Angle-specific isokinetic shoulder rotational strength can be reliably assessed in collision and contact athletes

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ABSTRACT:

An increased understanding of rotational strength as a potential prognostic factor for injury in contact-and-collision athletes may be important in planning return to sport. The aim of this study was to (1) determine the test-retest reliability of clinically-relevant, angle-specific rotational and peak torque measurements in a cohort of uninjured collision and contact athletes, (2) develop a normal descriptive profile of angle-specific rotational torque measurements in the same cohort, and (3) examine the effects of direction and joint angle on shoulder rotational strength inter-limb asymmetries. Twenty-three collision-and-contact athletes were recruited for the inter-day reliability sub study and 47 athletes were recruited for the remaining sub studies. We used intraclass correlation coefficients with 95% confidence intervals to quantify inter-day reliability of all variables. We used a two-way repeated measures ANOVA to analyse differences in absolute inter-limb asymmetries. Inter-day reliability for the isokinetic strength variables was good-to-excellent (0.78-0.90) on the dominant side and moderate-to-good (0.63-0.86) on the non-dominant side. Maximum angle-specific torque (as well as peak torque) can be measured reliably in internally and externally-rotated positions. A normal profile of clinically-relevant, angle-specific shoulder rotational torque measurements for collision-and-contact athletes has been established which provides a reference when assessing shoulder strength in this population.

Keywords

Shoulder; return to sport criteria; isokinetic dynamometry; shoulder strength; contact athletes.

INTRODUCTION:

Shoulder injuries are common in collision and contact sports. In professional and amateur rugby shoulder injuries have been associated with a high burden attributed to their incidence, recurrence, and severity in terms of time lost from sport[1,2]. In school-boy rugby shoulder injuries were responsible for more days lost than any other injury[3]. Glenohumeral joint dislocations in particular have the potential to result in long periods of absence from play[2,3]. The high rate of recurrence associated with shoulder injuries in contact and collision sports is of concern particularly in adolescent players, warranting an improved understanding of prognostic factors associated with injury.

Isokinetic dynamometry is the preferred technique for the quantification of muscle strength in the upper limb and is the current gold standard measure to identify asymmetries in rotational peak torque[4]. It is frequently used for diagnostic purposes and to assess the outcome of therapeutic interventions and rehabilitation[5]. Some studies in overhead sports have shown an association between imbalance of the rotational torque producing muscles and development of injury during the sporting season[6,7] , yet other studies particularly involving collision and contact sports demonstrate no association[8,9]. There are fewer studies examining the normal descriptive profiling of rotational shoulder strength, and its potential as a prognostic factor for injury in contact- and collision-athletes in comparison to overhead athletes. The relationship between shoulder muscle strength balance and prognostic factor for predicting injury in this cohort of athletes remains ambiguous.

Isokinetic dynamometry is widely used to measure peak torque, clinical practitioners however, often perform manual muscle testing of rotational strength throughout range. This establishes a more comprehensive picture of shoulder-rotational-torque-producing-muscle function and helps target rehabilitation[10]. It may therefore, be important to isokinetically measure rotational torque at more functional ranges such as the position of 90° externally rotated with 90° abduction . This may be particularly important in contact and collision sports (such as rugby), where combined abduction and external rotation positions (tackler and poached positions) are associated with a higher risk of anterior dislocation[11]. Obtaining information from peak rotational torque measures alone may fail to identify inter-limb strength asymmetries of clinical relevance in the athletic population.

The reliability of isokinetic testing for measuring torque at clinically-relevant internally rotated and externally rotated angles at the glenohumeral joint has yet to be explored. Additionally, limited normative data are available regarding clinically relevant rotational strength parameters for contact and collision athletes. Establishing a normal strength profile for these athletes will provide the clinician with a valuable reference point for comparison. Therefore, the primary aim of the present study was to determine the test-retest reliability of clinically-relevant, angle-specific shoulder rotational torque and peak rotational torque measurements in a cohort of uninjured collision and contact athletes. The secondary aim of this study was to develop a normal descriptive profile of angle-specific shoulder rotational torque measurements in the same cohort . The final aim of the study was to examine the effects of direction and joint angle on shoulder rotational strength inter-limb asymmetries.

METHODS:

Study Design

This is a cross-sectional, observational study.

Participants

A convenience sample of male participants, aged 18 to 40 years of age, who were participating in competitive collision and/or contact sport ~~locally~~, were invited to take part in the study. We defined athletes that purposely hit or collide with each other or with inanimate objects ~~as part of their main sport were defined~~ as collision or contact athletes, e.g. rugby~~.~~ basketball[12]. ~~Athletes that routinely make contact with each other or with inanimate objects but usually with less force than in collision sports were defined as athletes who played contact sport, e.g. basketball[12].~~ Athletes were classified as playing at a competitive level if they ~~actively competing~~ competed in competition and/or were registered in a local, regional or national federation. ~~We excluded~~ Anyone with symptomatic upper limb pathology that had been actively managed in the last 6 months or whom had under gone upper limb surgery in the previous 12 months was excluded . We also excluded participants that had a health condition that could explain reduction in shoulder strength (e.g. ~~inflammatory arthritis,~~ neurological disorder~~), they also were excluded.~~

Section one of the study assessed the inter-day reliability of an isokinetic dynamometer in capturing torque measurements of the shoulder joint at various angles in a uninjured cohort of collision and contact athletes. Section two of the study generated a descriptive profile of the strength measurements in a uninjured cohort of collision and contact athletes. The testing took place at the biomechanics laboratory at the XXX. The study was approved by the XXX.

Test protocol

~~The~~ We recorded the athlete's height, mass and dominant limb (defined as the preferred throwing arm) ~~were recorde~~d before testing. ~~commenced. Prior to Before testing~~ Participants then completed a standardised warm-up ~~comprising~~ which consisted of two minutes of light jogging, five body-weight squats and 20 shoulder internal and external rotations against light (banded) resistance at 90° abduction. For inter-day reliability testing ~~two testing sessions were completed with a~~ the test-retest interval time between sessions was 2-9 days ~~interval between sessions~~.

Isokinetic Dynamometry

The participants performed concentric shoulder internal rotation (IR) and ER isokinetic testing at 90°/s (Cybex Humac NORM, Computer Sports Medicine, Inc., Soughton, MA, USA) as previously described[13]. The non-dominant limb was tested first ~~followed by the dominant limb~~. Participants ~~lay down in the supine position~~ lay supine with their elbow and shoulder in line with the centre of rotation of the dynamometer (Figure 1). The upper limb was rested in the rotation cuff pad, with the olecranon approximating the axis of the dynamometer and the hand gripping the input shaft. Once in position participants forearm was strapped in with velcro straps. They were asked to keep their back flat and to rest the arm not been tested on their stomach throughout testing (Figure 1). Range of motion was set to 90° of ER and 60° of IR. Participants performed a 5-repetition ~~warm up~~ familiarisation set of concentric-concentric external and internal rotation at 90°/s followed by a 60 second rest period. They then performed 2 sets of 5 maximal repetitions with a 60 second rest period between sets. During their maximal repetitions they were instructed to "push and pull as hard and as fast as you can from stopper to stopper".

Figure 1 Setup for isokinetic shoulder internal and external rotation using an isokinetic dynamometer

Data processing

All torques were gravity-corrected. The following rotational torques were extracted from the working set with the highest peak ER torque : ER peak torque; ER torque at joint angle 0°(ER0°) ; ER torque at the internally rotated position of 50° (ER50°) , ER torque at the externally rotated position of 80° (ER80°), IR peak torque, IR torque at joint angle 0° (IR0°) ; IR torque at the internally rotated position of 50° (IR50°) and IR torque at the externally rotated position of 80° (IR80°) . All variables were divided by body mass prior to analysis. Absolute inter-limb asymmetries were calculated for each variables as:

$$AbsAsymmetry = \left(1 - \frac{Minimum\ of\ Dominant\ and\ Nondominant\ limb}{Maximum\ of\ Dominant\ and\ Nondominant\ limb}\right) \times 100$$

~~This metric~~ Absolute asymmetry quantifies the percentage asymmetry for each individual for the relevant variable, regardless of whether the maximum value was obtained on the dominant or on the non-dominant limb, ~~and thus avoids the requirement~~ therefore avoiding the need to select an arbitrary reference limb for the calculation[14].

Statistical analysis

Analyses were conducted in SPSS (version 26.0, USA). Descriptive statistics (mean, standard deviation and 95% confidence intervals) were calculated for all strength variables. In addition concentric external to internal rotation strength ratios were reported for peak torque and torque of all joint angles . All dependent variables were tested for normal distribution and homogeneity of variance using the one-sample Kolmogorov–Smirnov test and the Levene’s test. As no significant deviations from normality or homogeneity of variance were identified, parametric statistical models were used. We used intraclass correlation coefficients (ICCs) (average measurement, absolute agreement, 2-way mixed-effects model) with 95% confidence intervals to quantify inter-day reliability of all variables. Values less than 0.50 were indicative of poor reliability, values between 0.50 were 0.75 indicated moderate reliability, values between 0.75 and 0.90 indicated good reliability, and values greater than 0.90 indicated excellent reliability.[15] Absolute reliability was assessed by calculating the standard error of measurement (SEM) and minimum detectable change (MDC). SEM values were calculated as follows; $SEM = SD \times \sqrt{(1 - ICC)}$, with SD referring to all measurements in the sample (both test and retest measurements). The SEM was used to calculate MDC values ; $MDC_{90} = z\text{-score (90\% CI)} \times SEM \times \sqrt{2}$ and $MDC_{95} = z\text{-score (95\% CI)} \times SEM \times \sqrt{2}$[16]. We analysed differences in absolute inter-limb asymmetries using a 2-way analysis of variance (ANOVA) for repeated measures, in which the within-subject factors were direction (2 levels) and joint angle (4 levels). In the presence of an interaction effect, direction and joint angle were tested *post hoc* at each level of the interacting variable using a Bonferroni adjustment. In the absence of an interaction effect main effects were explored. Significance was accepted at $\alpha = 0.05$.

RESULTS:

Baseline characteristics for the study are shown in Table 1.

Data from the inter-day reliability analysis for the isokinetic strength measurements are summarised in Table 2. ICC values ranged from 0.78 to 0.90 on the dominant side and from 0.63 to 0.86 on the non-dominant side. The MDC_{90} varied from 5.66 $N.m.kg^{-1}$ (ER peak torque, dominant side) to 12.62 $N.m.kg^{-1}$ (IR 0° , dominant side). The descriptive analysis and absolute inter-limb asymmetry values of the isokinetic rotational strength presented in Table 3. The isokinetic concentric external to internal rotation strength ratios are presented in Table 4.

Mauchly's test indicated that the assumption of sphericity had been violated for the interaction between direction and joint angle, therefore Greenhouse-Geisser corrected degrees of freedom are reported. There was a statistically significant interaction effect between direction and joint angle (F(2,95) = 11.88, p= <.001, ηp^2=0.205) (Figure 2). There was no significant main effect of direction on absolute asymmetry values (F(1,46) = .845, p = 3.62, ηp^2 = . 018) while was a significant main effect of joint angle on absolute asymmetry values (F(2,96) = 20.94, p = <0.001, ηp^2 = .313). Post hoc analysis showed that mean IR absolute asymmetry values were significantly different from the mean ER absolute asymmetries for IR50° (p=0.049) , a mean difference of 3.97% (95% CI, 0.10 – 7.93) % and ER80° (p=<.001), a mean difference of 10.13% (95% CI, 4.62 – 15.65) %. There was no significant difference for the effect of joint angle for the direction of IR. However all externally rotated joint angle positions were significantly different to ER80° (ER50° (p=<.001), 0° (p=<.001), peak torque (p=<.001)).

DISCUSSION:

This study determines the reliability of isokinetic testing for measuring rotational torque at angles of clinical interest and establishes a normal descriptive profile of concentric internal and external rotational strength, at these angles, in male collision- and contact-athletes. Isokinetic rotational strength can be measured with good to excellent reliability (0.78 - 0.90) on the dominant side and moderate to good reliability (0.63 – 0.86) on the non-dominant side at the various angles throughout range in this cohort of athletes. Our ICCs for torque at ER0° ; ER50°, ER80°, IR0° ; IR50° and IR80° are comparable to peak torque, the standard measurement used in isokinetic dynamometry studies. The developed profile of isokinetic strength measures and external to internal rotation strength ratios can be used clinically as a comparative for pathological shoulders in male collision and contact athletes.

Most studies on isokinetic dynamometry that examine rotational strength report peak torques[17–19]. To our knowledge this is the first study to show that maximum angle-specific torque (as well as peak torque) can be measured reliably in internally and externally rotated positions in a cohort of un-injured collision and contact athletes. The purpose of testing rotational strength throughout range in an un-injured cohort of athletes is to allow us to identify potential 'normal' inter-limb asymmetry in vulnerable positions of the shoulder (e.g. towards the 90° externally rotated position with 90° abduction) and to establish a more comprehensive picture of the shoulder rotational torque-producing muscles in this cohort of athletes. Our results also show higher reliability for ER on the dominant side (0.78 - 0.90) compared to the non- dominant side (0.63 – 0.77). This may have clinical relevance in a pathological population. As the non-dominant limb may not be as reliable to test as the dominant limb in ER, direct side-to-side comparison in clinical practice should be interpreted with caution. We recommend that clinicians are aware of the SEM and MDC values to help determine meaningful change and baseline descriptive scores are continually established as reference.

Comparison of our data with that of other studies showed that the peak torques of ER (44.6 n.m.kg^{-1} dominant side, 44.7 n.m.kg^{-1} non- dominant side) and IR (58.7 n.m.kg^{-1} 1 dominant side, 59.1 n.m.kg^{-1} non- dominant side) are greater than isokinetic rotational strength described in un-injured overhead athletes, such as baseball, volleyball, water polo, and handball players[18,20]. Differences in how these populations train and prepare for their sport compared to contact and collision athletes can affect the strength and role of the rotational torque producing muscles. It is therefore imperative that reference values are available for unique cohorts of athletes. However we acknowledge that it remains extremely difficult to make direct comparison with other studies as there is still large variation on the angular velocity chosen, mode of contraction and position of participant during testing.

Inter-limb asymmetries were between 8.3% and 22.8%. Asymmetry magnitude for torque at ER80° (22.8±16.7%) was significantly greater than torque at all other joint angles of ER. Asymmetry magnitude for IR was significantly different to ER at joint angle of IR50° and ER80° . As the torque that athletes can generate is less at ER80 (22.5 N.m.kg-1 on the dominant side and 20.2 N.m.kg-1 on the non-dominant side), the percentage magnitude of difference will consequently be greater. Several studies have reported inter-limb asymmetries in healthy uninjured throwing athletes using isokinetic dynamometry and report broadly aiming for no more than 10% difference between dominant throwing arm and the non-dominant arm[21,22]. However in a cohort of rugby players Edouard et al. (2009)[23] found no significant difference between the dominant and non-dominant side for IR and ER concentric and eccentric muscle strength. It is important to note that for the majority of studies examining isokinetic rotational strength, inter-limb asymmetries have been reported as a percentage with distinctions being made between dominant and non-dominant limbs . Directional asymmetries may run the risk over interpreting the magnitude of asymmetry in normative cohorts and potentially setting unrealistic targets for an injured group[24]. In this study we present absolute asymmetry values. Absolute asymmetry values remove information regarding the direction of the asymmetry and hence the values are unaffected by reference values and potentially inflated scores[14]. Absolute asymmetry values will allow for a more standardised comparison to an injured group[24].

The isokinetic peak torque ratio values reported in adult overhead athletes are often between 66 and 75%, such that external rotators are at least two-thirds the strength of the internal rotators in the concentric mode[20]. Our peak torque ER:IR ratios are between 77 and 78%, suggesting that contact and collision athletes are less likely to develop stronger internal rotators compared to overhead athletes. They are slightly higher than a previous study examining isokinetic peak torque in rugby players[23]. However, we must draw caution from making too many comparisons due to differing methodologies used in the studies and the heterogenous population of collision and contact athletes used in our study. Our study also showed ER:IR ratio varied between 0.43 and 1.07 depending on joint angle. At ER80° the external rotators are less than half the strength of the internal rotators (0.48 for the dominant side and 0.43 for the non-dominant side). Although not directly comparable, it has been shown that isometric ER:IR ratio, measured with a handheld dynamometer, is similarly lower in the position of 90° of ER with 90° abduction in overhead male athletes, varying from 0.59 in the dominant hand 0.67 in the non-dominant side[25]. Our substantially lower ER:IR ratio at ER80° may be suggestive that the external rotators of contact and collision athletes are relatively weaker compared to the internal rotators in the abducted and externally rotated position. However, as this is the first exploratory study, to our knowledge, examining isokinetic torque at these joint angles, further studies are required to confirm findings. At IR50°, the external rotators are stronger than the internal rotators. These ratios are of interest as a comparative for pathological shoulders in contact and collision male athletes as ER:IR ratios are often used as a benchmark for return to sport.

STRENGTHS AND LIMITATIONS:

This is the first study examining the reliability of maximum angle-specific rotational torque (as well as peak torque) at the glenohumeral joint, however some limitations should be noted. We tested male athletes across a variety of collision and contact sports. Since shoulder rotational strength measurements and ratios are likely to be affected by the type of contact / collision sport played this will impact the generalisability of our results. Our population sample is also heterogenous for level of sport, including recreational and semi-professional athletes. We cannot extrapolate the results to injured athletes, female athletes or other sporting populations. In addition we only captured concentric IR and ER rotation strength measurements. There is a different pattern of torque production with isokinetic eccentric activity, however this may be of greater interest in the throwing athlete rather than the contact and collision athlete, where functionally specific eccentric activity is considered important. For angular velocity we limited ourselves to 90°/s. We may be missing clinically relevant data from higher velocities. However, in a pilot study we found that preset angular velocities higher than 90°/s could not be maintained during the whole movement trajectory and we therefore had to conduct testing at a slower angular velocity to obtain more reproducible measurements.

CONCLUSION:

Obtaining information from peak rotational torque measures alone could fail to identify shoulder rotational strength asymmetries of clinical relevance in the athletic population. The results of this study demonstrate maximum angle-specific isokinetic shoulder rotational strength can be reliably assessed in collision and contact athletes. The developed profile of isokinetic strength during internal and external rotation can be used clinically as a comparative to pathological shoulders in this cohort. ER:IR ratio varies depending on joint angle. At IR50°, the external rotators are stronger than the internal rotators while at ER80° the external rotators are less than half the strength of the internal rotators. Future research is required to determine whether the same or greater inter-limb asymmetries occur in injured or symptomatic shoulders.

Data availability request:

The data that support the findings of this study are available from the corresponding author upon request

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TABLES:

Table 1 *Baseline characteristics of A) reliability study and B) descriptive profile*

	Reliability Study	Descriptive Study
n	23	47
Age (years)	25.3+/-4.8	27.3+/-5.4
Height (cm)	177.8 +/-5.6	175.9 +/-24.3
Weight (kg)	78.5+/-10.1	85.5+/-11.4
Sport		
%Gaelic Football	26%	36%
%Rugby	18%	34%
%Soccer	26%	13%
% Mixed Martial Arts	4%	7%
%Multiple	9%	2%
%Hurling	4%	7%
%Basketball	0%	2%
%Field Hockey	13%	0%
Level of Participation		
%Recreational	91%	77%
%Semi-Professional	9%	23%
Dominance		
%Right	96%	85%
%Left	4%	15%

Table 2 *Inter-day reliability with their 95 % CI for the isokinetic strength measurements*

	Inter Session Reliability (Test-retest)							
	Dominant				Non-Dominant			
	ICC (95% CI)	SEM	MDC_{90}	MDC_{95}	ICC (95% CI)	SEM	MDC_{90}	MDC_{95}
(n=23)								
ER Peak Torque ($N.m.kg^{-1}$)	0.90 (0.75,0.96)	2.04	4.77	5.66	0.66 (0.19,0.86)	3.36	7.85	9.32
ER0° ($N.m.kg^{-1}$)	0.80 (0.51,0.91)	2.54	5.92	7.04	0.63 (0.10,0.84)	3.78	8.81	10.47
ER50° ($N.m.kg^{-1}$)	0.87 (0.69,0.95)	2.27	5.31	6.30	0.66 (0.20,0.86)	3.50	8.17	9.70
ER80° ($N.m.kg^{-1}$)	0.78 (0.49,0.91)	2.86	6.67	7.92	0.77 (0.44,0.90)	3.01	7.03	8.35
IR Peak Torque ($N.m.kg^{-1}$)	0.78 (0.50,0.90)	5.72	13.35	15.86	0.86 (0.68,0.94)	4.01	9.34	11.09
IR0° ($N.m.kg^{-1}$)	0.78 (0.48,0.90)	5.41	12.62	14.99	0.80 (0.53,0.91)	4.74	11.05	13.13
IR50° ($N.m.kg^{-1}$)	0.80 (0.53,0.91)	3.98	9.28	11.03	0.72 (0.36,0.88)	4.77	11.12	13.21
IR80° ($N.m.kg^{-1}$)	0.86 (0.67,0.94)	3.84	8.95	10.64	0.76 (0.48,0.90)	4.61	10.77	12.79

CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SEM, standard error of measurement; ER, external rotation; IR, internal rotation; ER0°, ER torque at joint angle; ER50°, ER torque at the internally rotated position of 50°; ER80°, ER torque at the externally rotated position of 80°; IR0°, IR torque at joint angle 0°; IR50°, IR torque at the internally rotated position of 50° ; IR80°, IR torque at the externally rotated position of 80°

Table 3 *Isokinetic concentric external and internal rotation strength*

	Limb Normative Data Mean +/-Standard Deviation (95% Confidence Interval)		
Measure	Dominant	Non-Dominant	Absolute Asymmetry
(n=47)			
ER Peak Torque (N.m.kg-1)	44.6+/- 7.8(42.3, 46.9)	44.7 +/-7.2 (42.6, 46.8)	8.4 +/- 5.6(6.8,10.7)
ER80° (N.m.kg-1)	22.5 +/-6.2(20.7,24.3)	20.2 +/- 6.7 (18.3, 22.2)	22.8 +/-16.7(17.9,27.7)
ER0° (N.m.kg-1)	39.2 +/-7.4 (37.0,41,2)	39.5 +/- 7.0 (37.4,41.5)	9.8 +/-8.2 (7.4,12.3)
ER50°(N.m.kg-1)	40.4 +/-7.0 (38.4,42,5)	40.1 +/- 7.0 (38.0,42.1)	8.3 +/-5.8 (6.6,10.0)
IR Peak Torque (N.m.kg-1)	58.7 +/- 11.0 (55.5,61.9)	59.1 +/- 13.7 (55.1,63.2)	9.8 +/- 7.4 (7.6,12.0)
IR80° (N.m.kg^{-1})	48.1 +/- 9.6 (45.3,50.9)	48.5 +/- 11.7 (45.0,51.9)	12.6 +/-8.4 (10.2,15.1)
IR0° (N.m.kg-1)	51.3 +/- 10.0 (48.3,54.2)	51.1 +/- 10.0 (47.6,54.6)	10.2 +/-8.8 (7.6,12.8)
IR50° (N.m.kg^{-1})	39.7 +/- 9.2 (37.0,42.4)	41.4 +/-10.3 (38.2,44.3)	12.2 +/-11.6 (8.8,15.6)

ER, external rotation; IR, internal rotation; ER0°, ER torque at joint angle; ER50°, ER torque at the internally rotated position of 50°; ER80°, ER torque at the externally rotated position of 80°; IR0°, IR torque at joint angle 0°; IR50°, IR torque at the internally rotated position of 50° ; IR80°, IR torque at the externally rotated position of 80°

Table 4 *Isokinetic concentric external: internal rotation strength ratio*

Mean +/-Standard Deviation (n=47)							
ER:IR Peak Torque		ER:IR 80° ER		ER:IR 0°		ER:IR 50° IR	
D	ND	D	ND	D	ND	D	ND
0.77 +/-0.12	0.78 +/-0.13	0.48 +/-0.14	0.43 +/- 0.15	0.78 +/-0.14	0.79 +/-0.13	1.07 +/-0.36	1.01 +/-0.21

FIGURES:

Figure 1 *Setup for isokinetic shoulder internal and external rotation using an isokinetic dynamometer*

(new picture)

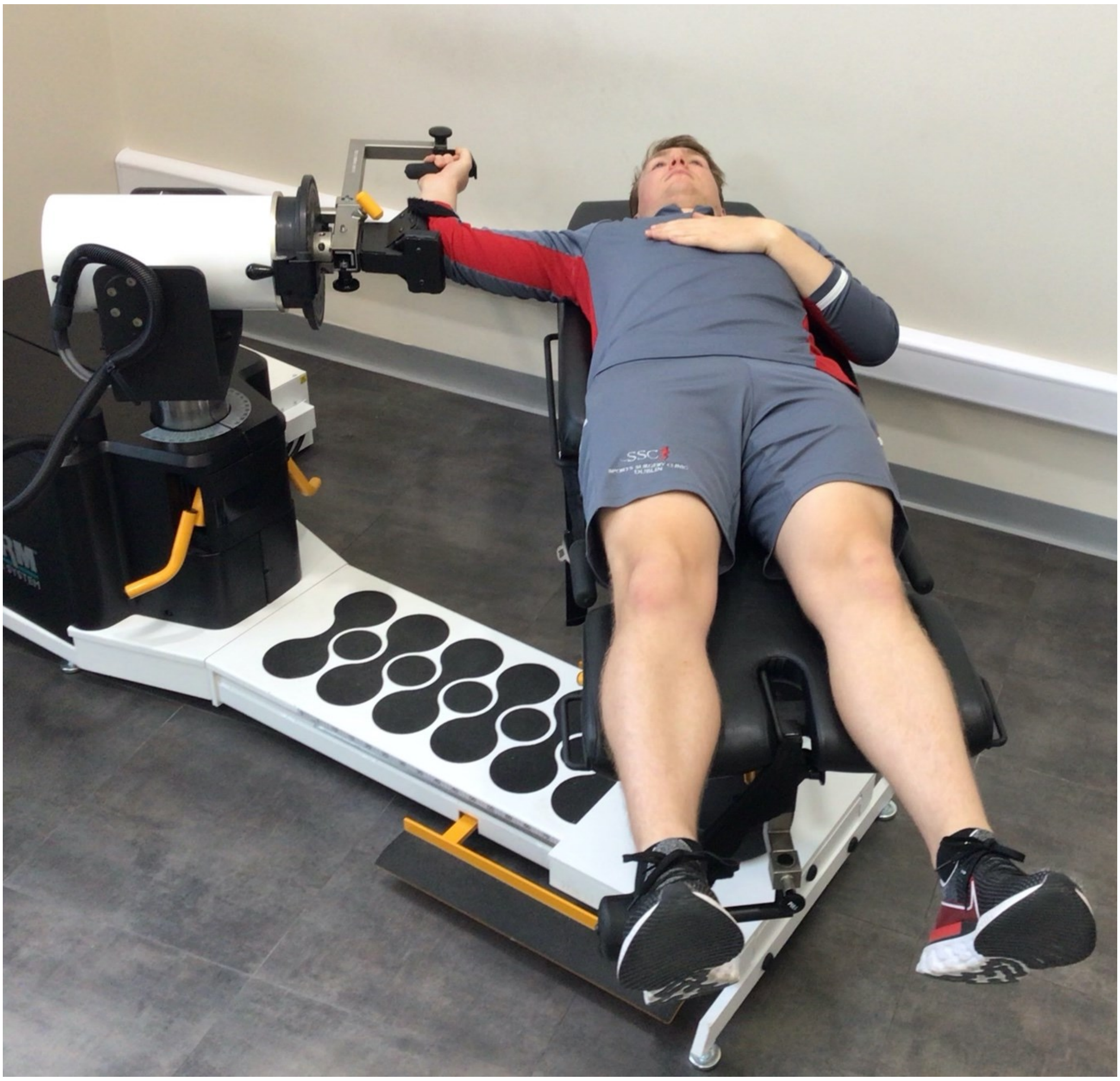

Figure 2 *Profile plot for interaction effect between direction and joint angles*