Physical Therapy in Sport 37 (2019) 120–127

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

The cricketer's shoulder: Not a classic throwing shoulder

Megan Dutton [a,*], Nicholas Tam [a,b], James C. Brown [c,d], Janine Gray [a,e]

[a] Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africa
[b] Department of Physiology, Faculty of Medicine and Nursing, University of the Basque Country UPV/EHU, Spain
[c] Institute of Sport and Exercise Medicine, Division of Orthopaedics, Department of Surgical Sciences, Faculty of Medicine and Health Sciences, Stellenbosch University, South Africa
[d] IOC Research Centre, South Africa
[e] Cricket South Africa, Johannesburg, South Africa

ARTICLE INFO

Article history:
Received 15 January 2019
Received in revised form
25 March 2019
Accepted 25 March 2019

Keywords:
Cricket
Thrower's paradox
Shoulder injury
Risk factors
Musculoskeletal screening

ABSTRACT

Objectives: To describe the musculoskeletal adaptations inherent to the cricketers' shoulder and determine potential predictors of shoulder injury in elite South African cricketers.
Design: Prospective longitudinal cohort study;
Setting: Non-clinical, at national cricket indoor training venues.
Participants: One hundred and six elite cricketers, representing 82% of the South African national and franchise teams, consent. A total of 105 cricketers (27 ± 4 years) were eligible for participation in this study.
Main outcome measures: A pre-season shoulder screening battery including a shoulder function questionnaire, two ultrasonographic shoulder measurements and 14 musculoskeletal tests including pain provocation, range of motion, strength and flexibility was assessed. Non-contact dominant shoulder injuries were documented throughout the 2016/2017 season.
Results: The musculoskeletal profile of a cricketer's shoulder is described. 17% (95%CI: 9–24%) of cricketers sustained an injury during the 2016/2017 season. Two of the 17 screening tests predicted seasonal dominant shoulder injury ($p < 0.05$): a dominant supraspinatus tendon thickness ≥5.85 mm (sensitivity: 72%, specificity: 63%) and non-dominant pectoralis minor length ≤12.85 cm (sensitivity: 83%, specificity: 55%).
Conclusion: The musculoskeletal adaptations inherent to cricketing shoulders are distinctly different to the classic "*thrower's shoulder*" described in baseball. A thickened dominant supraspinatus tendon and a shortened non-dominant pectoralis minor muscle are risk factors for developing shoulder injury in this group. This identifies the need to investigate preventative strategies (strengthening/flexibility) and throwing workload management in cricketers with shoulder injury.

1. Introduction

The Van Mechelen model of sport injury prevention (van Mechelen, Hlobil, & Kemper, 1992) states that only once injury incidence and severity is known, can risk factors of injury be assessed. The incidence of shoulder injuries has been reported as 5–36% of all injuries sustained by cricketers (Giles & Musa, 2008; Orchard, James, & Farhart, 2002; Ranson & Gregory, 2008). Numerous intrinsic risk factors for shoulder injury have been identified in overhead throwing athletes including amongst others, glenohumeral internal rotation deficit (GIRD) (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009); total glenohumeral (GH) rotational range of motion (ROM) loss (Amin et al., 2015; Routolo, Price, & Panchal, 2006); scapula dyskinesis (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009); variances in the acromiohumeral (AHD) distance (Leong, Tsui, & Fu, 2012; McCreesh, Anjum, & Lewis, 2015; Schmidt, Schmidt, & Gromnica-Ihle, 2004); and reduced hip mobility and strength (Burkhart, Morgan, & Kibler, 2000; Kibler, Wilkes, & Sciascia, 2013). Extant cricket literature has primarily focused on the GH rotational ROM (Giles & Musa, 2008) and scapula positioning (Green, Taylor, & Ardern, 2013) alterations as a

* Corresponding author. Division of Exercise Science and Sports Medicine, Department of Human Biology, University of Cape Town, P.O. Box 115, Newlands, Cape Town, 7725, South Africa
E-mail address: megandutton@gmail.com (M. Dutton).

https://doi.org/10.1016/j.ptsp.2019.03.014
1466-853X/

probable association with shoulder pain.

Musculoskeletal screening protocols pre-season/participation have been successful in identifying a variety of injury risk factors in football (Bahr & Krosshaug, 2005; Hewett et al., 2005), basketball (Bahr & Krosshaug, 2005; Hewett et al., 2005), volleyball (Bahr & Krosshaug, 2005) and running (Lun et al., 2004). Interestingly, only two studies have positively determined risk factors for trunk, back and lower limb cricket injuries (Dennis, Finch, & Elliott, 2008; Olivier & Gray, 2018). Currently, no study has investigated the relationship between musculoskeletal screening and upper limb cricket injuries. Further, insufficient knowledge of the risk factors associated with the development of shoulder pain and/or injury in cricketers exists; which if identified could allow for better rehabilitation and prevention strategies.

The dominant shoulder of overhead throwing athletes (e.g. baseball, cricket, tennis, volleyball, swimming) is thought to require a delicate balance between stability and mobility to achieve optimal performance (Downar & Sauers, 2005).

This balance is termed the *"thrower's paradox"* that contributes towards shifting the arc of GH rotational ROM with the aim of increasing external rotation ROM (Downar & Sauers, 2005), while maintaining a total 180° GH rotational ROM (Morgan, Burkhart, & Palmeri, 1998); an adaptation essential to generating ball velocity when throwing overhead (Lintner, Noonan, & Kibler, 2008; Reinold et al., 2008). Cricketers could exhibit the *"thrower's paradox"* as found in baseball, as the overhead baseball pitching motion has been likened to the overhead throwing motion in fielding in cricket (Freeston, Carter, & Rooney, 2016). However, limited data exists to support this (Giles & Musa, 2008). Therefore, it is questionable whether these athletes develop a true *"thrower's paradox"*, and the associated musculoskeletal adaptations responsible for the alteration in the arc of GH rotational ROM, potentially influencing overhead throwing performance.

The development of the *"throwers paradox"* is primarily thought to occur as a result of the increased humeral retroversion angle (~45°) noted in baseball research (Sabick, Kim, & Hawkins, 2005; Yamamoto et al., 2006). However, this osseous adaptation is absent in cricketers (Shaw & Stock, 2009), suggesting that the "pseudolaxity" (Arora, Shetty, & Dhillon, 2015) created by the contracture of the posterior shoulder complex and excessive stretching of the anterior shoulder capsule associated with repetitive overhead throwing, may allow cricketers to alter the arc of GH rotational ROM. Interestingly, these soft tissue adaptations promote excessive anterio-superior humeral head migration (Burkhart, Morgan, & Kibler, 2003; Kinsella, Thomas, & Kelly, 2014), leading to the development of shoulder impingement and pain (Belling Sorenson & Jorgensen, 2000; Ellenbecker & Cools, 2010; Walch, Boileau, & Donell, 1992). Long-term injury surveillance studies have reported that shoulder impingement (Bell-Jenje & Gray, 2005; Stretch, 2007), scapula dyskinesis (Bell-Jenje & Gray, 2005) and GIRD (Bell-Jenje & Gray, 2005) are associated with the development of rotator cuff musculature and/or tendinous injuries in cricketers (Arora et al., 2015; Leary & White, 2000; Stretch, 2003).

To date, no study has investigated the relationship between ultrasonographic measurement and musculoskeletal screening tests of the shoulder, as well as hip mobility and strength measures; and shoulder injury in cricket. Thus, this study aims to describe the musculoskeletal adaptations of a cricketer's shoulder to determine whether cricketers present with a similar *"thrower's paradox"* to that known of the baseball population. Secondly, to determine if any variables were associated with either a seasonal or historical shoulder injury in cricketers. Lastly, to determine if any of these are predictors of shoulder injury.

2. Methods

2.1. Participants

During annual pre-season musculoskeletal screening, all cricketers representing a South African franchise or senior national team during the 2016/2017 season were invited to participate in this study. Participants were included in this study if they were 18 years of age or older, performed at least two cricket specific (net), one fielding training and one to two fitness sessions per week. In addition, participants were expected to play in at least one format (Four day, One day or T20) of cricket matches, at elite level, throughout the 2016/2017 season. All eligible participants were informed of the experimental risks and signed an informed consent document prior to investigation. Ethical approval was obtained from the institutional research ethics committee (HREC: 364/2016).

All cricketers were tested within a two week period during September, at the start of the domestic cricket season. Each cricket squad (13–22 cricketers/squad) was assessed on a single day, with no other formal training scheduled for that day. As the National team play all year-round and lack a specific pre-season, testing was conducted at a training camp coinciding with the start of the domestic season. Injury data were collected over the subsequent six months (October–March) of the 2016/2017 domestic cricket season. Only non-traumatic injuries to the dominant shoulder were included in data analysis, as musculoskeletal risk factors are most likely associated with overuse injuries (Gabbett, 2010).

2.2. Measurement procedures

Participants completed a questionnaire for descriptive data, training, competition and injury history, prior to the pre-season shoulder screening protocol. This included a shoulder function questionnaire specific to overhead athletes (Alberta et al., 2010). A battery of screening tests were conducted and included two ultrasonographic shoulder measurements, eleven shoulder and three hip specific tests. A summary of the measurement protocol, testing positions, intra-rater reliability and sequence of testing is provided in Supplementary Table 1.

Digital inclinometers (Digi-Pas DWL80E, Digipas Technologies, Inc., Dundee, England) were used to measure GH and hip rotation, scapula upward rotation and GH horizontal adduction ROM (PSC stiffness), with an accuracy of 1°. Isometric muscle strength of the upper trapezius (UT), serratus anterior (SA), lower trapezius (LT), GH internal (GHIR) and external (GHER) rotators and gluteus medius (GM) muscles were determined using a hand-held dynamometer (MicroFET 2, Hoggan Scientific, LCC., Salt Lake City, Utah, USA). A calliper (Mastercraft Vernier Calliper, Mastercraft Tools, Johannesburg, South Africa) was used to measure PM length (PML) and lastly a diagnostic ultrasound (M7, Shenzen Mindray Biomedical electronics Co., Ltd., Guangdong, China) was used to measure AHD and supraspinatus tendon thickness (SsT).

Each test was repeated and an average of the two scores were recorded. All tests were performed on the non-dominant side, prior to dominant side testing. All testing procedures were reliable ($ICC = 0.64–0.99$; except the pain provocation tests, $\kappa = 1$) (Supplementary Table 1), repeatable and performed by the same author (MD) who was familiarised with the respective testing protocols.

2.3. Statistical analysis

Based on data from previous studies which have measured shoulder pain (Green, Taylor, Watson, & Ardern, 2013), the primary outcome measure of this study, sample size was estimated for an error probability of 0.05 and statistical power of 80%. Using a small meaningful difference of 10.1 and a standard deviation of 8, a sample of 25 participants was deemed sufficient. However, to ensure statistical significance of all variables measured, a sample in excess of 65 participants was required as demonstrated in Supplementary Table 2.

Pre-season shoulder screening data were analysed using SPSS version 24 (IBM, Armonk, New York, USA). Descriptive statistics were calculated for all variables and all variables screened for normality using the Shapiro Wilk test. Where data were normally distributed with equal variance, independent t-tests were performed to determine group differences for both injury history and injury sustained in the 2016/2017 season. However, data not normally distributed were analysed using the Mann-Whitney *U* test to determine potential differences between groups, as mentioned previously. A binary logistic regression (adjusting for unresolved injury symptoms) was performed, followed by a Receiver operating Curves (Roc) analysis to determine predictive capabilities of the pre-season shoulder screening tests on shoulder injuries that were sustained during the 2016/2017 season. Statistical significance and cut-off for prediction was set at $p < 0.05$ (for a sensitivity $\geq$70%). Sensitivity was defined as the probability that the test result will be positive in a cricketer who went on to develop a shoulder injury; whereas specificity was regarded as the probability that the test result will be negative in a cricketer who did not develop a shoulder injury (van Stralen, Stel, Reitsma, & et. al, 2009). Data are presented as mean ± standard deviation unless otherwise stated.

3. Results

3.1. Participants

One cricketer sustained a traumatic injury to the non-dominant shoulder and was excluded from this study. Therefore, 105 cricketers were eligible to participate in this study (27 ± 4 years), where 17% (95%CI: 9–24%) of this group sustained an injury during the 2016/2017 season. Thirty three cricketers reported a history of previous shoulder injury and 15 reported symptoms at the start of the season (Table 1). Cricketers with a history of previous shoulder injury exhibited lower pre-season KJOC scores ($Z = -3.18$; $p = 0.001$) and less dominant hip internal rotation ROM ($Z = -2.01$; $p = 0.045$), compared to those with no previous shoulder injury (Table 2). Irrespective of injury or a history there-of, pain provocation was elicited in 5–19 dominant shoulders depending on the test used.

3.2. Descriptive profile of the Cricketer's shoulder

All pre-season shoulder screening variables are presented in Table 2. These findings indicate that this cohort of elite cricketers presents with GIRD; a loss of total GH rotational ROM; a consistently downwardly rotated scapula from rest to 90° GH elevation; relatively normal UT strength, poor SA, GHIR and GHER strength, yet greater LT strength; relatively normal PML but substantial PSC stiffness; greater AHD measurement and relatively normal SsT measurement; a bilateral deficit in hip external and total rotational ROM, as well as GM muscle weakness.

3.3. Effect of injury on musculoskeletal screening variables

Only 3 of 17 musculoskeletal screening variables were different for cricketers who sustained seasonal injuries, after adjusting for pre-existing injury (Table 2). Participants who sustained a shoulder injury in the season had significantly thicker dominant SsT ($p = 0.011$), shorter non-dominant PML ($p = 0.017$) and lower post-season KJOC scores ($p < 0.001$), when compared to the uninjured group.

3.4. Potential predictive risk factors for shoulder injury in cricketers

Dominant shoulder SsT (AUC = 0.688; 95% CI: 0.561–0.814) and non-dominant shoulder PML (AUC = 0.704; 95% CI: 0.584–0.823) were found to be predictors of in-season shoulder injury (Table 3). In addition, the cut-off values for dominant shoulder SsT ≥5.85 mm (sensitivity: 72%, specificity: 63%) and non-dominant PML ≤12.85 cm (sensitivity: 83%, specificity: 55%) demonstrated high sensitivity but low specificity.

4. Discussion

4.1. Descriptive profile of the Cricketer's shoulder

The primary outcome of this study was that cricketers do not present with the classic "*thrower's paradox*". Specifically, they exhibited no ERG; scapula downward rotation from rest to 90° elevation; strong LT; and maintenance of the AHD. In addition, greater GIRD and loss of total GH rotational ROM; weaker SA, GHIR and GHER; and substantially shorter PSC and PML were noted in

Table 1
Description of the ordinal characteristics and significant musculoskeletal variables relating to injury history, for participants in the injured (n = 18) and uninjured (n = 87) groups, respectively. Data are expressed as mean ± standard deviation.

Variable		All (n = 105)	Injured (n = 18)[a]	Uninjured (n = 87)
Age (years)		27 ± 4.2	27.5 ± 3.9	26.5 ± 4.2
Dominance	Left	17	2	15
	Right	88	16	62
Speciality	Fast Bowler	50	7	43
	Spin Bowler	26	4	22
	Batsman	29	7	22
History of previous shoulder injury	Yes	33	8	25
	No	72	10	62
Symptoms of previous injury present at start of season	Yes	15	6	9
	No	18	2	16
Symptoms on Hawkin's Kennedy Test	Dominant Shoulder	19	6	13
	Non-dominant Shoulder	7	1	6
Symptoms on Jobe Test	Dominant Shoulder	16	4	12
	Non-dominant Shoulder	4	2	2
Symptoms on Full Can Test	Dominant Shoulder	5	-	5
	Non-dominant Shoulder	4	1	3

[a] One participant excluded as shoulder injury sustained was traumatic and to the non-dominant side.

Table 2
Description of the musculoskeletal variables for this cohort of cricketers (n = 105), in the injured (n = 18) and uninjured (n = 87) groups, respectively; compared to the known normative values for **A. The Shoulder Joint Complex** and **B. The Hip Joint.** Data are expressed as mean ± standard deviation or as median (range).

Variable	Shoulder	All (n = 105)	Injured (n = 18)	Uninjured (n = 87)	Reference Data
A. The Shoulder Joint Complex					
Pre-Season KJOC Score (%)		84.5 (36.4–100)	78.7 (40.0–92.7)*	84.8 (36.4–100)*	90 (Kraeutler et al., 2013)
Post-Season KJOC Score (%)		85.6 (19.1–100)	66.5 (19.1–100)**	86.8 (47.2–100)**	
AHD (mm)	Dominant	12 (7.7–20.7)	12.1 (8.8–17.6)	12.1 (7.7–20.7)	10.3 ± 1.0 (Harput et al., 2016)++
	Non-dominant	11.9 ± 2.3	11.3 ± 2.2	12.0 ± 2.4	11.0 ± 0.8 (Harput et al., 2016)++
SsT (mm)	Dominant	5.6 ± 1.1	6.1 ± 1.0**	5.4 ± 1.1**	4.6 ± 1.9 mm (Schmidt, Schmidt, Schicke, & Gromnica-Ihle, 2004)+++
	Non-dominant	5.6 ± 1.1	5.7 ± 1.1	5.6 ± 1.0	
GH IR ROM (°)	Dominant	40.0 (0–96.2)	34.2 (23.7–96.2)	40.9 (0–62.6)	56.6 ± 12.5 (Downar & Sauers, 2005)+
	Non-dominant	35.1 (10.1–88.1)	37.6 (21.0–88.1)	35.0 (10.1–79.0)	68.6 ± 12.6 (Downar & Sauers, 2005)+
GH ER ROM (°)	Dominant	90.0 (39.4–124.8)	96.8 (39.4–115.1)	90.0 (67.5–124.8)	108.9 ± 9.0 (Downar & Sauers, 2005)+
	Non-dominant	89.5 (30.6–162.6)	90.0 (30.6–1223.0)	89.5 (36.6–162.6)	101.9 ± 5.9 (Downar & Sauers, 2005)+
Total GH Rot ROM (°)	Dominant	135.6 (67.5–167.4)	133.9 (106.5–163)	136.1 (67.5–167.4)	165.5 ± 14.4 (Downar & Sauers, 2005)+
	Non-dominant	133.6 (54.6–179.5)	138.1 (54.6–167.5)	131.3 (57.7–179.5)	170.4 ± 10.5 (Downar & Sauers, 2005)+
Upward scapula rotation at rest (°)	Dominant	−3.6 (−23.1–11.0)	−1.6 (−21.3–6.1)	−4.0 (−23.1–11.0)	6.4 ± 4.7 (Downar & Sauers, 2005)+
	Non-dominant	−12.6 (−22.7–11.0)	−12.3 (−21.9–5.6)	−12.8 (−22.7–11.0)	4.7 ± 4.1 (Downar & Sauers, 2005)+
Upward scapula rotation at 45° GH Abd (°)	Dominant	1.2 (−24.5–9.3)	0.8 (−24.5–6.4)	1.2 (−20.8–9.3)	Unknown
	Non-dominant	−5.8 (−22.8–15.9)	−8.9 (−22.7–9.7)	−5.2 (−18.6–15.9)	
Upward scapula rotation at 90° GH Abd (°)	Dominant	10.4 (−13.0–28.7)	9.5 (−13.0–9.3)	10.8 (−1.9–28.7)	14.2 ± 6.5 (Downar & Sauers, 2005)+
	Non-dominant	5.0 (−12.8–22.4)	5.1 (−12.8–18.5)	5.0 (−11.6–22.4)	10.1 ± 6.1 (Downar & Sauers, 2005)+
Upward scapula rotation at 120° GH Abd (°)	Dominant	22.2 (7.9–44.9)	23.0 (7.9–40.2)	22.2 (11.1–44.9)	22.4 ± 6.3 (Downar & Sauers, 2005)+
	Non-dominant	17.2 (3.7–42.0)	15.4 (4.8–36.5)	17.2 (3.7–42.0)	20.0 ± 5.8 (Downar & Sauers, 2005)+
UT strength (N)	Dominant	150.0 (106.1–330.6)	154.8 (130–330.6)	148.4 (106.1–260.2)	158.6 ± 47.7 (Cools et al., 2010)++
	Non-dominant	144.6 (81.8–299.9)	151.0 (116.3–299.9)	143.0 (81.8–199.5)	148.4 ± 49.6 (Cools et al., 2010)++
SA strength (N)	Dominant	133.2 (90.3–331.7)	128.3 (91.8–331.7)	135.5 (90.3–238.7)	154.8 ± 61.9 (Cools et al., 2010)++
	Non-dominant	147.7 (60.3–299.4)	135.5 (94.5–299.4)	149.5 (60.3–255.6)	136.8 ± 44.8 (Cools et al., 2010)++
LT strength (N)	Dominant	70.7 (0.0–136.3)	66.0 (0–96.4)	72.3 (38.0–136.3)	67.2 ± 18.6 (Donatelli et al., 2000)+
	Non-dominant	69.0 (38.0–124.3)	62.5 (46.5–96.5)	69.4 (38.0–124.3)	59.6 ± 12.0 (Donatelli et al., 2000)+
GH IR strength (N)	Dominant	132.7 (70.5–312.6)	124.3 (74.3–187.8)	133.5 (70.5–312.6)	178.5 ± 38.8 (Donatelli et al., 2000)+
	Non-dominant	130.6 (72.7–408.0)	125.2 (89.9–161.0)	130.6 (72.7–408.0)	170.9 ± 35.8 (Donatelli et al., 2000)+
GH ER strength (N)	Dominant	109.5 ± 26.3	100.7 ± 28.2	111.3 ± 25.7	147.6 ± 36.0 (Donatelli et al., 2000)+
	Non-dominant	102.0 ± 23.9	98.6 ± 17.4	102.7 ± 25.0	168.1 ± 40.1 (Donatelli et al., 2000)+
GH ER:IR	Dominant	0.83 (0.17–1.5)	0.82 (0.47–0.99)	0.83 (0.17–1.50)	0.71–1.08 (Moore, Uhl, & Kibler, 2013)+
	Non-dominant	0.80 ± 0.17	0.80 ± 0.20	0.80 ± 0.17	
Pec Minor length (cm)	Dominant	12.7 ± 1.0	12.6 ± 1.1	12.7 ± 1.0	11.7 ± 1.2 (Cools et al., 2010)++
	Non-dominant	12.8 (10.5–15.1)	12.2 (10.7–15.0)**	13.1 (10.5–15.1)**	12.9 ± 1.3 (Cools et al., 2010)++
PSC flexibility (°)	Dominant	13.8 ± 6.5	14.0 ± 7.5	13.7 ± 6.3	45.9 ± 5.9 (Myers et al., 2007)+
	Non-dominant	21.5 ± 8.5	23.7 ± 7.8	21.0 ± 8.6	24.1 ± 9.2 (Myers et al., 2007)+
B. The Hip Joint					
Variable	**Hip**	**All (n = 105)**	**Injured (n = 18)**	**Uninjured (n = 87)**	**Reference Data**
Hip IR ROM (°)	Dominant	23.0 (12.5–52.0)	22.4 (12.8–30.9)*	23.1 (12.5–51.9)*	34.6 ± 4.4 (Laudnar, Moore, Sipes, & Meister, 2010)+
	Non-dominant	22.4 (7.0–48.0)	24.1 (13.3–35.7)	21.3 (7.0–48.0)	34.4 ± 6.1 (Laudnar et al., 2010)+
Hip ER ROM (°)	Dominant	32.8 (14.4–60.4)	30.7 (14.4–46.8)	33.0 (15.1–60.4)	41.0 ± 6.3 (Laudnar et al., 2010)+
	Non-dominant	33.6 (15.1–68.1)	31.9 (15.1–46.0)	34.0 (19.5–68.1)	40.9 ± 8.1 (Laudnar et al., 2010)+
Total Hip Rot (°)	Dominant	55.4 (34.0–112.3)	53.2 (33.9–77.7)	56.1 (37.1–112.3)	75.6 ± 5.9 (Laudnar et al., 2010)+
	Non-dominant	56.1 (31.2–116.1)	55.8 (31.2–74.2)	56.1 (36.0. – 116.1)	75.3 ± 7.8 (Laudnar et al., 2010)+
GM strength (N)	Dominant	190.2 (108.1–281.5)	190.2 (134.6–277.0)	190.2 (108.1–281.5)	406.0 ± 61.8 (Laudnar et al., 2010)+
	Non-dominant	180.6 (105.4–296.7)	180.7 (135.9–262.3)	180.6 (105.4–296.7)	410.9 ± 70.6 (Laudnar et al., 2010)+

+Based on baseball pitchers.
++Based on other overhead athletes e.g.: tennis, volleyball.
+++Based on healthy, inactive people.
*Significantly different between cricketers with and without a history of previous shoulder injury ($p < 0.05$).
*Significantly different between cricketers who sustained a seasonal shoulder injury and those who did not.

this cohort, when compared to baseball pitchers and other overhead sportsmen (Table 2).

It is interesting to note that this cohort of cricketers did not demonstrate the concomitant ERG (Thomas et al., 2011), increased upward scapula rotation at 60°, 90° and 120° GH elevation (Thomas et al., 2011) or reduced AHD measurement (Maenhout, van Eessel, & Cools, 2012), observed when GIRD and PSC inflexibility occur in baseball pitching shoulders. The GH rotational asymmetries of ERG and GIRD noted in baseball pitchers, are known to be attenuated by adaptive humeral retroversion (Sabick, Kim, Torry, Keirns, & Hawkins, 2005); a structural anomaly undetected in cricketers (Shaw & Stock, 2009). Thus, it appears that young developing cricketers may not achieve the throwing load required to obtain the adaptive humeral retroversion associated with ERG, as this skill is regarded as less essential than batting and bowling by junior cricket coaches (Freeston, Ferdinands, & Rooney, 2007).

In addition, dominant shoulder GIRD has been associated with PSC inflexibility (Thomas et al., 2011; Tyler, Roy, & Gleim, 1999), loss of total GH rotational ROM (Amin et al., 2015) and poor shoulder strength in baseball pitchers. This study found a similar trend for GIRD in cricketers. Although GHIR and GHER strength in these cricketers is substantially lower than that reported for baseball pitchers (Downar & Sauers, 2005), the GHER:GHIR ratio falls within the normal (Moore et al., 2013). Thus, cricketers do not necessarily have an imbalance between GHIR and GHER, but rather global muscle weakness, when compared to their overhead throwing counterparts (Donatelli et al., 2000).

This may explain the lack of ERG and poor GHIR and GHER

Table 3
Receiver Operating Characteristics (RoC), cut-off values, sensitivity and specificity for continuous variables showing significant differences for injury sustained in 2016/2017 season.

Variable	Area	Std Error	Asymptotic Sig.	Asymptotic Sig. 95% CI		Cut-off	Sensitivity (true positive rate)	Specificity (true negative rate)
				Lower	Upper			
Dominant SsT	0.688	0.064	0.012	0.561	0.814	≥5.85 mm	72%	63%
Non-dominant PML	0.704	0.061	0.007	0.584	0.823	≤12.85 cm	83%	55%

strength which ultimately contributes to the loss of total GH rotational ROM, demonstrated by the mature cricketers in this study. In addition, a potential reduction in overhead throwing velocity is expected (Lintner et al., 2008; Reinold et al., 2008) and may result in adaptations to overhead throwing technique which could strain the kinetic chain, resulting in an increased risk of injury.

Further, this cohort of cricketers presented with consistently downwardly rotated scapulae from rest to 90° GH elevation. The lack of association between PSC stiffness and scapula upward rotation previously observed in baseball pitchers (Thomas et al., 2011), may occur due to numerous muscular imbalances. In this study, cricketers demonstrated greater lower trapezius (LT), yet weaker serratus anterior (SA) strength when compared to known data for baseball pitchers. Scapula upward rotation requires the synergistic activity of primarily the middle (Phadke, Camargo, & Ludewig, 2009) and lower trapezius (Ludewig & Braman, 2011; Phadke et al., 2009) muscles, and secondarily, the SA (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009; Phadke et al., 2009). However, the efficacy of the SA as a scapula upward rotator, may be limited in the presence of scapula anterior tilt as it is predominantly responsible for scapula posterior tilt (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009; Phadke et al., 2009). Scapula anterior tilting occurs as a result of PM inflexibility (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009). The PML in this study was similar to those reported in tennis players, but shorter than the average for the general population (Borstad, 2008). Consequently, this cohort of cricketers may not have sufficient SA strength to counteract the scapula anterior tilt created by PM inflexibility. In addition, the slightly greater LT strength demonstrated in this study's cricketers, may be insufficient to produce scapula upward rotation in the absence of synergistic SA activity. A resultant scapula position of downward rotation and anterior tilt may thus occur. Subsequently, this scapula position increases the risk for shoulder impingement as the rotator cuff tendons are approximated towards the coracoacromial arch/glenoid lip and excessive anterior or superior humeral head migration occurs (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009).

The maintenance of the AHD in this study is another unexpected finding, indicating that the subacromial space is preserved, despite a thicker supraspinatus tendon. Similar findings have been reported in volleyball players (Leong, Tsui, Ying, Leung, & Fu, 2012) where a large AHD was associated with a thicker supraspinatus tendon and greater GH external rotation strength. Conversely, this study demonstrated general weakness of the GHER and GHIR in cricketers that may have occurred as a result of anterior humeral head translation (Ludewig & Reynolds, 2009; Myers, Laudner, & Lephart, 2005) or potential internal (glenoid) impingement (Cools, Johansson, & Maenhout, 2015; Walch, Boileau, Noel, & Donell, 1992) which would inhibit the supra- and infraspinatus muscles.

The findings of this study suggest that the dominant throwing shoulder of cricketers is atypical to that of other overhead throwers, however numerous variables indicate that cricketers as a population are particularly vulnerable to shoulder pain and injury risk. This is further highlighted by the number of uninjured cricketers reporting symptoms with the pain provocation tests, indicating the possibility that a symptomatic shoulder which does not influence performance, is not reported as an injury by cricketers. Clarsen, Myklebust, and Bahr (2013) have found that many elite athletes demonstrate this phenomenon of pain without reporting an "injury". Consequently, early diagnosis and treatment is essential to reduce the chronicity and severity of shoulder injuries in this overhead throwing population. Therefore, the implementation of preventative strategies targeted at improving strength and flexibility, managing throwing workload and assessing overhead throwing biomechanics is suggested.

Notably, the influence of these musculoskeletal variables on shoulder function is emphasised by the low mean KJOC scores noted in this study at the start of the season, irrespective of injury. The low KJOC scores may further be attenuated by the deficit in non-dominant hip external rotation ROM and weakness in the dominant hip GM demonstrated by these cricketers, as these biomechanical deficiencies are known to increase the load on the shoulder and negatively influence the performance of overhead throwing in baseball pitchers (Dillman, Fleisig, & Andrews, 1993; Kibler et al., 2013; Weber, Kontaxis, & Bedi, 2014).

Further, the potential association between low pre-season KJOC scores and a deficit (≤22.75°) in dominant hip internal rotation ROM was shown in cricketers with a history of previous shoulder injury. Extant research has found that dominant hip internal rotation ROM ≤30° reduces the risk for trunk, back and lower limb injuries in fast bowlers (Dennis, Finch, McIntosh, & Elliott, 2008). Traditionally, these specialists are positioned in the outer ring when fielding (Green et al., 2013; Ranson & Gregory, 2008; Saw, Dennis, & Farhart, 2011), requiring overhead throws over a distance of approximately 30 m (Hussain & Bari, 2011), placing them at risk for shoulder injury due to workload (MacDonald, Mills, & Stretch, 2013). Consequently, it is suggested that the optimal range of dominant hip internal rotation to prevent shoulder, back, trunk and lower limb injuries in cricketers, may lie between 25° and 30°. Lastly, the importance of including the entire kinetic chain in musculoskeletal screening protocols and the assessment of performance parameters is highlighted.

4.2. The musculoskeletal screening variables predictive of shoulder injury

The secondary outcome of this study was that dominant SsT and non-dominant shoulder PML predicted dominant shoulder injury. The increase in dominant SsT is thought to occur as a result of repetitive overhead throwing load (Green et al., 2013; Ranson & Gregory, 2008; Saw, Dennis, Bentley, & Farhart, 2011), in the absence of sufficient GHER strength (Leong et al., 2012). Previous researchers have found that a thicker SsT is associated with a larger AHD, increased GHER strength and a higher GHER:GHIR strength ratio in volleyball players (Leong et al., 2012). These cricketers demonstrated a thicker SsT and an AHD on the upper spectrum of the normal, weakness of the GHER and a lower GHER:GHIR strength ratio. This may indicate that the SsT becomes overloaded as it attempts to resist the superior humeral head migration known to occur with deltoid contraction, as the dominant arm cocks in preparation to throw overhead (Reinold, Escamilla, & Wilk, 2009). Thus, a resultant hypertrophy of the SsT may occur with repetitive throwing, similar to that observed in swimmers post-training (Porter, Blanch, & Shield, 2017).

Further, this study observed that dominant shoulder SsT thickness ≥5.85 mm predicts shoulder injury in cricketers, which is a substantially lower cut-off than that reported to increase the risk of shoulder impingement in volleyball players (Leong et al., 2012). This may have occurred as these cricketers did not demonstrate the associated increase in AHD. Lastly, the clinical relevance of SsT thickness as a predictor of shoulder injury in this study is shown to be minimal as the RoC curves demonstrate large measurement variability (4.3−6.7 mm). Further research is indicated to fully understand the significance of this finding.

Non-dominant shoulder PML inflexibility will result in scapula anterior tilt, consequently impeding clavicular elevation, retraction and posterior rotation, reducing the range of scapula upward rotation required for GH elevation >60° (Crosbie, Kilbreath, & York, 2008; Ludewig & Braman, 2011; Ludewig & Reynolds, 2009). Further, scapula upward rotation has been positively correlated with upper thoracic rotation ROM (Crosbie, Kilbreath, Hollmann, & York, 2008; Fayad et al., 2008; Theodoridis & Ruston, 2002). Although this measurement was not included in this study, these cricketers did demonstrate a delay in non-dominant upward scapula rotation from rest to 90°, indicating potential rotational stiffness in the thoracic spine. Consequently, when throwing overhead, cricketers will attempt to position the dominant arm behind the body in greater GH abduction and external rotation in the preparatory and stride phases to compensate for the lack of thoracic rotation (Chu, Jayabalan, & Press, 2016; Kibler et al., 2013). A resultant increase in dominant shoulder GH compression occurs (Chu, Jayabalan, Kibler, & Press, 2016; Kibler et al., 2013) highlighting the susceptibility of the supraspinatus tendon to irritation in the subacromial space (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009).

4.3. Value of pre-season screening

Numerous variables associated with shoulder injury in overhead sport were tested as part of a comprehensive pre-season shoulder screening protocol suggested for cricketers. Importantly, only 2 of 17 screening tests were shown to be predictive of seasonal shoulder injury in cricketers.

In addition, these tests were shown to have either a poor (AUC > 0.60), or fair (AUC > 0.70) ability to distinguish between cricketers who did and didn't sustain an injury. However, the poor association between musculoskeletal screening tests and injury found in this study may have occurred as this entire cohort of cricketers appear to be at higher risk for shoulder injury. Despite the paucity of evidence supporting the use of pre-season screening for injury risk, its value cannot be ignored. Pre-season screening has the potential to highlight and educate clinicians and athletes on specific intrinsic deficits which may increase injury potential. In addition, individualised target-based interventions can be developed, with the long-term aim of enhancing performance through a reduction in injury risk.

4.4. Methodological considerations and future directions

This study was conducted over a single season (six months) and longer documentation should be considered in the future. However, this was a well-controlled trial as all screening tests were performed by the same author (MD), minimising potential measurement error; and injury data were captured by the respective squad medical personal at the time of injury, thus reducing the reliance on self-report measures. As a saturation sample was utilised in this study, a multi-centre study of cricketers of similar level of play, is suggested to improve statistical power and allow for player speciality/position comparisons with risks factors for injury.

Future research in the development of shoulder specific screening tools, using different measurement techniques, is essential to identify novel injury risk factors and cut-off values. The influence of modifiable shoulder injury risk factors on performance measures in cricket, should be investigated in the development of injury prevention programmes. In addition, studies are suggested that explore the effectiveness of injury prevention programmes on modifiable shoulder injury risk factors in cricket.

5. Conclusion

In conclusion, a cricketer's shoulder does not demonstrate the characteristics associated with the classic *"thrower's paradox"* and may increase a cricketer's risk of developing shoulder impingement. Although most pre-season screening variables in this cohort were not associated with seasonal injury, dominant SsT thickness and non-dominant PML predicted injury with a high sensitivity and moderate specificity. Thus continued investigation of these variables in a longitudinal study is warranted. Further, the efficacy of a shoulder specific rehabilitation protocol on injury prevention and throwing performance in cricketers should be explored.

Ethical approval

Ethical approval was obtained from the Research Ethics Committee of the University of Cape Town (HREC: 364/2016). The subjects were required to sign the informed consent prior to the commencement of the trial.

Conflicts of interest

No conflicts of interest for any author.

Funding

This work is based on the research supported in part by the National Research Foundation of South Africa (Grant Number: 110941); and the International Society of Biomechanics (Matching Dissertation Grant) and Cricket South Africa.

Acknowledgements

Thanks to the National Research Foundation of South Africa, the International Society of Biomechanics and Cricket South Africa for their support of this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.03.014.

References

Alberta, F. G., ElAttrache, N. S., Bissel, S., Mohr, K., Browdy, J., Yocum, L., et al. (2010). The development and validation of a functional assessment tool for the upper extremity in the overhead athlete. *The American Journal of Sports Medicine*. https://doi.org/10.1177/0363546509355642.

Amin, N. H., Ryan, J., Fening, S. D., Soloff, L., Schickendantz, M. S., & Jones, M. (2015). The relationship between glenohumeral internal rotational deficits, total range of motion, and shoulder strength in professional baseball pitchers. *Journal of the American Academy of Orthopaedic Surgeons*. https://doi.org/10.5435/JAAOS-D-15-00292.

Arora, M., Shetty, S. H., & Dhillon, M. S. (2015). The shoulder in cricket: What's causing all the painful shoulders? *Journal of Arthroscopy and Joint Surgery*. https://doi.org/10.1016/j.jajs.2015.06.003.
Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: A key component of preventing injuries in sport. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.2005.018341.
Bell-Jenje, T. C., & Gray, J. (2005). Incidence, nature and risk factors in shoulder injuries of national academy cricket players over 5 years - a retrospective study. *South African Journal of Sports Medicine, 17*(4), 22–28.
Belling Sorenson, A. K., & Jorgensen, U. (2000). Secondary impingement in the shoulder. An improved terminology in impingement. *Scandinavian Journal of Medicine & Science in Sports*. https://doi.org/10.1034/j.1600-0838.2000.010005266.x.
Borstad, J. D. (2008). Measurement of pectoralis minor muscle length: Validation and clinical application. *Journal of Orthopaedic & Sports Physical Therapy*. https://doi.org/10.2519/jospt.2008.2723.
Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2000). Shoulder injuries in overhead athletes, the "dead arm" revisited. *Clinical Sports Medicine*. https://doi.org/10.1016/S0278-5919(05)70300-8.
Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2003). The disabled throwing shoulder: Spectrum of pathology: Part I: Anatomy and biomechanics. *Arthroscopy*. https://doi.org/10.1053/jars.2003.50128.
Chu, S. K., Jayabalan, P., Kibler, W. B., & Press, J. (2016). The kinetic chain revisited: New concepts on throwing mechanics and injury. *American Academy of Physical Medicine and Rehabilitation*. https://doi.org/10.1016/j.pmrj.2015.11.015.
Clarsen, B., Myklebust, G., & Bahr, R. (2013). Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: The Oslo sports trauma research centre (OSTRC) overuse injury questionnaire. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2012-091524.
Cools, A. M., Johansson, F. R., Borms, D., & Maenhout, A. (2015). Prevention of shoulder injuries in overhead athletes: A science-based approach. *Brazilian Journal of Physical Therapy*. https://doi.org/10.1590/bjpt-rbf.2014.0109.
Cools, A. M., Johansson, F. R., Cambier, D. C., van de Velde, A., Palmans, T., & Witvrouw, E. E. (2010). Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.2009.070128.
Crosbie, J., Kilbreath, S. L., Hollmann, L., & York, S. (2008). Scapulohumeral rhythm and associated spinal motion. *Clinical Biomechanics*. https://doi.org/10.1016/j.clinbiomech.2007.09.012.
Dennis, R. J., Finch, C. F., McIntosh, A. S., & Elliott, B. C. (2008). Use of field-based tests to identify risk factors for injury to fast bowlers in cricket. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.2008.046698.
Dillman, C. J., Fleisig, G. S., & Andrews, J. R. (1993). Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic & Sports Physical Therapy*. https://doi.org/10.2519/jospt.1993.18.2.402.
Donatelli, R., Ellenbecker, T. S., Ekedahl, S. R., Wilkes, J. S., Kocher, K., & Adam, J. (2000). Assessment of shoulder strength in professional baseball players. *Journal of Orthopaedic & Sports Physical Therapy*. https://doi.org/10.2519/jospt.2000.30.9.544.
Downar, J. M., & Sauers, E. L. (2005). Clinical measures of shoulder mobility in the professional baseball player. *Journal of Athletic Training, 40*(1), 23–29.
Ellenbecker, T. S., & Cools, A. M. (2010). Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: An evidence-based review. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.2009.058875.
Fayad, F., Hanneton, S., Lefevre-Colau, M., Poiraudeau, S., Revel, M., & Roby-Brami, A. (2008). The trunk as a part of the kinematic chain for arm elevation in healthy subjects and in patients with frozen shoulder. *Brain Research*. https://doi.org/10.1016/j.brainres.2007.11.046.
Freeston, J., Carter, T., Whitaker, G., Nicholls, O., & Rooney, K. (2016). Strength and power correlates of throwing velocity on subelite male cricket players. *The Journal of Strength & Conditioning Research*. https://doi.org/10.1519/JSC.0000000000001246.
Freeston, J., Ferdinands, R., & Rooney, K. (2007). Throwing velocity and accuracy in elite and sub-elite cricket players: A descriptive study. *European Journal of Sport Science*. https://doi.org/10.1080/17461390701733793.
Gabbett, T. J. (2010). The development and application of an injury prediction model for non-contact, soft-tissue injuries in elite collision sport athletes. *The Journal of Strength & Conditioning Research*. https://doi.org/10.1519/JSC.0b013e3181f19da4.
Giles, K., & Musa, I. (2008). A survey of glenohumeral joint rotational range and non-specific shoulder pain in elite cricketers. *Physical Therapy in Sport*. https://doi.org/10.1016/j.ptsp.2008.03.002.
Green, R. A., Taylor, N. F., Watson, L., & Ardern, C. (2013). Altered scapula position in elite young cricketers with shoulder problems. *Journal of Science and Medicine*. https://doi.org/10.1016/j.jsams.2012.05.017.
Harput, G., Guney, H., Toprak, U., Kaya, T., Colakoglu, F. F., & Baltaci, G. (2016). Shoulder-rotator strength, range of motion, and acromiohumeral distance in asymptomatic adolescent volleyball attackers. *Journal of Athletic Training*. https://doi.org/10.4085/1062-6050-51.12.04.
Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., … Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546504269591.
Hussain, I., & Bari, M. A. (2011). Biomechanical analysis of cricket ball throwing techniques. *Journal of Education and Practice, 2*(3), 29–35.
Kibler, W. B., Wilkes, T., & Sciascia, A. (2013). Mechanics and pathomechanics in the overhead athlete. *Clinical Sports Medicine*. https://doi.org/10.1016/j.csm.2013.07.003.
Kinsella, S. D., Thomas, S. J., Huffman, G. R., & Kelly, J. D. (2014). The thrower's shoulder. *Orthopaedic Clinician of North America*. https://doi.org/10.1016/j.ocl.2014.04.003.
Kraeutler, M. J., Ciccotti, M. G., Dodson, C. C., Frederick, R. W., Cammarota, B., & Cohen, S. B. (2013). Kerlan-jobe orthopaedic clinic overhead athlete scores in asymptomatic professional baseball pitchers. *Journal of Shoulder and Elbow Surgery*. https://doi.org/10.1016/j.jse.2012.02.010.
Laudnar, K. G., Moore, S. D., Sipes, R. C., & Meister, K. (2010). Functional hip characteristics of baseball pitchers and position players. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546509347365.
Leary, T., & White, J. A. (2000). Acute injury incidence in professional county club cricket players (1985-1995). *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.34.2.145.
Leong, H., Tsui, S., Ying, M., Leung, V. Y., & Fu, S. N. (2012). Ultrasound measurements on acromiohumeral distance and supraspinatus tendon thickness: Test-retest reliability and correlations with shoulder rotational strengths. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2011.11.259.
Lintner, D., Noonan, T. J., & Kibler, W. B. (2008). Injury patterns and biomechanics of the athlete's shoulder. *Clinical Sports Medicine*. https://doi.org/10.1016/j.csm.2008.07.007.
Ludewig, P. M., & Braman, J. P. (2011). Shoulder impingement: Biomechanical considerations in rehabilitation. *Manual Therapy*. https://doi.org/10.1016/j.math.2010.08.004.
Ludewig, P. M., & Reynolds, J. F. (2009). The association of scapular kinematics and glenohumeral joint pathologies. *Journal of Orthopaedic & Sports Physical Therapy*. https://doi.org/10.2519/jospt.2009.2808.
Lun, V., Meeuwisse, W. H., Stergiou, P., et al. (2004). Relation between running injury and static lower limb alignment in recreational runners. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.2003.005488.
MacDonald, D., Mills, J., McGuigan, M., & Stretch, R. (2013). A review of cricket fielding requirements. *South African Journal of Sports Medicine*. https://doi.org/10.17159/2413-3108/2013/v25i3a366.
Maenhout, A., van Eessel, V., van Dyck, L., Vanraes, A., & Cools, A. M. (2012). Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546512454530.
McCreesh, K. M., Anjum, S., Crotty, J. M., & Lewis, L. S. (2015). Ultrasound measures of supraspinatus tendon thickness and acromiohumeral distance in rotator cuff tendinopathy are reliable. *Journal of Clinical Ultrasound*. https://doi.org/10.1002/jcu.22318.
van Mechelen, W., Hlobil, H., & Kemper, H. C. G. (1992). Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Medicine*. https://doi.org/10.2165/00007256-199214020-00002.
Moore, S. D., Uhl, T. L., & Kibler, W. B. (2013). Improvements in shoulder endurance following a baseball-specific strengthening program in high school baseball players. *Sport Health*. https://doi.org/10.1177%2F1941738113477604.
Morgan, C. D., Burkhart, S. S., & Palmeri, M. (1998). Type II SLAP lesions: Three subtypes and their relationships to superior instability and rotator cuff tears. *Arthroscopy*. https://doi.org/10.1016/S0749-8063(98)70049-0.
Myers, J. B., Laudner, K. G., Pasquale, M. R., Bradley, J. P., & Lephart, S. M. (2005). Scapular position and orientation in throwing athletes. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546504268138.
Myers, J. B., Oyama, S., Wassinger, C. A., Ricci, R. D., Abt, J. P., Conley, K. M., et al. (2007). Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546507304142.
Olivier, B., & Gray, J. (2018). Musculoskeletal predictors of non-contact injuries in cricket - few and far between? A longitudinal cohort study. *Physical Therapy in Sport*. https://doi.org/10.1016/j.ptsp.2018.10.014.
Orchard, J., James, T., Alcott, E., Carter, S., & Farhart, P. (2002). Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.36.4.270.
Phadke, V., Camargo, P. R., & Ludewig, P. M. (2009). Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Revista Brasileira de Fisioterapia*. https://doi.org/10.1590/S1413-35552009005000012.
Porter, K., Blanch, P., Walker, H., & Shield, A. (2017). Supraspinatus tendon response to swimming training. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2017.01.223.
Ranson, C., & Gregory, P. L. (2008). Shoulder injury in professional cricketers. *Physical Therapy in Sport*. https://doi.org/10.1016/j.ptsp.2007.08.001.
Reinold, M., Escamilla, R., & Wilk, K. (2009). Current concepts in the scientific and clinical rationale behind exercises for the glenohumeral and scapulothoracic musculature. *Journal of Orthopaedic & Sports Physical Therapy*. https://doi.org/10.2519/jospt.2009.2835.
Reinold, M., Wilk, K., Macrina, L., Sheheane, C., Dun, S., Fleisig, G., et al. (2008). Current changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546507308935.
Routolo, C., Price, E., & Panchal, A. (2006). Loss of total arc of motion in collegiate baseball players. *Journal of Shoulder and Elbow Surgery*. https://doi.org/10.1016/

j.jse.2005.05.006.
Sabick, M. B., Kim, Y., Torry, M. R., Keirns, M. A., & Hawkins, R. J. (2005). Biomechanics of the shoulder in youth baseball pitchers. Implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *The American Journal of Sports Medicine*. https://doi.org/10.1177%2F0363546505275347.
Saw, R., Dennis, R. J., Bentley, D., & Farhart, P. (2011). Throwing workload and injury risk in elite cricketers. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.2009.061309.
Schmidt, W. A., Schmidt, H., Schicke, B., & Gromnica-Ihle, E. (2004). Standard reference values for musculoskeletal ultrasonography. *Annals of the Rheumatic Diseases*. https://doi.org/10.1136/ard.2003.015081.
Shaw, C. N., & Stock, J. T. (2009). Habitual throwing and swimming correspond with upper limb diaphyseal strength and shape in modern human athletes. *American Journal of Physical Anthropology*. https://doi.org/10.1002/ajpa.21063.
van Stralen, K. J., Stel, V. S., Reitsma, J. B., et al. (2009). Diagnostic methods I: Sensitivity, specificity, and other measures of accuracy. *Kidney International*. https://doi.org/10.1038/ki.2009.92.
Stretch, R. A. (2003). Cricket injuries: A longitudinal study of the nature of injuries to South African cricketers. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.37.3.250.
Stretch, R. A. (2007). A review of cricket injuries and the effectiveness of strategies to prevent cricket injuries at all levels. *South African Journal of Sports Medicine*. https://doi.org/10.17159/2078-516X/2007/v19i5a256.
Theodoridis, D., & Ruston, S. (2002). The effect of shoulder movements on thoracic spine 3D motion. *Clinical Biomechanics*. https://doi.org/10.1016/S0268-0033(02)00026-8.
Thomas, S. J., Swanik, C. B., Higginson, J. S., Kaminski, T. W., Swanik, K. A., Bartolozzi, A. R., et al. (2011). A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *Journal of Shoulder and Elbow Surgery*. https://doi.org/10.1016/j.jse.2010.08.031.
Tyler, T. F., Roy, T., Nicholas, S. J., & Gleim, G. W. (1999). Reliability and validity of a new method of measuring posterior shoulder tightness. *Journal of Orthopaedic & Sports Physical Therapy*. https://doi.org/10.2519/jopst.1999.29.5.262.
Walch, G., Boileau, P., Noel, E., & Donell, S. T. (1992). Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: An arthroscopic study. *Journal of Shoulder and Elbow Surgery*. https://doi.org/10.1016/S1058-2746(09)80065-7.
Weber, A. E., Kontaxis, A., O'Brien, S., & Bedi, A. (2014). The biomechanics of throwing: Simplified and cogent. *Sports Medicine and Arthroscopy*. https://doi.org/10.1097/JSA.0000000000000019.
Yamamoto, N., Mingagawa, H., Urayama, M., Saito, H., Seki, N., Iwase, T., et al. (2006). Why is humeral retroversion of throwing athletes greater in dominant shoulders than in nondominant shoulders? *Journal of Shoulder and Elbow Surgery*. https://doi.org/10.1016/j.jse.2005.06.009.