RESEARCH ARTICLE

The Reliability of Throwing-related Musculoskeletal Screening Tests Commonly Used in Cricket

Steve McCaig[1], Craig Ranson[2], Andrew Miles[3], Isabel Moore[4]

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ABSTRACT

Aim and background: Throwing arm pain (TAP) is common in cricketers and can negatively affect performance. Understanding the factors contributing to TAP is essential for developing prevention strategies. This study aimed to assess the intrarater reliability of musculoskeletal screening tests frequently used to identify TAP risk factors.

Methods: A total of 10 male cricket players from a United Kingdom University Cricket Center of Excellence participated. A single tester, experienced in musculoskeletal screening, performed three consecutive trials of field-based tests to evaluate scapulothoracic posture, shoulder, elbow, and hip range of motion, and shoulder strength. Intrarater reliability was assessed using the intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC).

Results: Most musculoskeletal measures demonstrated good to excellent reliability. The mean of three trials showed consistently higher ICCs and lower SEMs than a single trial. Measures of asymmetry had lower ICCs and higher SEMs but generally demonstrated acceptable reliability.

Conclusion: The intrarater reliability of musculoskeletal tests for TAP in cricket players was generally acceptable. Using the mean of three trials is recommended to detect differences between individuals or groups and assess changes over time. While most measures demonstrated good reliability, measures of asymmetry require careful interpretation. These findings contribute to the understanding of musculoskeletal screening and aid researchers and clinicians in using these tests effectively for cricketer injury prevention and management. Further studies are needed to evaluate interrater reliability and the association between these screening measures and TAP susceptibility.

Keywords: Cricket, Elbow, Injury, Screening, Shoulder, Throwing.

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INTRODUCTION

Throwing is an essential part of fielding in cricket, and the ability to throw accurately at high velocity is considered critical for performance.[1] Shoulder and elbow pain, which has been termed throwing arm pain (TAP),[2] is common in throwing sports and has been reported to affect performance in cricketers,[3] therefore, there is a need to understand the factors which contribute to TAP in order to develop prevention strategies.

Musculoskeletal screening has been proposed as a method to identify intrinsic risk factors for injuries that can then be addressed with targeted interventions; however, despite its widespread use, there is little evidence at present to support its efficacy in modifying injury risk, and few studies have attempted to validate a screening protocol.[4] The first step in validating a screening protocol requires risk factors with defined injury risk cut-off values to be identified, which depends upon our ability to measure them accurately.[5]

Several reliability studies have been conducted on field-based tests commonly performed on throwing athletes.[6–10] Most of these studies investigated only a single test or tests related to one joint or physical quality; they were not performed on throwing athletes, and side dominance was not considered. In most screening protocols, a battery of tests is performed on a specific group of athletes within a brief period,[11] therefore, the findings of these studies may not be representative of the real-world test application. Studies have often used different measures to calculate reliability, with the mean of three measures being the most common.[6–10] In practice, due to time constraints, it may not be appropriate to take multiple measures, and therefore it is preferable that the first trial has acceptable reliability.[12]

Asymmetries between the dominant and nondominant upper limbs are considered TAP risk factors.[13–15] In throwers, asymmetry is usually calculated by subtracting the measurement of the nondominant side from the dominant side, yet despite the widespread use of asymmetry measures clinically in throwers, the reliability of these measures has received little attention.[16,17] In contrast, in the lower limb, interlimb asymmetry is usually expressed as a percentage difference between limbs. Several different methods can be used to calculate this percentage difference, and it is recommended that the method chosen should vary depending on the nature of the sport.[18] At present, the reliability of these measures has not been assessed in the upper limbs of throwing athletes.

[1,2] UK Sports Institute, Manchester, England, United Kingdom; Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, United Kingdom

[3,4] Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, United Kingdom

Corresponding Author: Craig Ranson, UK Sports Institute, Manchester, England, United Kingdom; Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, United Kingdom, e-mail: craigranson@me.com

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The aim of this study was to assess the intrarater reliability of a single tester performing a battery of musculoskeletal screening tests used to identify risk factors associated with TAP. The reliability of measures calculated from these tests, such as asymmetry measures, was also determined. For each test, the reliability for both a single measure and the mean of three trials was assessed, with side dominance considered for each bilateral measure. It was hypothesized that all measures would have acceptable levels of reliability but that the measures of asymmetry would have lower levels of reliability.

METHODS

Participants

A total of 10 members of a male United Kingdom University Cricket Center of Excellence squad participated in the study. To be included, participants had to be fully participating in off-season training with the squad at the time of the study, and all participants were familiar with musculoskeletal screening. Prior to testing, each participant received an outline of the testing protocol from the tester before informed consent was obtained. The tester was a physiotherapist with postgraduate qualifications in manipulative therapy and 20 years of experience as a clinician, with the last 10 of those years working exclusively in cricket, where they regularly performed musculoskeletal screening.

Ethical approval was approved by the Cardiff Metropolitan University Ethics Committee.

Musculoskeletal Screening Protocol

The musculoskeletal screening protocol consisted of several field-based tests thought to be risk factors associated with TAP, which are commonly used in musculoskeletal screening test batteries. These tests included measures of scapulothoracic posture, shoulder, elbow, and hip range of motion, and shoulder strength measures. An outline of each test is provided in Appendices 1 to 3.

Equipment

The following equipment was required to perform the musculoskeletal screening tests; gravity dependant inclinometer (Isomed Inc., 975 SE Sandy Blvd, Portland, Oregon 97214, United States of America), digital inclinometer (Solatronic model EN17, Fisco Tools Limited Essex SS6 7XD Great Britain), Economy Jamar 32 cm Plastic Goniometer (Patterson's Medical Ltd., Bolingbrook, Illinois, 60440, United States of America), Jamar Plus+ Digital Dynamometer (Patterson Medical Ltd., Warrenville, Illinois 60555, United States of America), Lafayette manual muscle tester (Model No. 01165, Lafayette Instrument, Lafayette, Indiana, 47904, United States of America), and a nonstretch tape measure.

Data Collection

Participants were required to attend one testing day, where the tester performed each musculoskeletal screening test three times in succession in the same order each time. The examiner verbally relayed the measurement to the assistant, who recorded each set of measurements on an individualized data sheet.

All bilateral measurements were recorded according to hand dominance. The dominant hand was identified as the hand they would throw or bowl. Any cricketer who threw or bowled with opposite hands was excluded as a dominant hand could not be defined. The results were used to calculate other measures, such as total rotation range, IR:ER strength ratio, and measures of asymmetry. The total rotation range of motion was calculated for both dominant and nondominant sides by adding the magnitude of the external rotation range to the magnitude of the internal rotation range. IR:ER strength ratio was calculated using the following equation:

$$R{:}ER\ \text{strength ratio} = \frac{\text{Internal rotation strength(maximum)}}{\text{External rotation strength(maximum)}}$$

Two different measures of asymmetry were calculated. The side-to-side difference was calculated for each bilateral measure using the below equation:

$$\text{Side to side difference} = DOM - NDOM$$

The Asymmetry Index (Robinson, Herzog, and Nigg, 1987) is considered the most appropriate method to calculate the percentage of limb asymmetry in sports which are unilateral in nature, and there is a dominant (DOM) and nondominant (NDOM) side (Bishop et al.). It was calculated using the below equation:

$$\text{Asymmetry index}(\%) = \frac{DOM - NDOM}{\left(\frac{DOM + NDOM}{2}\right)} \times 100$$

Data Analysis

Means and standard deviations were calculated for all dependent variables, and normality assumptions were tested using Shapiro–Wilk test. A one-way ANOVA (for normally distributed variables) or Kruskal–Wallis (for non-normally distributed variables) test was then used to determine if any systematic differences existed between trials one, two, and three for each musculoskeletal screening test for each session. As there were no systematic differences between trials one, two, or three for all measures, intrarater reliability was then assessed for each screening test.

Intrarater and intersession reliability was then determined using intraclass correlation coefficient (ICC), with 95% confidence intervals (CI), standard error of measurement (SEM), and minimal detectable change (MDC) then calculated. The analysis of intrarater reliability involved determining the reliability for either the first measurement for a range of motion or posture tests or maximum strength measure; and the mean of three measurements, as well as for measures of bilateral difference and asymmetry. This was conducted using Statistical Package for the Social Sciences version 24 software, IBM. The ICC model selected was the two-way random, single measure, absolute agreement for the first trial or maximum strength recorded, and two-way random, average measures, absolute agreement for the mean of three trials (Cools et al.). ICC interpretation was based on a previous reliability study of similar musculoskeletal tests (Cools et al.). ICCs were considered either; low (<0.70), moderate (0.71–0.80), good (0.81–0.90), or excellent (>0.90), with an ICC >0.6 considered acceptable for musculoskeletal screening in sports research (Hayen et al.). The SEM was calculated as follows equation:

$$SEM = SD \times \sqrt{1 - ICC}$$

Where SD is the standard deviation of the first testing session, SEM was expressed in the same units as the test measured (e.g., degrees or mms). MDC was calculated using the following equation and was expressed in the unit used in the test (Weir, 2005).

$$MDC = SEM \times 1.65 \times \sqrt{2}$$

RESULTS

The normative values for each musculoskeletal measure for both testing sessions one and two and the results of the reliability analysis are summarized in Tables 1 to 7.

Table 1: Intrarater reliability for measurements of scapulothoracic posture

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC (95% CI)*	*Classification*	*SEM*	*MDC*
Thoracic kyphosis T1–2 (°)	First trial	24.8 (±8.0)	25.6 (±6.9)	0.89 (0.63–0.97)	Good	2.7	6.2
	The mean of three trials	24.8 (±7.5)	25.5 (±6.9)	0.97 (0.87–0.99)	Excellent	1.3	3.0
Thoracic kyphosis T11–T12 (°)	First trial	11.6 (+6.1)	10.1 (±5.5)	0.9 (0.60–0.98)	Excellent	1.9	4.5
	The mean of three trials	11.6 (+6.1)	10.2 (±5.5)	0.96 (0.79–0.99)	Excellent	1.2	2.9
Thoracic kyphosis total (°)	First trial	36.4 (+12.4)	35.7 (±10.8)	0.94 (0.77–0.94)	Excellent	3.0	7.1
	The mean of three trials	36.4 (±11.7)	35.8 (±11.1)	0.98 (0.93–1)	Excellent	1.7	3.9
The root of the spine of the scapula to spine DOM (mm)	First trial	90.3 (±17.8)	90.2 (±15.7)	0.93 (0.74–0.98)	Excellent	4.7	11.0
	The mean of three trials	91.4 (±17.9)	90.7 (±15.1)	0.96 (0.83–0.99)	Excellent	3.6	8.4
The root of the spine of the scapula to spine NDOM (mm)	First trial	91.0 (±10.2)	92.2 (±10.4)	0.92 (0.71–0.98)	Excellent	2.9	6.7
	The mean of three trials	90.8 (±9.9)	92.3 (±10.9)	0.97 (0.87–0.99)	Excellent	1.7	4.0
The root of the spine of the scapula to spine difference (mm)	First trial	−0.7 (±16.2)	−2.0 (±13.6)	0.85 (0.5–0.96)	Good	6.3	14.6
	The mean of three trials	0.6 (±15.7)	−1.5 (±12.9)	0.9 (0.6–0.97)	Excellent	5.0	11.6
The root of the spine of the scapula to spine asymmetry (%)	First trial	−2.0 (+17.3)	−3.0 (±14.8)	0.87 (0.55–0.97)	Good	6.2	14.6
	The mean of three trials	−0.6 (±16.6)	−2.3 (±14.0)	0.91 (0.64–0.98)	Excellent	5.0	11.6
Scapula inferior angle to spine DOM (mm)	First trial	101.3 (±5.9)	101.1 (±8.3)	0.8 (0.36–0.95)	Good	2.6	6.2
	The mean of three trials	102.2 (±6.0)	101.4 (±8.2)	0.92 (0.68–0.98)	Excellent	1.7	4.0
Scapula inferior angle to spine NDOM (mm)	First trial	96.4 (±7.5)	97.8 (±7.4)	0.9 (0.67–0.97)	Excellent	2.4	5.5
	The mean of three trials	96.2 (±8.2)	98.9 (±7.5)	0.94 (0.76–0.99)	Excellent	2.0	4.7
Scapula inferior angle to spine difference (mm)	First trial	4.9 (±6.2)	3.3 (±5.5)	0.65 (0.11–0.90)	Low	3.7	8.6
	The mean of three trials	6 (±7.1)	3.4 (±5.6)	0.81 (0.29–0.95)	Good	3.2	7.4
Scapula inferior angle to spine asymmetry (%)	First trial	5.1 (±6.3)	3.3 (±5.6)	0.61 (0.06–0.89)	Low	3.9	9.2
	The mean of three trials	6.3 (±7.3)	3.3 (±5.7)	0.78 (0.21–0.95)	Moderate	3.4	8.0
Scapula spine rotation DOM (°)	First trial	0.0 (±4.5)	1.2 (±u5.6)	0.88 (0.6–0.97)	Good	1.6	3.6
	The mean of three trials	−0.1 (±4.9)	0.9 (±5.4)	0.96 (0.83–0.99)	Excellent	1.0	2.3
Scapula spine rotation NDOM (°)	First trial	−1.1 (±4.6)	−1.5 (±4.8)	0.97 (0.9–0.99)	Excellent	0.8	1.9
	The mean of three trials	−1 (±4.5)	−1.1 (±5.0)	0.99 (0.96–1)	Excellent	0.5	1.1
Scapula spine rotation difference (°)	First trial	1.1 (±4.5)	2.7 (±4.4)	0.79 (0.34–0.94)	Moderate	2.1	4.9
	The mean of three trials	0.97 (±5.3)	2.0 (±4.9)	0.95 (0.8–0.99)	Excellent	1.2	2.8

Table 2: Intrarater reliability for measurements of pectoralis minor length

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC (95% CI)*	*Classification*	*SEM*	*MDC*
Pectoralis minor length DOM (mm)	First trial	64.1 (±8.5)	64.4 (±7.4)	0.91 (0.67–0.98)	Excellent	2.6	6.0
	The mean of three trials	64.4 (±8.9)	64.6 (±7.5)	0.96 (0.81–0.99)	Excellent	1.8	4.2
Pectoralis minor length NDOM (mm)	First trial	59.8 (±10.7)	58.6 (±9.9)	0.95 (0.81–0.99)	Excellent	2.4	5.6
	The mean of three trials	59.5 (±11.1)	58.4 (±9.8)	0.97 (0.89–0.99)	Excellent	1.9	4.5
Pectoralis minor length difference (mm)	First trial	4.3 (±3.3)	5.8 (±3.8)	0.61 (0.07–0.88)	Low	2.1	4.9
	The mean of three trials	4.9 (±3.1)	6.2 (±4.2)	0.69 (−0.13–0.92)	Low	1.7	4.0
Pectoralis minor length asymmetry (%)	First trial	7.6 (±6.4)	10.2 (±7.6)	0.69 (0.19–0.91)	Low	3.6	8.5
	The mean of three trials	8.6 (±6.2)	10.9 (±8.4)	0.76 (0.11–0.94)	Moderate	3.0	7.1

Scapulothoracic Posture and Pectoralis Minor Length

All scapulothoracic postural and pectoralis minor length measures demonstrated good to excellent reliability (ICC 0.85–0.99) (Tables 1 and 2). The reliability of all asymmetry measures using the distance between the root of the spine of the scapula and the spine and the spine of scapula rotation was either good or excellent (ICC 0.85–0.95), except for trial one for the spine of scapula rotation, which was moderate (ICC 0.78). While all asymmetry measures for the distance between the inferior angle of the scapula and the spine and pectoralis minor length were either low or moderate (ICC between 0.6 and 0.78), except for the mean inferior angle to spine difference which was good (ICC 0.81). SEMs for all scapulothoracic and pectoralis minor length measures varied between 1.7 mm and 6.3 mm for linear measures, 0.5° and 3° for angular measures, and 3.0–6.2% for all asymmetry indices.

Shoulder and Elbow Measures

All shoulder rotation and elbow extension measures demonstrated good to excellent reliability (ICC between 0.88 and 0.99), except for total rotation difference and asymmetry on trial one, which were

Table 3: Intrarater reliability for measurements of shoulder rotation range of motion

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC (95%CI)*	*Classification*	*SEM*	*MDC*
External rotation DOM (°)	First trial	123.7 (±8.2)	124.3 (±8.2)	0.88 (0.6–0.97)	Good	2.8	6.6
	The mean of three trials	124 (±8.6)	124 (±8.2)	0.96 (0.83–0.99)	Excellent	1.7	4.0
External rotation NDOM (°)	First trial	112.1 (±8.7)	112.2 (±6.4)	0.89 (0.63–0.97)	Good	2.9	6.7
	The mean of three trials	112.7 (±8.7)	111.9 (±6.3)	0.96 (0.84–0.99)	Excellent	1.7	4.1
External rotation difference (°)	First trial	11.6 (±12)	12.1 (±10.2)	0.94 (0.77–0.98)	Excellent	2.9	6.9
	The mean of three trials	11.3 (±12.9)	12 (±10.4)	0.96 (0.85–0.99)	Excellent	2.6	6.0
External rotation asymmetry (%)	First trial	2.5 (±2.6)	2.5 (±2.2)	0.94 (0.77–0.98)	Excellent	0.6	1.5
	The mean of three trials	2.4 (±2.8)	2.5 (±2.2)	0.96 (0.86–0.99)	Excellent	0.6	1.3
Internal rotation DOM (°)	First trial	60.1 (±12.8)	59.1 (±12.3)	0.92 (0.72–0.98)	Excellent	3.2	7.5
	The mean of three trials	60.4 (±11.8)	59.9 (±11.4)	0.95 (0.81–0.99)	Excellent	2.6	6.2
Internal rotation NDOM (°)	First trial	76.8 (±9.2)	76.5 (±10.5)	0.92 (0.71–0.98)	Excellent	2.6	6.1
	The mean of three trials	76 (±9.4)	76.4 (±9.8)	0.97 (0.9–0.99)	Excellent	1.6	3.8
Internal rotation difference (°)	First trial	−16.7 (±15.4)	−17.4 (±18.4)	0.91 (0.68–0.98)	Excellent	4.6	10.8
	The mean of three trials	−15.6 (±15.5)	−16.5 (±17.1)	0.96 (0.85–0.99)	Excellent	3.1	7.2
Internal rotation asymmetry (%)	First trial	−6.3 (±6)	-6.6 (±7.2)	0.91 (0.68–0.98)	Excellent	1.8	4.2
	The mean of three trials	−5.9 (±6.2)	−6.2 (±6.7)	0.96 (0.85–0.99)	Excellent	1.2	2.9
Total rotation DOM (°)	First trial	183.8 (±12.5)	183.4 (±12.4)	0.99 (0.96–1)	Excellent	1.3	2.9
	The mean of three trials	184.4 (±13.7)	183.8 (±12.3)	0.98 (0.93–1)	Excellent	1.9	4.5
Total rotation NDOM (°)	First trial	188.9 (±10.3)	188.7 (±10.8)	0.80 (0.37–0.95)	Good	4.5	10.5
	The mean of three trials	188.8 (±10)	188.3 (±9.8)	0.94 (0.74–0.98)	Excellent	2.5	5.7
Total rotation difference (°)	First trial	−5.1 (±7.6)	−5.3 (±10.4)	0.75 (0.26–0.93)	Moderate	3.7	8.7
	The mean of three trials	−4.3 (±8.5)	−4.5 (±9.5)	0.90 (0.59–0.98)	Excellent	2.7	6.3
Total rotation asymmetry (%)	First trial	−0.7 (±1)	−0.7 (±1.4)	0.76 (0.26–0.93)	Moderate	0.5	1.1
	The mean of three trials	−0.6 (±1.1)	−0.6 (±1.3)	0.90 (0.58–0.98)	Excellent	0.4	0.8

Table 4: Intrarater reliability for elbow range of motion and postural measures

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC (95% CI)*	*Classification*	*SEM*	*MDC*
Extension DOM (°)	First trial	2.1 (±5.6)	3.8 (±5.7)	0.93 (0.29–0.98)	Excellent	1.5	3.5
	The mean of three trials	2.4 (±5.2)	3.7 (±5.8)	0.98 (0.37–0.99)	Excellent	0.7	1.7
Extension NDOM (°)	First trial	3.8 (±4.1)	4.8 (±4.2)	0.88 (0.57–0.97)	Good	1.4	3.3
	The mean of three trials	4.5 (±4.3)	4.0 (±4)	0.96 (0.85–0.99)	Excellent	0.9	2.0
Extension difference (°)	First trial	−1.7 (±3.9)	−1.0 (±3.1)	0.89 (0.64–0.97)	Good	1.3	3.0
	The mean of three trials	−2.1 (±3.9)	−0.3 (±3.4)	0.88 (0.22–0.97)	Good	1.4	3.3
Valgus carrying angle DOM (°)	First trial	15.2 (±3.2)	14.9 (±5.7)	0.79 (0.33–0.94)	Moderate	1.5	3.4
	The mean of three trials	15.4 (±2.8)	15.3 (±5.5)	0.89 (0.54–0.97)	Good	0.9	2.2
Valgus carrying angle NDOM (°)	First trial	11.7 (±2.8)	12.2 (±3.5)	0.83 (0.49–0.96)	Good	1.2	2.7
	The mean of three trials	11.9 (±3.3)	12.3 (±3.5)	0.95 (0.8–0.99)	Excellent	0.7	1.7
Valgus carrying angle difference (°)	First trial	3.5 (±3)	2.7 (±3.6)	0.59 (−0.01–0.88)	Low	1.9	4.5
	The mean of three trials	3.5 (±2.1)	2.9 (±3.3)	0.60 (−0.74–0.90)	Low	1.3	3.1
Valgus carrying angle asymmetry (%)	First trial	26.4 (±22.9)	16.8 (±23.8)	0.58 (0.03–0.87)	Low	14.8	34.6
	The mean of three trials	27.3 (±18.3)	18.5 (±23.4)	0.65 (−0.25–0.91)	Low	11	25.6

both considered moderate (ICC 0.75 and 0.76) (Tables 3 and 4). SEMs for all shoulder and elbow range of motion measures ranged between 0.7 and 4.6° and 0.4 and 1.8% for differences in asymmetry indices. Most measurements of elbow valgus were considered to have good or excellent reliability (ICC between 0.83 and 0.95), except for the first trial on the dominant side (ICC 0.79), with SEM reported between 0.7 and 1.5°. All measures of valgus asymmetry, however, were considered to have low reliability (ICC between 0.58 and 0.65), with reported SEMs of 1.3 and 1.9° for side-to-side difference and 11.0 and 14.8% for asymmetry indices.

Hip Rotation Measures

All measures of hip internal rotation were to have considered good to excellent reliability (ICC between 0.86 and 0.96), except for the first trial for NDOM, which was considered moderate (ICC 0.79) (Table 5). For hip external rotation, all measures of DOM

Table 5: Intrarater reliability for measurements of hip rotation range of motion

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC*	*Classification*	*SEM*	*MDC*
External rotation DOM (°)	First trial	47.2 (±5.4)	47.4 (±7.5)	0.81 (0.38–0.95)	Good	2.4	5.5
	The mean of three trials	47.9 (±4.8)	48.4 (±6.4)	0.90 (0.58–0.97)	Excellent	1.5	3.5
External rotation NDOM (°)	First trial	46.5 (±6)	49.2 (±5.2)	0.61 (0.07–0.88)	Low	3.8	8.7
	The mean of three trials	46.9 (±5.7)	49.2 (±5.2)	0.87 (0.41–0.97)	Good	2.1	5.0
External rotation difference (°)	First trial	0.7 (±5.8)	−1.8 (±7.3)	0.34 (−0.3–0.78)	Low	4.7	11.0
	The mean of three trials	1.0 (±5.2)	−0.8 (±6.4)	0.67 (−0.24–0.92)	Low	3.0	7.0
External rotation asymmetry (%)	First trial	1.7 (±12.4)	−4.3 (±14.9)	0.32 (−0.33–0.77)	Low	10.3	24.0
	The mean of three trials	2.3 (±10.8)	−2.0 (±13.1)	0.66 (−0.26–0.91)	Low	6.3	14.7
Internal rotation DOM (°)	First trial	31.8 (±8.6)	32.4 (±8.8)	0.86 (0.53–0.96)	Good	3.1	7.2
	The mean of three trials	31.7 (±8)	32.9 (±10.2)	0.92 (0.7–0.98)	Excellent	2.3	5.3
Internal rotation NDOM (°)	First trial	33.7 (±10.1)	32.6 (±8.9)	0.79 (0.35–0.94)	Moderate	4.6	10.8
	The mean of three trials	33.1 (±9.8)	32.7 (±8.2)	0.96 (0.84–0.99)	Excellent	2.0	4.6
Internal rotation difference (°)	First trial	−1.9 (±7.2)	−0.2 (±8.9)	0.91 (0.68–0.98)	Excellent	2.2	5.0
	The mean of three trials	−1.4 (±6.6)	0.2 (±7.7)	0.93 (0.72–0.98)	Excellent	1.7	4.1
Internal rotation asymmetry (%)	First trial	−5 9 (±22.1)	−0.1 (±30.4)	0.90 (0.65–0.97)	Excellent	7.3	17.1
	The mean of three trials	−3.1 (±21.1)	−0.8 (±25.8)	0.94 (0.78–0.99)	Excellent	5.2	12.1
Total rotation DOM (°)	First trial	79 (±8.5)	79.8 (±7.9)	0.65 (0.04–0.90)	Low	5.0	11.7
	The mean of three trials	79.6 (±8.4)	81.3 (±8.7)	0.90 (0.61–0.97)	Excellent	2.7	6.2
Total rotation NDOM (°)	First trial	80.2 (±10)	81.8 (±11.7)	0.81 (0.42–0.95)	Good	4.4	10.2
	The mean of three trials	80.0 (±10.7)	81.9 (±10.2)	0.96 (0.84–0.99)	Excellent	2.1	5.0
Total rotation difference (°)	First trial	−1.2 (±7.8)	−2.0 (±12.7)	0.74 (0.24–0.93)	Moderate	3.9	9.1
	The mean of three trials	−0.4 (±7.2)	−0.6 (±9.8)	0.92 (0.67–0.98)	Excellent	2.0	4.8
Total rotation asymmetry (%)	First trial	−1.3 (±9.8)	−2.0 (±16)	0.72 (0.18–0.92)	Moderate	5.2	12.1
	The mean of three trials	−0.2 (±9.1)	−0.5 (±12.1)	0.92 (0.68–0.98)	Excellent	2.6	6.0

Table 6: Intersession reliability shoulder rotation strength measures

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC (95% CI)*	*Classification*	*SEM*	*MDC*
External rotation DOM (kgs)	Maximum trial	16.7 (±1.9)	17.1 (±2.0)	0.79 (0.37–0.94)	Moderate	0.9	2.1
	The mean of three trials	15.7 (±2.2)	16.1 (±2.0)	0.85 (0.42–0.96)	Good	0.8	1.9
External rotation DOM (% mass)	Maximum trial	21.9 (±1.6)	22.5 (±2.5)	0.66 (0.12–0.90)	Low	1.0	2.2
	The mean of three trials	20.6 (±2.0)	21.2 (±2.6)	0.78 (0.13–0.94)	Moderate	0.9	2.2
External rotation NDOM (kgs)	Maximum trial	15.6 (±2.8)	15.4 (±2.4)	0.88 (0.59–0.97)	Good	1.0	2.2
	The mean of three trials	14.7 (±2.7)	14.7 (±2.2)	0.92 (0.67–0.98)	Excellent	0.8	1.8
External rotation NDOM (% mass)	Maximum trial	20.6 (±3.6)	20.3 (±3.0)	0.86 (0.58–0.97)	Good	1.3	3.1
	The mean of three trials	19.4 (±3.6)	19.3 (±2.8)	0.92 (0.65–0.98)	Excellent	1.0	2.4
Internal rotation DOM (kgs)	Maximum trial	20.2 (±3.5)	19.7 (±4.0)	0.88 (0.61–0.97)	Good	1.2	2.8
	The mean of three trials	18.8 (±3.2)	18.5 (±3.9)	0.94 (0.76–0.99)	Excellent	0.8	1.8
Internal rotation DOM (% mass)	Maximum trial	26.5 (±2.9)	25.8 (±4.1)	0.76 (0.31–0.93)	Moderate	1.4	3.4
	The mean of three trials	24.6 (±2.5)	24.3 (±4.0)	0.87 (0.49–0.97)	Good	0.9	2.1
Internal rotation NDOM (kgs)	Maximum trial	17.7 (±4.8)	17.2 (±5.3)	0.93 (0.75–0.98)	Excellent	1.3	2.9
	The mean of three trials	16.4 (±5.0)	15.8 (±5.1)	0.98 (0.91–0.99)	Excellent	0.7	1.7
Internal rotation NDOM (% mass)	Maximum trial	23.3 (±5.8)	22.6 (±6.8)	0.92 (0.73–0.98)	Excellent	1.6	3.8
	The mean of three trials	21.5 (±6.1)	20.9 (±6.6)	0.98 (0.91–0.99)	Excellent	0.9	2.0
External rotation difference (kgs)	Maximum trial	1.1 (±1.7)	1.6 (±1.6)	0.62 (0.07–0.88)	Low	1.1	2.5
	The mean of three trials	1.0 (±1.5)	1.4 (±1.2)	0.76 (0.09–0.94)	Moderate	0.7	1.7
External rotation asymmetry index (%)	Maximum trial	7.5 (±11.7)	10.2 (±10.5)	0.63 (0.07–0.89)	Low	7.1	16.5
	The mean of three trials	7.5 (±10.4)	9.3 (±7.9)	0.78 (0.13–0.95)	Moderate	4.9	11.3
Internal rotation difference (kgs)	Maximum trial	2.5 (±3.1)	2.5 (±3.2)	0.90 (0.64–0.97)	Good	1.0	2.3
	The mean of three trials	2.4 (±3.3)	2.7 (±2.9)	0.93 (0.71–0.98)	Excellent	0.9	2.0
Internal rotation asymmetry index (%)	Maximum trial	15.0 (±20.4)	16.7(±24.0)	0.91 (0.69–0.98)	Excellent	6.1	14.3
	The mean of three trials	16.9 (±24.1)	18.9 (±23.6)	0.97 (0.87–0.99)	Excellent	4.2	9.7
Internal: external rotation ratio DOM	Maximum trial	1.21 (±0.12)	1.15 (±0.17)	0.65 (0.14–0.90)	Low	0.07	0.17
	The mean of three trials	1.20 (±0.12)	1.15 (±0.14)	0.69 (−0.12–0.92)	Low	0.07	0.16
Internal: external rotation ratio NDOM	Maximum trial	1.12 (±0.15)	1.10 (±0.23)	0.73 (0.21–0.92)	Moderate	0.08	0.18
	The mean of three trials	1.10 (±0.18)	1.06 (±0.23)	0.91 (0.64–0.98)	Excellent	0.05	0.13

Table 7: Intersession reliability shoulder abduction strength measures

Measurement		*Mean (SD) first session*	*Mean (SD) second session*	*ICC (95% CI)*	*Classification*	*SEM*	*MDC*
Shoulder abduction DOM (kgs)	Maximum trial	12.8 (+2.4)	12.7 (+2.2)	0.94 (0.79–0.97)	Excellent	0.6	1.4
	The mean of three trials	12.2 (+2.2)	11.8 (+2.0)	0.98 (0.90–0.96)	Excellent	0.3	0.7
Shoulder abduction DOM (% mass)	Maximum trial	16.8 (+2.3)	16.6 (+2.2)	0.90 (0.65–0.97)	Good	0.7	1.7
	The mean of three trials	15.9 (+2.1)	15.5 (+2.0)	0.96 (0.82–0.99)	Excellent	0.4	1.0
Shoulder abduction NDOM (kgs)	Maximum trial	11.8 (+1.5)	11.5 (+2.0)	0.82 (0.45–0.95)	Good	0.7	1.5
	The mean of three trials	11.1(+1.5)	10.8 (+1.8)	0.88 (0.52–0.97)	Good	0.5	1.2
Shoulder abduction NDOM (% mass)	Maximum trial	15.5 (+1.5)	15.1 (+1.9)	0.66 (0.11–0.90)	Low	0.9	2.0
	The mean of three trials	14.6 (+1.5)	14.2 (+1.7)	0.72 (−0.13–0.93)	Moderate	0.8	1.8
Shoulder abduction difference (kgs)	Maximum trial	1.0 (+1.4)	1.2 (+1.1)	0.67 (0.09–0.91)	Low	0.8	1.9
	The mean of three trials	1.1 (+1.3)	1.0 (+1.0)	0.84 (0.35–0.96)	Good	0.5	1.2
Shoulder abduction asymmetry index (%)	Maximum trial	7.7 (+10.4)	9.9 (+8.7)	0.56 (−0.06–0.87)	Low	6.9	16.1
	The mean of three trials	8.8 (+10.0)	8.6 (+7.3)	0.71 (−0.29–0.93)	Moderate	5.4	12.6

hip external rotation and the mean of three measures for NDOM hip external rotation were considered to have either good or excellent reliability (ICC between 0.81 and 0.9), while the first trial for NDOM hip external rotation and all measures of external rotation asymmetry were considered to have low reliability (ICC between 0.32 and 0.67). Most measures of total hip joint rotation were considered either good or excellent (ICC 0.81 and 0.96), apart from the first trial for both asymmetry measures and the first trial for DOM total hip rotation, which were considered moderate or low (ICC between 0.65 and 0.74). SEMs for all hip range of motion measures ranged between 1.5 and 5.0° and 2.6 and 10.3% for differences in the asymmetry index.

Shoulder Rotation Strength Measures

Most measures of shoulder internal rotation strength had good to excellent reliability (ICC 0.87–0.98, SEM 0.7–1.6 kgs and 0.9–1.6%), except for relative dominant internal rotation (ICC 0.76, SEM 1.4%) (Table 6). All nondominant shoulder external rotation had either good to excellent reliability (ICC 0.86–0.92, SEM 0.8–1.3 kgs and 1.0–1.3%), however on the dominant side, only the mean measures had good to excellent reliability (ICC 0.86–0.92., SEM 0.8 kgs and 1.0%), and maximum measures had either low to moderate reliability (ICC 0.66–0.79, SEM 0.9 kgs and 1.0%). All measures of shoulder internal rotation strength asymmetry had good to excellent reliability (ICC 0.9–0.97, SEM 0.9–1.0 kgs and 4.2–6.8%), but all measures of shoulder external rotation strength asymmetry were either low or moderate (ICC 0.62–0.78, SEM 0.7–1.1 kgs and 4.9–7.1%).

The reliability for measures of DOM IR: ER strength ratio was low (ICC 0.65 and 0.69, SEM 0.07) when using maximum and mean measures, respectively, while for NDOM IR:ER strength ratio was considered moderate to excellent (ICC 0.73 and 0.91, SEM 0.08 and 0.05 for maximum and mean measures respectively).

Shoulder Abduction Strength Measures

All measures of absolute shoulder abduction strength were considered to have good to excellent reliability (ICC 0.82–0.98, SEM between 0.3 and 0.7 kgs), while relative strength measured varied from low to excellent reliability (ICC 0.66–0.96, SEM 0.4–0.9%) (Table 7). Measures of shoulder abduction strength asymmetry varied from low to good (ICC 0.56–0.84, SEM 0.5–0.8 kgs for side-to-side difference, and 5.4–6.9% for the asymmetry index).

DISCUSSION

The primary aim of this study was to establish the reliability of a single rater when performing a battery of TAP-related musculoskeletal screening tests. Almost all musculoskeletal measures demonstrated good to excellent reliability, and while measures of asymmetry tended to have lower ICC and higher SEMs, most demonstrated acceptable reliability for use as musculoskeletal screening tests. The mean of three trials consistently demonstrated higher ICCs and lower SEMs than when a single trial was used. This indicates that the mean of three trials should be used by clinicians where possible to detect differences between groups or changes over time in individuals. In circumstances where it is not possible to conduct three trials due to time constraints, such as when performing musculoskeletal screening test battery on a large squad of athletes, a single measure in most cases is acceptable. However, this may make it harder to detect any differences between individuals or groups or observe changes over time due to these measures having larger MDC. Despite the measures that were used to calculate asymmetry having good to excellent reliability in many cases, the reliability of many asymmetry calculations was not considered to be acceptable for use in musculoskeletal screening.[5] This indicates that the findings of any study using these measures should be interpreted with caution, and for all of the measures, it is recommended the MDC be exceeded before any differences be considered "real."[19]

Athletes are often assessed and treated by multiple practitioners, which makes the interrater reliability of any test important. At present, the interrater reliability of these measures collected in this screening battery is unknown. The tester in the current study had several years' experience as a musculoskeletal physiotherapist working exclusively in cricket and performed these tests on a frequent basis; therefore, the findings of this study may not be applicable to less experienced clinicians unfamiliar with these tests. Other studies which investigated both intra and interrater reliability of a musculoskeletal screening test battery reported lower ICCs and larger SEMs for interrater reliability.[11] Therefore, it could be expected that a similar finding would occur if the interrater reliability of the musculoskeletal screening test battery used in the current study was assessed.

The follow-up testing sessions occurred on the same day, approximately 30 minutes after the initial testing, which was similar to other reliability studies of musculoskeletal tests.[9,20,21] Reliability studies that involve a shorter period between testing sessions are thought to demonstrate greater levels of reliability than longer time periods, where uncontrolled variables can influence results.[22] For example, throwing has been demonstrated to result in acute musculoskeletal changes at the shoulder and elbow that can last up to 48 hours.[23] As the participants were undertaking a winter training program at the time of the study, had there been a longer period between testing sessions, reliability would likely be lower. When assessing the reliability of tests used to collect preparticipation data, such as musculoskeletal screening tests, shorter time intervals between tests is thought to be preferable,[5]and given the focus of this study, the time period used between testing sessions was appropriate.

Previous reliability studies often excluded participants with current or previous symptoms,[6–8,16] while some studies assessed the reliability of those with and without symptoms separately.[9,10,20] In the current study, it is possible some participants had TAP despite each of them participating fully in the off-season training.[3] These participants were not excluded as the aim of the reliability study was to be representative of current musculoskeletal screening practice, where clinicians will conduct these tests on athletes both with and without symptoms. It is possible there were differences in the reliability of these measures when performed on cricketers with and without TAP, although, in reliability studies that did separate symptomatic and asymptomatic groups, there was little difference.[9,10,20]

Conclusion

The intrarater reliability reported for almost all measures in this study is considered acceptable for sports injury research using musculoskeletal screening tests. Overall, the mean of three trials demonstrated better reliability, indicating that, where possible, researchers and clinicians should use multiple trials to determine if differences exist between groups or if a change has occurred over time. The findings of this study will aid in the interpretation of these tests when performed either clinically or in research, and while most measures demonstrated acceptable reliability, some did not, and caution should be used when interpreting the results of these measures.

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Appendix 1: Scapulothoracic postural measures and pectoralis minor length

Test	*Participant position*	*Procedure*
Thoracic kyphosis (Lewis and Valentine)	Participants in relaxed standing with arms by sides	Prior to assessing, the tester marks the T1–2 and T11–12 interspinous space. The participant then assumes a comfortable standing position. The tester then places the inclinometer on the T1–2 interspinous space and records the angle with the vertical. The examiner then places the inclinometer on the T12–L1 interspinous space and records the angle with the vertical. These angles are added together to determine thoracic kyphosis.
Distance between the superior angle of the scapula and the spine (Lewis and Valentine)	Participants in relaxed standing with arms by sides	Prior to assessing, the tester marks the root of the spine of the scapula and the adjacent spinous process. In the same standing posture as was used for measuring thoracic kyphosis, the tester measures the distance from the root of the spine of the scapula to the spinous process to the nearest mm.
Distance between the inferior angle of the scapula and the spine (Lewis and Valentine)	Participants in relaxed standing with arms by sides	Prior to assessing, the tester marks the inferior angle of the scapula and the adjacent spinous process. In the same standing posture as was used for measuring thoracic kyphosis, the tester measures the distance from the superior angle to the spinous process to the nearest mm.
The spine of scapula rotation (Lewis and Valentine)	Participants in relaxed standing with arms by sides	Prior to assessing, the tester marks the root of the spine of the scapula and the angle of the acromion. In the same standing posture as was used for measuring thoracic kyphosis, the tester measures the angle of the spine of the scapula from the horizontal plane. If the acromion angle is superior to the root of the spine of the scapula, this is recorded as positive; if it is below, this is recorded as negative.
Pectoralis minor length (Lewis and Valentine)	The participant is supine in a crook lying, elbows by sides resting on the plinth with hands resting on the lower abdomen.	Prior to lying supine, the tester marks the posterior aspect of the acromion. The distance between the plinth and the posterior aspect of the acromion is measured in mms.

Appendix 2: Shoulder, elbow, and hip range of motion and postural measures

Test	*Participant position*	*Procedure*
Shoulder external rotation passive range of motion (Dacombe et al.)	The participant is in crook, lying with the shoulder to be tested abducted to 90° and elbow flexed to 90° with the forearm in mid-prone	The tester passively externally rotates the shoulder until the end of the range whilst stabilizing the scapula and humeral head. An inclinometer was placed on the anterior aspect of the forearm, just distal to the wrist joint. The angle between the forearm and the vertical was recorded to the nearest whole degree.
Shoulder internal rotation passive range of motion (Dacombe et al.)	The participant is in crook, lying with the shoulder to be tested abducted to 90° and elbow flexed to 90° with the forearm in mid-prone	The tester passively internally rotates the shoulder until the end of the range whilst stabilizing the scapula and humeral head. An inclinometer was placed on the posterior aspect of the forearm, just distal to the wrist joint. The angle between the forearm and the vertical was recorded to the nearest whole degree.
Elbow extension passive range of motion (Chapleau et al.)	The participant is in crook, lying with the distal aspect of the humerus resting on a rolled-up towel.	The tester passively extends the elbow until the end of the range while maintaining the forearm in mid-prone. In this position, the examiner places a goniometer on the lateral aspect of the arm with its axis centered on the lateral epicondyle, the fixed arm aligned with the tip of the acromion, and the mobile arm aligned with the midpoint of the wrist and records the angle to the nearest degree. If this was below full extension, the degrees short of full extension were recorded as a minus.
Valgus carrying angle (Chapleau et al.)	The participant is in crook, lying with the distal aspect of the humerus resting on a rolled-up towel.	The tester fully supinates the forearm and extends the elbow while maintaining the humerus in neutral rotation. At the end of range elbow extension, a goniometer was placed on the anterior aspect of the forearm with the axis at the midpoint between the humerus epicondyles, and the stationary arm was aligned to the tip of the acromion and the mobile arm was aligned to the midpoint of the wrist. The valgus angle was recorded to the nearest whole degree.
Hip internal rotation is a passive range of motion (Malliaris et al.)	The participant is lying in prone with knees flexed to 90°	The subject allows both legs to fall into internal rotation whilst keeping the thighs together. A spirit level was placed across the buttocks to monitor for any pelvic rotation. At the end of the range, the examiner gives a gentle overpressure to ensure the end range is reached. An inclinometer was then placed on the superior part of the medial border of the tibia, just inferior to the medial condyle. The angle between the tibia and the vertical was measured to the nearest whole degree.
Hip external rotation passive range of motion (Malliaris et al.)	The participant is lying supine on the edge of the plinth with the leg to be tested hanging freely off the plinth and the foot of the other leg resting on the plinth.	The examiner passively externally rotates the hip until the pelvis is observed to move. An inclinometer is then placed on the superior part of the lateral border of the fibula just inferior to the medial condyle. The angle between the tibia and the vertical was measured to the nearest whole degree.

Appendix 3: Shoulder strength measures

Test	*Participant position*	*Procedure*
Shoulder external rotation strength (Hurd et al.)	The participant is sitting on a plinth with the arm to be tested in 90° shoulder abduction and 45° external rotation; in 90° elbow flexion, the opposite hand is holding onto the plinth.	The tester places the hand-held dynamometer on the forearm dorsally proximal to the wrist crease and instructs the participant to resist them as they attempt to move the participant into the internal rotation while an assistant is supporting the participant's elbow and thoracic spine. The tester slowly generates force over 3–5 seconds into internal rotation. The test is stopped when the participant begins to move into internal rotation, and the maximal strength is recorded to the nearest 0.1 kg.
Shoulder internal rotation strength (Hurd et al.)	The participant is sitting on a plinth with the arm to be tested in 90^0 shoulder abduction and 45° external rotation; in 90° elbow flexion, the opposite hand is holding onto the plinth.	The tester places the hand-held dynamometer on the forearm ventrally proximal to the wrist crease and instructs the participant to resist them as they attempt to move the participant into the external rotation while an assistant is supporting the participant's elbow and thoracic spine. The tester slowly generates force over 3 to 5 seconds into internal rotation. The test is stopped when the participant begins to move into external rotation, and the maximal strength is recorded to the nearest 0.1 kg.
Shoulder abduction strength (Byram et al.)	Participant is sitting on a plinth with the arm to be tested in 90° elevations and 45° horizontal flexion with the elbow extended and in mid-prone.	The tester places the hand-held dynamometer in the forearm just proximal to the wrist crease and instructs the participant to resist them as they attempt to move them into adduction while an assistant is supporting the participant's thoracic spine. The tester slowly generates force over 3–5 seconds into adduction. The test is stopped when the participant begins to move into adduction, and the maximal strength is recorded to the nearest 0.1 kg.