in rugby union'. *Sports Med*, 2014;44(12):1717-1731.
13. Geary K, Green B, Delahunt E. Effects of neck strength training on isometric neck strength in rugby union players. *Clin J Sport Med*. 2014;24(6):502-508.
14. Geary K, Green BS, Delahunt E. Intrarater reliability of neck strength measures of rugby union players using a handheld dynamometer. *J Manipulative Physiol Ther.* 2013;37(7):444-449.
15. Hamilton DF, Gatherer D, Robson J, Graham N, Rennie N, MacLean JGB, Simpson AHRW. Comparative cervical profiles of adult and under-18 front-row rugby players: implications for playing policy. *BMJ Open*, 2014;4(5):004975.
16. Hislop MD, Stokes KA, Williams S, McKay CD, England ME, Kemp SPT, Trewartha, G. Reducing musculoskeletal injury and concussion risk in schoolboy rugby players with a pre-activity movement control exercise programme: a cluster randomised controlled trial'. *Br J Sports Med.* 2017;51(15):1140-1146.
17. Hopkins WG. A scale of magnitudes for effect sizes. *SportsSci.* 2002; http://www.sportsci.org/resource/stats/effectmag.html
18. Jackson SM, Cheng MS, Smith Jr AR, Kolber MJ. Intrarater reliability of hand held dynamometry in measuring lower extremity isometric strength using a portable stabilization device'. *Musculoskelet Sci Pract.* 2017;27:137-141.
19. Jones, PA, Bampouras TM. A Comparison of isokinetic and functional methods of assessing bilateral strength imbalance. *J Strength Cond Res.* 2010;24(6):1553-1558.
20. Katoh, M., Hiiragi, Y. and Uchida, M. (2011) Validity of isometric muscle strength measurements of the lower limbs using a hand-held dynamometer and belt: a comparison with an isokinetic dynamometer. *J Phys Ther Sport,* 23, 553-557.

21. Kim WK, Kim DK, Seo KM, Kang SH. Reliability and validity of isometric knee extensor strength test with hand-held dynamometer depending on its fixation: A pilot study'. *Ann Rehabil Med.* 2014;38(1):84.
22. Kolber MJ, Cleland JA. Strength testing using hand-held dynamometry.' *Phys Ther Rev*. 2005;10(2):99-112.
23. Krause DA, Hansen KA, Hastreiter MJ, Kuhn TN, Peichel ML, Hollman JH. A comparison of various cervical muscle strength testing methods using a handheld dynamometer. *Sports Health,* 2018;11(1):59-63.
24. Manley G, Gardner AJ, Schneider KJ, et al. A systematic review of potential long-term effects of sport-related concussion'. *Br J Sports Med*. 2017;51(12): 969-977.
25. McInnes K, Friesen CL, MacKenzie DE, Westwood DA, Boe SG. Mild traumatic brain injury (mTBI) and chronic cognitive impairment: A scoping review.' *PLoS One*. 2017;12(4):e0174847.
26. Moore IS, Ranson C, Mathema P.Injury risk in international rugby union. *Orthop J Sports Med*. 2015;3(7):1-9.
27. Naish R, Burnett A, Burrows S, Andrews W, Appleby B. Can a specific neck strengthening program decrease cervical spine injuries in a men's professional rugby union team? A retrospective analysis.' *J Sports Sci Med.* 2013;12(3):524-550.
28. Oliver, PE, Du Toit, DE. Isokinetic neck strength of senior elite rugby union players. *J Sci Med Sport.* 2011;11:96-105.
29. Roberts S, Attwood M, Stokes, KA, England M, Hood K, Brown, R. *RFU Community Rugby Injury Surveillance and Prevention Project*. 2017: Available at: http://www.bath.ac.uk/health/projects/rfu-rugby-injury/documents/CRISP_Season_Report_2015-16_Main_Final_PDF.pdf [Accessed 18 Sep. 2019].
30. Scott DA, Bond EQ, Sisto SA, Nadler SF. The intra- and interrater reliability of hip muscle strength assessments using a handheld versus a portable dynamometer anchoring station.' *Arch Phys Med Rehabil*. 2004;85(4):598-603.
31. Seminati E, Cazzola D, Preatoni E, Trewartha G. Specific tackling situations affect the biomechanical demands experienced by rugby union players.' *Sports Biomech*, 2017;16(1):58-75.
32. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review'. *PM R*. 2011;3(5):472-479.
33. Sung KS, Yi YG, Shin HI. Reliability and validity of knee extensor strength measurements using a portable dynamometer anchoring system in a supine position'. *BMC Musculoskelet Disord*, 2019;20(1):320.
34. Toninato J, Casey H, Uppal M, Abdallah T, Bergman T, Eckner JT, Samadani, U. Traumatic brain injury reduction in athletes by neck strengthening (TRAIN). *Contemp Clin Trials Commun.* 2018;11:102-106.
35. Tudini F, Myers B, Bohannon R. Reliability and validity of measures of cervical retraction strength obtained with hand-held dynamometer. *J Man Manip Ther.* 2019;27(4):222-228.
36. Versteegh T, Beaudet D, Greenbaum M, Hellyer L, Tritton A, Walton D. Evaluating the reliability of a novel neck-strength assessment protocol for healthy adults using self-generated resistance with a hand-held dynamometer'. *Physiother Can.* 2015;67(1):58-64.

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