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Literature Review

A systematic review of shoulder injury prevalence, proportion, rate, type, onset, severity, mechanism and risk factors in female artistic gymnasts

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ABSTRACT

Objectives: Systematically review shoulder injury prevalence, proportion, rate, type, onset, severity, mechanism, risk factors in female artistic gymnasts.
Methods: PubMed, Web of Science, Scopus, Cochrane Library were searched on 7/01/2017. Original studies reporting data for female artistic gymnasts only, of any age or level were included. Quality assessment was undertaken using Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.
Results: Fifteen observational studies were included. Thirteen were poor/fair quality. Shoulder injury prevalence (0%–86.9%) was higher in international (29.2%) versus national (20%) gymnasts. As a proportion of all injuries, shoulder injuries made up 4.2%–7.5%. Rates (0.35–5.7/1000 athlete exposures) were greater during practice (5.0/1000) than competition (2.4/1000). Multidirectional instability (33.8%, 37.7%) and musculotendinous injury (26.6%–90.9%) were the most common injury. In four studies 66.2%–100% of total shoulder injuries were acute onset. Most (59.3%) shoulder injuries were minor, 7.4% required surgery and 80% caused symptoms post-retirement. Asymmetric bars were the most frequent mechanism of shoulder injury. One study reported excessive shoulder stretching, hyperlaxity and instability as significant ($p < 0.001$) potential risk factors.
Conclusions: Shoulder injuries are a problem among female artistic gymnasts. Interventional studies reporting age and competition level-specific data may guide prevention strategy implementation.

1. Introduction

Female artistic gymnastics involves four pieces of apparatus – asymmetric bars, balance beam, floor and vault. Artistic gymnasts typically commence specific training at five years old (Bradshaw & Hume, 2012; Kolt & Kirkby, 1995). The average junior (10–14 years old) female elite gymnast trains 5.04 h per day, 5.36 days per week (Sands, Eisenman, & Johnson, 1987a). Senior elite female gymnasts may train up to 40 h per week (Dixon & Fricker, 1993). Gymnast-specific technical elements, such as vaults and dismounts, produce large impact loads and joint compression forces, require high velocity muscle contractions and are trained repetitively throughout childhood (Bradshaw & Hume, 2012; Caine et al., 2003; Daly, Bass, & Finch, 2001; French et al., 2004; Koh, Grabiner, & Weiker, 1992). These early physical demands may explain why artistic gymnastics has one of the highest rates of injury among female athletes (Caine et al., 2003, 2006; Singh, Smith, Fields, & McKenzie, 2008).

The lower limb and back are the most common anatomical areas of injury in female artistic gymnasts (Bak, Kalms, & Olesen, 1994; De Vita, Panetta, Prattico, & Foti, 2015; Fellander-Tsai & Wredmark, 1995; Garrick & Requa, 1980). However, upper extremity injuries tend to be more severe, involving fractures and dislocations, resulting in higher admission rates to emergency departments (Fellander-Tsai & Wredmark, 1995; Singh et al., 2008). Within the upper limb, asymptomatic shoulder changes that are associated with repetitive microtrauma have also been identified on radiographs; including lesser tubercle sclerosis of the humerus, arthrosis of the acromioclavicular joint and osteochondrotic bodies within the scapulohumeral joint (Silvij & Nocini, 1982). Furthermore, 80%

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of shoulder injuries cause long-term symptoms which may increase the risk of early-onset degenerative disease (Bradshaw & Hume, 2012; Wadley & Albright, 1993).

The women's artistic gymnastics Code of Points is updated every Olympic cycle, therefore technical difficulty has increased considerably over the years (Nattiv & Mandelbaum, 1993; Meeusen & Borms, 1992; Federation Internationale De Gymnastique Women's Technical Committee, 2017). Skills such as giant swings (360° rotations around a bar in the straight position) require large torques and power outputs from the shoulder joint of the young gymnast which may increase injury risk (Arampatzis & Bruggemann, 1999). Furthermore, elite gymnasts are now encouraged to perform multiple high level elements, such as the *Tkatchev*, in which a gymnast releases the bar near the top of a backward swing, flies backwards over the bar in a straddle or pike position and catches the bar on the other side, in one routine. Release and catch skills, such as the *Tkatchev*, also require extreme ranges of motion from the shoulder, resulting in higher tension on the glenohumeral ligaments, which increases injury risk (Arampatzis & Bruggemann, 2001; Caplan, Julien, Michelson, & Neviaser, 2008).

By evaluating prevalence, rate, type and severity of shoulder injury and detecting injury mechanisms and risk factors, efficient injury prevention strategies can be developed (van Mechelen, Hlobil, & Kemper, 1992) For this reason, it is important to ascertain shoulder injury epidemiology and aetiology amongst female gymnasts; however, no study has yet systematically synthesised all evidence within this population. The aim of this study was to assess shoulder injury prevalence, shoulder injury as a proportion of total injuries, shoulder injury rate, type, onset, severity, mechanism and risk factors amongst female artistic gymnasts by systematically reviewing current literature.

2. Methods

The review was conducted according to PRISMA checklist (Moher, Liberati, Tetzlaff, & Altman, 2009). Peer-reviewed studies available in full English text, that reported shoulder injuries among a population of female only, artistic gymnasts of any age, any level, were included. Studies that collected shoulder injuries into generic groups, or did not report shoulder injuries separately, were excluded. Due to discrepancies in apparatus trained, skills performed, and subsequent differences in injury patterns, data from non-artistic gymnasts were excluded (Bak et al., 1994). Data including a mixed gender population were included if female gymnasts were presented separately. Case reports, reviews, books, conference proceedings, letters and commentaries were excluded.

Two independent researchers performed the literature search on 7th January 2017 by searching PubMed, Web of Science, Scopus and Cochrane Library from inception with no added limits.

The following search strategy was used:

1. Shoulder injury OR shoulder injuries OR shoulder pathology OR shoulder pathologies OR shoulder OR shoulders OR shoulder joint OR shoulder pain OR acromioclavicular OR coracoclavicular OR glenohumeral OR scapulothoracic OR sternoclavicular injury OR injuries OR injury type OR injury types OR injury prevalence OR injury incidence OR injury rate OR injury rates OR acute injury OR acute injuries OR chronic injury OR chronic injuries OR overuse injury OR overuse injuries
2. Gymnastics OR gymnasts OR gymnast OR gymnastic training OR gym OR artistic gymnastics OR artistic gymnasts
3. 1 AND 2

Results were output into Endnote (Online Version, Thomson Reuters Co. Toronto, Ontario, Canada) and duplicate records electronically discarded, after which titles and abstracts were individually screened. Records were excluded if the title was irrelevant or if they did not meet the eligibility criteria. Full text articles were reviewed for final inclusion/exclusion. Reference lists of eligible papers were then screened for relevant articles.

Outcome variables included for the data extraction were: shoulder injury prevalence, proportion of total injuries, rate, type, onset, severity, mechanism and risk factors. Where possible, outcomes were reported separately for each level of exposure (*i.e.* training/competition, level).

To assess quality and risk of bias, the fourteen-item Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies ((National Institute of Health: US Department of Health and Human Services, 2017)) was implemented (Aasa, Svartholm, Andersson, & Berglund, 2017; Shuang et al., 2014). Item 1 of the tool assessed research question and aims; items 2 to 5 evaluated sample quality, external validity and selection bias risk; item 6 and 7 assessed timing of exposure and outcome measurements; item 8 assessed reporting of different levels of exposure. Items 9 and 11 assessed definition, validity, reliability, and implementation of exposure and outcome variables; item 10 evaluated repetition of exposure measurements. Item 12 considered outcome assessor blinding and measurement bias risk; item 13 evaluated loss to follow up bias risk and item 14 assessed confounding and internal validity (Aasa et al., 2017). Each study was reviewed by two independent investigators, who scored each item yes (Y), no (N), cannot determine (CD) or not applicable (NA). For an objective quality score, total Y scores were added up for each study and recorded as a percentage of maximum possible score for that study. N and CD items were not counted and NA items were deducted from the maximum possible score for that study. Study quality was assessed via percentage (≥50% good, 30–50% fair, ≤30% poor).

3. Results

A total of 1971 records, from which 1352 titles/abstracts and 84 full text articles were reviewed, and 15 studies met the inclusion criteria (Fig. 1).

A total of 1064 female artistic gymnasts were assessed for shoulder injuries in twelve of the eligible studies (Caine et al., 1989, 2003; Caplan et al., 2008; Dixon & Fricker, 1993; Homer & Mackintosh, 1992; Kolt & Kirkby, 1999; Mackie & Taunton, 1994; Sands et al., 1987b, 1993; Snook, 1979; Wadley & Albright, 1993; Westermann, Giblin, Vaske, Grosso, & Wolf, 2015). Kerr et al. (Kerr, Hayden, Barr, Klossner, & Dompier, 2015a), Marshall et al. (Marshall, Covassin, Dick, & Nassar, 2007) and Saluan et al. (Saluan, Styron, Ackley, Prinzbach, & Billow, 2015) did not report total number of gymnasts included. Studies that used intercollegiate athletes were classed as national level (Caplan et al., 2008; Kerr et al., 2015a; Marshall et al., 2007; Sands et al., 1987b, 1993; Snook, 1979; Wadley & Albright, 1993; Westermann et al., 2015). Characteristics were reported separately for each gymnast level where possible, however thirteen studies did not report sample characteristics separately (Caine et al., 1989, 2003; Caplan et al., 2008; Dixon & Fricker, 1993; Homer & Mackintosh, 1992; Kerr et al., 2015a; Mackie & Taunton, 1994; Marshall et al., 2007; Sands et al., 1987b, 1993; Snook, 1979; Wadley & Albright, 1993; Westermann et al., 2015). All studies were observational, none had a control group, seven were prospective, six retrospective and two cross-sectional (Caine et al., 1989, 2003; Caplan et al., 2008; Dixon & Fricker, 1993; Homer & Mackintosh, 1992; Kerr et al., 2015a; Kolt & Kirkby, 1999; Mackie & Taunton, 1994; Marshall et al., 2007; Saluan et al., 2015; Sands et al., 1987b, 1993; Snook, 1979; Wadley & Albright, 1993; Westermann et al., 2015). Length of data collection ranged from one to twenty-one years (Caine et al., 1989; Saluan

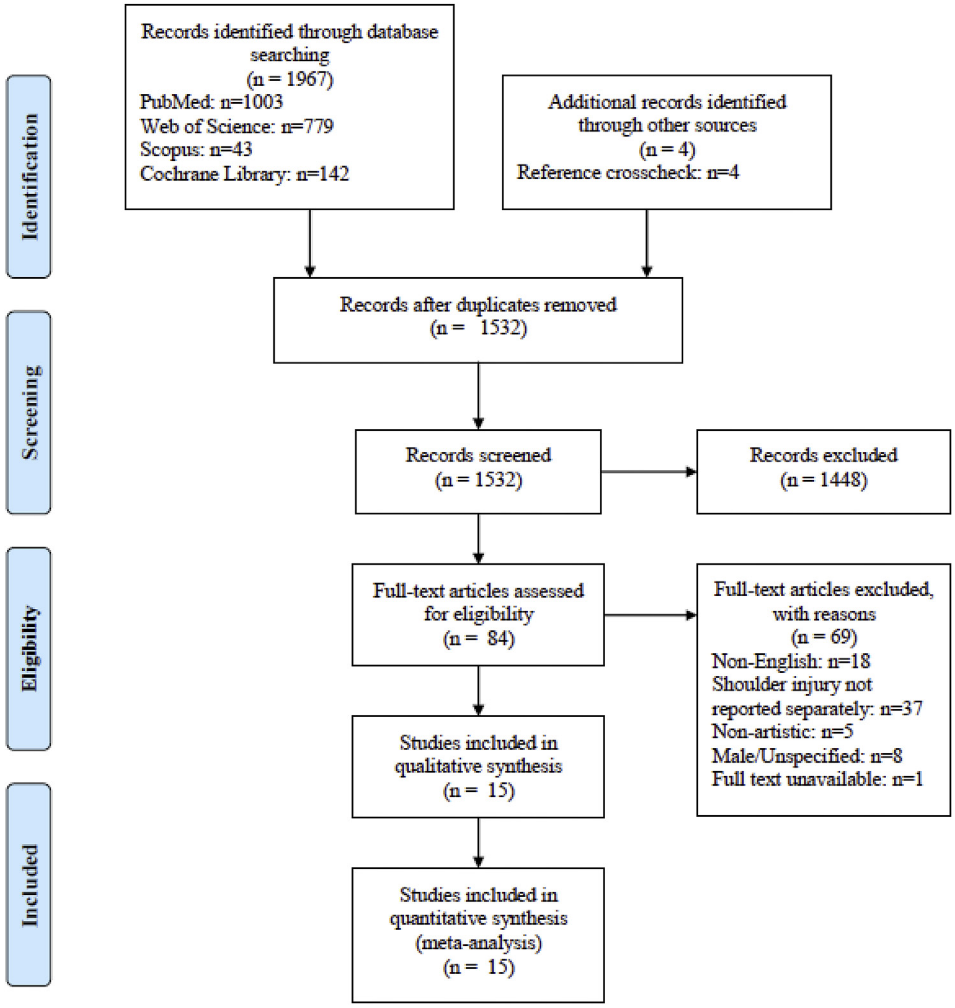

Fig. 1. PRISMA flow chart of the literature search and record screening process.

et al., 2015). Six studies (4, 34–38) used medical records/physician diagnosis for injury data collection methods and six (21, 29–33) used reports, questionnaires or interviews. Caine et al. (1989) (Caine et al., 1989), Caine et al. (2003) (8) and Wadley et al. (Wadley & Albright, 1993) used a combination of gymnast/coach injury reports and physician diagnosis.

Injury definition varied between studies (Table 1). Six studies (8, 28, 30–33) included the definition: "any injury causing modified participation in gymnastics"; four (4, 34, 35, 38) included "any injury requiring attention from a physician or athletic trainer"; three studies (16, 36, 37) combined "reduced participation" and "requiring athletic trainer or physician attention"; Caplan et al. (Caplan et al., 2008) used the definition of 'any traumatic shoulder injury' and Homer et al. (Homer & Mackintosh, 1992) provided no definition.

Two studies were rated good quality (>50%) (Kerr et al., 2015a; Sands et al., 1987b). Kerr et al. was the only study that met both items nine and eleven as exposure and outcome measures were 'clearly defined, valid, reliable, and implemented consistently across all study participants' (Kerr et al., 2015a). Eight studies (Caine et al., 1989, 2003; Dixon & Fricker, 1993; Kolt & Kirkby, 1999; Mackie & Taunton, 1994; Marshall et al., 2007; Saluan et al., 2015; Westermann et al., 2015) were considered fair quality, scoring 30%–50%, whereas five (Caplan et al., 2008; Homer & Mackintosh, 1992; Sands et al., 1993; Snook, 1979; Wadley & Albright, 1993) were considered poor quality (<30%).

4. Shoulder injury prevalence

Twelve studies reported shoulder injury prevalence (Table 2). Sands et al. (1993) reported the highest prevalence (86.9%) (Sands et al., 1993), followed by Caplan et al. (Caplan et al., 2008), Westermann et al. (Westermann et al., 2015) and Kolt et al. (Kolt & Kirkby, 1999) who reported 33.7%, 27.3% and 23.4% respectively. Kolt et al. reported higher shoulder injury prevalence among international (29.2%) compared to national/regional level gymnasts (20.0%) (Kolt & Kirkby, 1999). Homer et al. reported lowest prevalence with zero shoulder injuries (Homer & Mackintosh, 1992).

5. Shoulder injury proportion

Fourteen studies reported shoulder injury as a proportion of total injuries (Table 2). Eight studies reported between 4.2% and 7.5% of total injuries to be a shoulder injury (Caine et al., 2003; Kerr et al., 2015a; Kolt & Kirkby, 1999; Marshall et al., 2007; Saluan et al., 2015; Sands et al., 1993; Wadley & Albright, 1993; Westermann et al., 2015). Snook et al. reported the highest proportion (32.4%) (Snook, 1979), whereas Homer et al. demonstrated the lowest proportion (0%) (Homer & Mackintosh, 1992). Marshall et al. found that shoulder injuries made up a larger proportion of total injuries

Table 1
Included study characteristics (n = 15).

Study	Study design	Duration of Data Collection	Injury Definition	Method of Injury Data Collection	Sample Size (n) Country Level	Age (yrs) Mean ± SD (Range)	Training Hours (/week)	Shoulder Injury Outcomes
Caine et al. (2003) (8)	Prospective cohort	3 years	Missed training/ competition	Club physician (levels 7–10) Student athletic trainer Coach injury reports	79 USA Precollegiate (USGF Levels 4 –10)	(Bak et al., 1994; Caine et al., 2003, 2006; Daly et al., 2001; De Vita et al., 2015; Fellander-Tsai & Wredmark, 1995; Garrick & Requa, 1980; Meeusen & Borms, 1992; Nattiv & Mandelbaum, 1993; Silvij & Nocini, 1982; Singh et al., 2008; Wadley & Albright, 1993)	Range 7.5–22.5	Prevalence Proportion Rate Onset
Caine et al. (1989) (28)	Prospective cohort	1 year	Missed training/ competition	Gymnast training diary Gymnast/ coach verbal injury report Injury observation by investigator	50 USA Precollegiate (Division III to Elite)	12.6	Mean 15.4 (±SD NR)	Prevalence Proportion Rate Onset
Caplan et al. (2008) (21)	Cross-sectional	N/A	Major traumatic shoulder injury MDI[a]	Questionnaire	457 USA Collegiate (Divisions I & II)	18+	NR	Prevalence Type Onset Risk factors
Dixon et al. (1993)(4)	Retrospective cohort	10 years	Attention from athletic trainer/ physician	Medical records	74 Australia National team	13.5	Range 36–40	Prevalence Proportion Onset
Homer et al. (1992)(29)	Cross-sectional	N/A	ND	Interview	29 UK Regional squad or higher	13 (Singh et al., 2008; Caine et al., 2006; Fellander-Tsai & Wredmark, 1995; De Vita et al., 2015; Garrick & Requa, 1980; Bak et al., 1994; Silvij & Nocini, 1982; Wadley & Albright, 1993; Nattiv & Mandelbaum, 1993; Meeusen & Borms, 1992; Federation Internationale De Gymnastique Women's Technical Committee, 2017-; Arampatzis & Bruggemann, 1999; Caplan et al., 2008)	Mean 17.7 (±SD NR)	Prevalence Proportion
Kerr et al. (2015) (36)	Retrospective cohort	5 years	Attention from athletic trainer/ physician	NCAA[b] Injury Surveillance Program (ISP)	NR USA Collegiate (Divisions I-III)	18+	NR	Proportion Rate Severity Mechanism
Kolt et al. (1999)(30)	Prospective cohort	18 months	≥1 missed/modified training sessions and/or competitions	Gymnast injury report	Australia 24 National Team 40 State/ National Championship	12.5 ± 1.1 14.4 ± 1.6	Mean 33.3 ± 2.4 Mean 16.8 ± 4.5	Prevalence Proportion
Mackie et al. (1994)(31)	Retrospective cohort	40 months	Missed training/ competition on ≥1 apparatus	Questionnaire	Canada 23 National 77 Provincial	13.3 (Bak et al., 1994; De Vita et al., 2015; Fellander-Tsai & Wredmark, 1995; Garrick & Requa, 1980; Nattiv & Mandelbaum, 1993; Silvij & Nocini, 1982; Wadley & Albright, 1993) 11.4 (Bak et al., 1994; Caine et al., 2003, 2006; Daly et al., 2001; De Vita et al., 2015; Fellander-Tsai & Wredmark, 1995; Garrick & Requa, 1980; Meeusen & Borms, 1992; Nattiv & Mandelbaum, 1993; Silvij & Nocini, 1982; Singh et al., 2008; Wadley & Albright, 1993)	25.3 17.7	Prevalence Proportion Type Onset
Marshall et al. (2007) (37)	Retrospective cohort	16 years	Attention from athletic trainer/ physician AND Restricted participation	NCAA[a] injury surveillance data	NR USA Collegiate (Divisions I-III)	18+	NR	Proportion Rate Type
Saluan et al. (2015) (38)	Retrospective cohort	21 years	Treatment from single orthopaedic surgeon	Medical records	NR USA Precollegiate Elite High Intermediate Novice	NR	20+ 16–19 8–15 ≤9	Proportion Rate Type
Sands et al. (1993) (33)	Prospective cohort	5 years	Interfered with training	Gymnast injury report	37 USA Collegiate (Division I)	18+	20+	Prevalence Proportion Rate

(continued on next page)

Table 1 (*continued*)

Study	Study design	Duration of Data Collection	Injury Definition	Method of Injury Data Collection	Sample Size (n) Country Level	Age (yrs) Mean ± SD (Range)	Training Hours (/week)	Shoulder Injury Outcomes
Sands et al. (1987) (32)	Prospective cohort	16 months	Interfered with training	Gymnast injury report	23 USA Collegiate	18+	NR	Prevalence Proportion Rate
Snook et al. (1979)(34)	Prospective cohort	5 years	Attention from physician AND Produced disability	Team physician reports	70 USA Collegiate	NR	NR	Prevalence Proportion Type Onset
Wadley et al. (1993)(16)	Prospective cohort	4 years + 3 years follow up post retirement	Limited participation AND Tissue damage confirmed by athletic trainer	Athletic trainer reports Gymnast questionnaire	26 USA Collegiate (Division I)	18+	22	Prevalence Proportion Type Severity Mechanism
Westermann et al. (2015) (35)	Retrospective cohort	10 years	Reported in the Sports Injury Monitoring System at an NCAA institution	Athletic training room injury reports Physician records	55 USA Collegiate (Division I)	NR	NR	Prevalence Proportion Rate

NA = not applicable, ND = not defined, NR = not reported.
SD = standard deviation.
[a] MDI = multidirectional instability (no previous traumatic shoulder injury + instability symptoms in ≥2 activities).
[b] NCAA = National Collegiate Athletic Association.

during training (5%) compared to competition (2.4%) (Marshall et al., 2007).

6. Shoulder injury rate

Eight studies reported shoulder injury rate. Six studies (8, 32, 33, 35–37) defined injury rate 'per 1000 athlete exposures (AEs)'. One AE was equivalent to one gymnast participating in one practice/competition, however two studies (Sands et al., 1987b, 1993) excluded competitions within their 'athlete exposure' definition (Table 2). Shoulder injury rate per 1000 AEs ranged from 0.354 (8) to 5.7 (Sands et al., 1993). Caine et al. (1989) (28) and Saluan et al. (Saluan et al., 2015) reported shoulder injury rates of 0.025 and 0.1 per 1000 h training, respectively. Marshall et al. reported greater shoulder injury rate during practice (5.0/1000 AEs) compared to competition (0.36/1000 AEs) (Marshall et al., 2007). Muscle/tendon strain was the largest rate of shoulder injury type during both practice (2.5/1000 AEs, 95% CI 0.11–0.19) and competition (0.21/1000 AEs, 95% CI 0.06–0.37). (Marshall et al., 2007).

7. Shoulder injury type

Multidirectional shoulder instability (MDI) and musculotendinous injuries, including tendinitis, rotator cuff pathologies and strains/sprains, were most common (Caplan et al., 2008; Mackie & Taunton, 1994; Marshall et al., 2007; Saluan et al., 2015; Snook, 1979; Wadley & Albright, 1993). Snook et al. (Snook, 1979) and Wadley et al. (Wadley & Albright, 1993) found that rotator cuff pathologies, specifically supraspinatus tendinitis and subacromial bursitis made up 91% and 80% of all shoulder injuries, respectively (Snook, 1979; Wadley & Albright, 1993). Caplan et al. (Caplan et al., 2008) and Saluan et al. (Saluan et al., 2015) reported multidirectional shoulder instability as the most common shoulder injury type. Saluan et al. found that shoulder subluxation was also common, making up 20.5% of shoulder injuries (Saluan et al., 2015). Marshall et al. reported a similar percentage of subluxations (22.6%), most of which occurred during training (Marshall et al., 2007). 41.7% of competition shoulder injuries were due to subluxation, whereas all tendinitis injuries were acquired during training (Marshall et al., 2007). Only Caplan et al. reported any labral pathologies or shoulder dislocations (Caplan et al., 2008).

8. Shoulder injury onset

Four studies reported higher percentages of acute than chronic onset shoulder injury (Caine et al., 2003; Caplan et al., 2008; Kerr et al., 2015a; Mackie & Taunton, 1994). Mackie et al. (2003) (Mackie & Taunton, 1994), Caine et al. (2003) (8) and Kerr et al. (Kerr et al., 2015a) reported high percentages of acute injuries (100%, 87.5% and 70.4% respectively). Dixon et al. (Dixon & Fricker, 1993) reported acute and chronic shoulder injuries equally. Snook et al. (Snook, 1979) and Caine et al. (1989) (28) reported higher percentages of chronic than acute onset shoulder injury (90.9% and 100%, respectively).

9. Shoulder injury severity

Three definitions of shoulder injury severity were extracted – days lost in participation, requiring surgery and causing symptoms post-retirement (Caine et al., 2003; Kerr et al., 2015a; Wadley & Albright, 1993). Kerr et al. found that 59.3% of shoulder injuries were minor, resulting in less than 1 day lost participation, and 33.3% of injuries were moderate, resulting in 1–21 days lost participation (Kerr et al., 2015a). Nonetheless 7.4% (Kerr et al., 2015a) of shoulder injuries resulted in over three weeks restricted participation or early termination of a season, and 7.4% (Kerr et al., 2015a) of shoulder injuries required surgery. Caine et al. (Caine et al., 2003) and Wadley et al. (Wadley & Albright, 1993) did not report any shoulder injuries requiring surgery, however Wadley et al. (Wadley & Albright, 1993) found that 80% of shoulder injuries caused symptoms post-retirement.

10. Shoulder injury mechanism

Kerr et al. (Kerr et al., 2015a) and Wadley et al.[19] (Federation Internationale De Gymnastique Women's Technical Committee, 2017-) reported asymmetric bars as most common shoulder injury mechanism (55.6% and 80% respectively). Kerr et al. (Kerr et al., 2015a) reported 7.4% of shoulder injuries from the floor exercise, whilst Wadley et al. (Wadley & Albright, 1993) found that

Table 2
Shoulder injury prevalence, proportion, rate and type.

Study	Sample (n)	Injuries (n)	Shoulder Injuries (n)	Exposure (n)	Shoulder Injury Prevalence (%)	Shoulder Injury Proportion (%)	Shoulder Injury Rate (95% CI)	Shoulder Injury Type n (%)
Caine et al. (2003) (8)	79	192	8	76919.5 h 22584 AEs	10.1	4.2	0.104/1000 h 0.354/1000 AEs	NR
Caine et al. (1989) (28)	50	147	1	40127 h[a]	2.0	0.7	0.025/1000 h	NR
Caplan et al. (Caplan et al., 2008)	457	NR	154	NR	33.7	NR	NR	MDI: 52 (33.8) Rotator Cuff Injury: 56 (36.4) Subluxation: 20 (13.0) Dislocation: 11 (7.1) Labral Pathology: 12 (7.8) Other: 1 (0.6)
Dixon et al. (Dixon & Fricker, 1993)	74	325	4	NR	5.4	1.2	NR	NR
Homer et al. (Homer & Mackintosh, 1992)	29	49	0	NR	0.0	0	NR	NR
Kerr et al. (Kerr et al., 2015a)	NR	418	27	45351 AEs[b]	NR	6.5	0.60/1000 AEs (0.37–0.82)	NR
Kolt et al. (Kolt & Kirkby, 1999)	International: 24	151	7	NR	29.2	4.6	NR	NR
	Regional/ National: 40	198	8	NR	20.0	4.0	NR	NR
	Total: 64	349	15	NR	23.4	4.3	NR	NR
Mackie et al. (Mackie & Taunton, 1994)	100	279	2	NR	2.0	0.7	NR	Subluxation: 1 (Sleeper, Kenyon, & Casey, 2012) Fracture: 1 (Sleeper et al., 2012)
Marshall et al. (Marshall et al., 2007)	Practice: NR	2244	112	NR	NR	5.0	5.0/1000 AEs	Tendinitis: 33 (29.5) Strain/Sprain: 56 (50.0) Subluxation: 23 (20.5)
	Competition: NR	495	12	NR	NR	2.4	0.36/1000 AEs	Tendinitis: 0 (0.0) Strain/Sprain: 7 (58.3) Subluxation: 5 (41.7)
	Total: NR	2739	124	NR	NR	4.5	5.36/1000 AEs	Tendinitis: 33 (26.6) Strain/Sprain: 63 (50.8) Subluxation: 28 (22.6)
Saluan et al. (Saluan et al., 2015)	NR	3681	146	1,452,574 h[a]	NR	4.0	0.1/1000 h	MDI: 55 (37.7) Rotator Cuff Injury: 31 (21.2) Strain/Sprain: 15 (10.3) Subluxation: 30 (20.5) Contusion: 3 (2.1) Other: 3 (2.1) Non-Specific Pain: 9 (6.2)
Sands et al. (1993) (33)	37	509	32	5602 AEs[a]	86.5	6.3	5.7/1000 AEs	NR
Sands et al. (1987) (32)	1984–85: 10	54	2	624 AEs[a]	20.0	3.7	3.2/1000 AEs	NR
	1985–86: 13	70	2	1012 AEs[a]	15.4	2.9	2.0/1000 AEs	NR
	Total: 23	124	4	1636 AEs[a]	17.4	3.2	2.4/1000 AEs	NR
Snook et al. (Snook, 1979)	70	66	11	NR	15.7	32.4	NR	Rotator Cuff Injury: 10 (90.9) Fracture: 1 (9.1)
Wadley et al. (Wadley & Albright, 1993)	26	106	5	NR	19.2	4.7	NR	Rotator Cuff: 4 (80) Strain/Sprain: 1 (Arampatzis & Bruggemann, 1999)
Westermann et al. (Westermann et al., 2015)	55	201	15	21453 AEs	27.3	7.5	0.7/1000 AEs (0.35–1.05)	NR

NR = not reported.
1 Athlete Exposure (AE) = 1 gymnast participating in 1 practice/competition.
MDI = multidirectional shoulder instability.
[a] Athlete exposure definition only included practices (competitions excluded).
[b] Athlete exposure definition only included NCAA competitions and practices.

20% of shoulder injuries were from conditioning. No shoulder injuries were reported from beam or vault (Kerr et al., 2015a; Wadley & Albright, 1993).

11. Shoulder injury risk factors

Caplan et al. analyzed differences in potential risk factors between a group of gymnasts with and without traumatic shoulder injury (Caplan et al., 2008). No significant differences in previous gymnastics participation, number of hours trained, other exercise apart from gymnastics, separate shoulder strength training, participation in all four apparatus or having only 1 sign of hyperlaxity were found (Caplan et al., 2008). The group with traumatic shoulder injury spent significantly more time shoulder stretching ($p < 0.001$), had significantly more frequent sensations of shoulder instability ($p < 0.001$) and significantly more gymnasts with at least 2 hyperlaxity signs or symptoms ($p = 0.003$). (Caplan et al., 2008).

12. Discussion

This systematic review aimed to assess shoulder injury prevalence, proportion, rate, type, onset, severity, mechanism and risk factors amongst female artistic gymnasts. Shoulder injury prevalence varied from 0% (Homer & Mackintosh, 1992) to 86.5% (Sands et al., 1993) with most studies reporting shoulder injury proportion between 4.5% (Caine et al., 2003) and 7.5% (Westermann et al., 2015). Shoulder injury rate ranged from 0.354 (8) to 5.7/1000 AEs (33). MDI and musculotendinous injuries were the most commonly reported shoulder injury types (Caplan et al., 2008; Mackie & Taunton, 1994; Marshall et al., 2007; Saluan et al., 2015; Snook, 1979; Wadley & Albright, 1993). Acute injury was more frequently reported than chronic injury onset (Caine et al., 2003; Caplan et al., 2008; Kerr et al., 2015a; Mackie & Taunton, 1994). The majority (59.3%) of shoulder injuries were of minor severity, 7.4% were severe, requiring surgery (Kerr et al., 2015a), and 80% caused problems post retirement (Wadley & Albright, 1993). Asymmetric bars were the most frequent shoulder injury mechanism (Kerr et al., 2015a; Wadley & Albright, 1993), and one study reported increased shoulder stretching, shoulder instability sensations and hyperlaxity signs or symptoms as potential shoulder injury risk factors (Caplan et al., 2008).

Shoulder injury prevalence was inconsistent between studies, possibly due to different study designs, data collection methods, prevalence definitions and sample heterogeneity. Sands et al. (1993) carried out a 5 year prospective study on a cohort of national level USA gymnasts and reported an extremely high shoulder injury prevalence of 86.5% (Sands et al., 1993). These gymnasts had high injury exposure, training high-level, risky skills on a repetitive basis for approximately 20 h per week. Furthermore, injuries were recorded before every training session and an all-encompassing injury definition of “causing interference with training” was used, which may explain the high prevalence. Homer et al. carried out a cross-sectional study and reported 0% shoulder injury prevalence in regional competitive gymnasts and higher, with a lower injury exposure time (mean 17.9 h/week training) compared to Sands et al. (1993) (Homer & Mackintosh, 1992). Homer et al. also focused on back injuries, gave no set injury definition and collected injury data via a one-off interview, hence some shoulder injuries may have been missed. Shoulder injury prevalence was hard to compare between studies due to lack of standardization in epidemiological definitions (Knowles, Marshall, & Guskiewicz, 2006). Ten studies (4, 8, 16, 28, 30–35) collected data over time, hence shoulder injury frequency could be more accurately reported as incidence proportion (Knowles et al., 2006). Length of data collection ranged from 1 year (28) to 10 years (4, 35). Two studies (21, 29) were cross-sectional, thus shoulder injury frequency should be reported as prevalence. Standardization of sports injury statistics and separate comparison depending on definition could be valuable in promoting injury prevention and safety (Knowles et al., 2006).

Shoulder injury prevalence in female gymnastics is higher than in many other sports. Five studies (16, 30, 32, 34, 35) reported shoulder injury prevalence from 15.7% (Snook, 1979) to 27.3% (Westermann et al., 2015), which is similar to sports acrobatic gymnasts (15.9%) —a discipline in which gymnasts compete floor routines in groups of 2–4 and use each other as apparatus to perform both dynamic and static skills, such as somersaults and hand balancing (Purnell, Shirley, Nicholson, & Adams, 2010). However, this data is higher when compared to other upper body weight bearing athletes, such as cross-fitters (8.3%) (Weisenthal, Beck, Maloney, DeHaven, & Giordano, 2014) and female divers (5.4%) (Kerr et al., 2015b), but is low compared to female circus artists (55%) (Shrier et al., 2009). Compared to other upper limb dependent sports, shoulder injury prevalence was greater in female artistic gymnasts compared to tennis players (9.3%) (Dakic, Smith, Gosling, & Perraton, 2018), however was lower than rock climbers (64%) (Nelson, Rayan, Judd, Ding, & Stoner, 2017). Eight studies reported 4.2% (Caine et al., 2003) to 7.5% (Westermann et al., 2015) of all injuries to be shoulder injuries (Caine et al., 2003; Kerr et al., 2015a; Kolt & Kirkby, 1999; Marshall et al., 2007; Saluan et al., 2015; Sands et al., 1993; Wadley & Albright, 1993; Westermann et al., 2015). These results highlight the extent of shoulder injuries amongst female gymnasts, emphasising the need to develop injury prevention strategies.

Injury rate data is difficult to compare because of differences in injury rate definition. Six studies (8, 32, 33, 35–37) reported shoulder injury rate per 1000 AEs and two studies reported injury rates per 1000 h training. However, four studies (28, 32, 33, 38) excluded competitions from their exposure definition, thus shoulder injury rates may be inaccurate. Westermann et al. (Westermann et al., 2015) and Kerr et al. (Kerr et al., 2015a) reported similar shoulder injury rates of 0.7 and 0.6/1000 AEs (95% CI 0.37–0.82) respectively. Despite differences in study design, these studies included both training and competition within their exposure definitions; used similar injury definitions and used physician diagnosis/injury reports (Kerr et al., 2015a; Westermann et al., 2015). Both studies found higher shoulder injury rates than those reported elsewhere in female volleyball (0.058/1000AEs), basketball (0.24/1000AEs) and softball players (0.16/1000AEs) (Bonza, Fields, Yard, & Dawn Comstock, 2009). However, Westermann *et al.* (Westermann et al., 2015) and Kerr *et al.* (Kerr et al., 2015a) reported similar shoulder injury rates to those reported elsewhere in female swimmers (0.6/1000AEs) (Kerr et al., 2015b). All of these studies are comparable as both training and competitions were included in athlete exposure definitions (Bonza et al., 2009; Kerr et al., 2015a, 2015b; Westermann et al., 2015). Many swimmer-specific screening tools, including hypermobility and range of motion tests, such as abduction with internal rotation have been proposed within the literature (Bak & Fauno, 1997; Bak & Magnusson, 1997; Beach, Whitney, & Dickoff-Hoffman, 1992). No such shoulder injury prevention strategies have been tested specifically for gymnasts. General screening tools, such as the Gymnast's Functional Measurement Tool (GFMT) (Sleeper et al., 2012), were validated and reliable in assessing gymnasts' physical fitness levels. However, gymnastics-specific tests to screen for shoulder joint abnormalities need to be developed and validated.

Neer and Foster define MDI as 2 or more shoulder laxity symptoms (at least one being inferior) (Neer & Foster, 1980). Caplan *et al.* used a similar MDI definition to this and reported MDI frequency of 33.8% (Caplan et al., 2008). However, MDI frequency reported by Saluan *et al.* was 37 .7% and was based on physician diagnosis, so MDI definition was not included (Saluan et al., 2015). Similar to other overhead sports, including swimming, tennis and throwing sports, gymnasts repetitively expose their shoulder joints to extreme ranges of motion, forces and accelerations from which the joint capsule, muscles and ligaments may be subject to extensive microtrauma, thus resulting in acquired laxity and high reporting of MDI (Atwater, 1979; Bassett, Browne, Morrey, & An, 1990; Flatow & Warner, 1998). Equally, gymnasts are generally considered for their flexibility, hence athletes with naturally lax connective tissue may excel within the sport; therefore high prevalence of shoulder MDI may be genetically related (Arkaev & Sutsilin, 2004). MDI also predisposes an athlete to other shoulder injuries, such as subluxation and rotator cuff pathologies, due to an overly lax or dynamically unstable shoulder joint, muscle weakness, imbalances and overworked rotator cuff muscles (Jobe & Pink, 1993; Snook, 1979; Wadley & Albright, 1993). Many injury types, such as supraspinatus bursitis and impingement, were included within the rotator cuff pathology definition (Supplement 2), however high frequency of MDI may explain the large percentage of rotator cuff pathologies, reported by Snook et al. (90.9%) (Snook, 1979) and Wadley et al.(80%) (Wadley & Albright, 1993). Nonetheless, both studies scored poorly (21%) on quality assessment due to lack of sample size justification and small sample sizes of 70 (Snook, 1979) and 26 gymnasts (Wadley & Albright, 1993). Both studies failed to implement clearly defined, valid, reliable exposure measures and potential confounding variables were not considered or adjusted for. Conversely, Saluan et al. reported a rotator cuff pathology frequency of 21.2% (Saluan et al., 2015). This study was of better quality, scoring 50% on quality assessment, due to clear, pre-defined subject eligibility criteria and less potential selection and loss of follow up bias (Saluan et al., 2015). High shoulder MDI frequencies, which increases risk of other shoulder injuries, highlights the need for clinicians to address this issue when screening for and treating shoulder injuries within female artistic gymnasts. To guide screening, prevention and rehabilitation, clinicians should be aware of training patterns expected of these athletes and the possible movement patterns and muscle imbalances that may result from gymnast-specific skills. For example in a cohort of experienced gymnasts, Kochanowicz et al. reported a low glenohumeral flexor to extensor isometric peak torque (PKQT) ratio of 0.72 (Kochanowicz, Niespodzinski, Mieszkowski, Kochanowicz, & Sawczyn, 2017). Gymnasts also demonstrated 41% lower EMG activation during shoulder flexion and 30% ($p < 0.01$) higher PKQT in the glenohumeral extensors compared to non-gymnasts (Kochanowicz et al., 2017). The handstand is a fundamental skill within artistic gymnastics, with many skills often beginning, finishing or passing through the handstand position. Therefore, one could hypothesize that glenohumeral muscle imbalances may have resulted from repetitive training of handstands in which the shoulder is extended to 180°, which could predispose to shoulder injury.

DiFiori *et al.* noted that chronic injuries can be underreported when injury definition depends on time lost from participation (Difiori et al., 2014). To prevent physical deconditioning, chronically injured gymnasts may modify the training, therefore those with chronic shoulder injury can continue training other skills with less demand on the shoulder joint (Difiori et al., 2014; Kolt & Kirkby, 1999). Consequently, studies by Caine et al. (2003) (8) and Mackie et al. (Mackie & Taunton, 1994) that incorporated missed training or competition into their injury definitions may have underestimated total number of chronic shoulder injuries. Furthermore, the six studies (8, 28, 30–33) that used 'missed training or competition' definition, may have underestimated the number of shoulder injuries in generalist gymnasts participating in more than one piece of apparatus. Coaches and clinicians should be aware that gymnasts are subject to both chronic and acute shoulder injury and should not discount injury based purely on gymnast attendance at training.

Only 7.4% (Kerr et al., 2015a) of shoulder injuries were severe and required surgery but 80% (Wadley & Albright, 1993) caused symptoms post-retirement from gymnastics. Nonetheless, Caplan et al. (Caplan et al., 2008) demonstrated a 41% response rate to a shoulder injury questionnaire. This may highlight a lack of self-reporting of injury within more competitive gymnasts, possibly due to fear of having to stop or reduce training and subsequent risk of replacement on a team. Kerr et al. (Kerr et al., 2015a) collected injury data via an injury surveillance programme, and Wadley et al. (Wadley & Albright, 1993) used a questionnaire; both studies were therefore subject to lack of self-reporting of injury, which may have impacted upon data accuracy. Better self-reporting of injury could be encouraged by informing gymnasts and coaches of athletes' right to confidentiality.

Arampatzis et al. (1999) found that giant swings, involving 360° rotation on an axis around the bar in a straight position, exhibited up to 12.0 Watt/kg of power and 3.5 Nm/kg of flexion torque at the shoulder joint (Arampatzis & Bruggemann, 1999). Similarly, up to 9.66 Watt/kg of power and 3.5 Nm/kg of flexion torque were generated at the shoulder joint prior to the Tkatchev release and catch skill (Arampatzis & Bruggemann, 2001). Repetitive training of these skills demands large power outputs and torques at the shoulder joint, and may explain why asymmetric bars were the most frequent injury mechanism (Kerr et al., 2015a; Wadley & Albright, 1993).

Limited evidence regarding shoulder injury risk factors is available. Caplan et al. reported that shoulder stretching, sensations of shoulder instability and hyperlaxity signs/symptoms were significantly greater in a group of gymnasts with compared to a group without shoulder injury (Caplan et al., 2008). Hyperlaxity symptoms and signs, shoulder stretching behaviour and instability, assessed via humeral head translation tests, such as the multidirectional instability sulcus test (Gerber & Ganz, 1984; Manske & Ellenbecker, 2013; McFarland, Torpey, & Curl, 1996), could be useful in screening for shoulder injury risk. Nevertheless, due to cross-sectional study design (Caplan et al., 2008), it is unknown whether shoulder stretching, hyperlaxity or instability were contributing or consequential factors of shoulder injury. Further prospective longitudinal studies are required to investigate causal relationships between risk factors and shoulder injury.

Our results were limited by a number of factors. Eight studies were retrospective or cross-sectional in design, of which seven relied on gymnast injury reports or questionnaires for injury data collection. Potential recall bias may impact the accuracy of shoulder injury data from these studies, therefore future research should employ prospective study design to improve data accuracy. Studies did not take into account potential confounding variables, including activities outside of gymnastics or previous shoulder injuries. To improve internal validity, future studies should account for potential confounding. This review maximised external validity by including gymnasts of all ages and levels, however it's currently not possible to report shoulder injury data separately for each gymnast age or level. Differences in age, training levels, skills performed, environment, safety and healthcare facilities could influence shoulder injury rates, types, onset, severity and mechanisms. Furthermore, the high level of methodological heterogeneity did not allow for meta-analysis to be implemented in the current study. Future research should be exposure specific and report injury data separately according to gymnast age, level and environment, thus helping clinicians evaluate what stage in a gymnast's training to implement shoulder injury risk assessment.

13. Conclusion

Shoulder injuries are a frequent problem among female artistic gymnasts. MDI and musculotendinous injury were the most common shoulder injury types, acute shoulder injury onset was more common than chronic, and the majority of shoulder injuries were minor. Asymmetric bars were the most common mechanism and limited evidence suggests hyperlaxity, excess stretching and instability as potential risk factors. Although most studies were of poor/fair quality, with potential biases and poor internal validity, results suggest the need for development of shoulder injury prevention strategies which include injury risk assessment and screening for multidirectional instability, apparatus specialisation, stretching behaviour and hyperlaxity. Further prospective studies, reporting age and level-specific outcomes, are warranted to establish accurate data regarding magnitude, mechanisms and risk factors of shoulder injury.

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References

Aasa, U., Svartholm, I., Andersson, F., & Berglund, L. (2017). Injuries among weightlifters and powerlifters: A systematic review. *British Journal of Sports Medicine, 51*(4), 211–219.

Arampatzis, A., & Bruggemann, G. P. (1999). Mechanical energetic processes during the giant swing exercise before dismounts and flight elements on the high bar and the uneven parallel bars. *Journal of Biomechanics, 32*(8), 811–820.

Arampatzis, A., & Bruggemann, G. P. (2001). Mechanical energetic processes during the giant swing before the Tkatchev exercise. *Journal of Biomechanics, 34*(4), 505–512.

Arkaev, L., & Sutsilin, N. (2004). *The theory and methodology of training top-class gymnasts. Gymnastics: How to create champions Moscow Fizkultura I sport*.

Atwater, A. E. (1979). Biomechanics of overarm throwing movements and of throwing injuries. *Exercise and Sport Sciences Reviews, 7*, 43–85.

Bak, K., & Fauno, P. (1997). Clinical findings in competitive swimmers with shoulder pain. *The American Journal of Sports Medicine, 25*(2), 254–260.

Bak, K., Kalms, S., & Olesen, e (1994). Epidemiology of injuries in gymnastics. *Scandinavian Journal of Medicine & Science in Sports, 4*(2), 148–154.

Bak, K., & Magnusson, S. P. (1997). Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *The American Journal of Sports Medicine, 25*(4), 454–459.

Bassett, R. W., Browne, A. O., Morrey, B. F., & An, K. N. (1990). Glenohumeral muscle force and moment mechanics in a position of shoulder instability. *Journal of Biomechanics, 23*(5), 405–415.

Beach, M. L., Whitney, S. L., & Dickoff-Hoffman, S. (1992). Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *Journal of Orthopaedic & Sports Physical Therapy, 16*(6), 262–268.

Bonza, J. E., Fields, S. K., Yard, E. E., & Dawn Comstock, R. (2009). Shoulder injuries among United States high school athletes during the 2005-2006 and 2006-2007 school years. *Journal of Athletic Training, 44*(1), 76–83.

Bradshaw, E. J., & Hume, P. A. (2012). Biomechanical approaches to identify and quantify injury mechanisms and risk factors in women's artistic gymnastics. *Sports Biomechanics, 11*(3), 324–341.

Caine, D., Caine, C., & Maffulli, N. (2006). Incidence and distribution of pediatric sport-related injuries. *Clinical Journal of Sport Medicine : Official Journal of the Canadian Academy of Sport Medicine, 16*(6), 500–513.

Caine, D., Cochrane, B., Caine, C., & Zemper, E. (1989). An epidemiologic investigation of injuries affecting young competitive female gymnasts. *The American Journal of Sports Medicine, 17*(6), 811–820.

Caine, D., Knutzen, K., Howe, W., Keeler, L., Shepprd, L., Henrichs, D., et al. (2003). A three-year epidemiological study of injuries affecting young female gymnasts. *Physical Therapy in Sport, 4*(1), 10–23.

Caplan, J., Julien, T. P., Michelson, J., & Neviaser, R. J. (2008). Multidirectional instability of the shoulder in elite female gymnasts. *American Journal of Orthopedics, 36*(12), 660–665.

Dakic, J. G., Smith, B., Gosling, C. M., & Perraton, L. G. (2018). Musculoskeletal injury profiles in professional Women's Tennis Association players. *British Journal of Sports Medicine, 52*(11), 723–729.

Daly, R. M., Bass, S. L., & Finch, C. F. (2001). Balancing the risk of injury to gymnasts: How effective are the counter measures? *British Journal of Sports Medicine, 35*(1), 8–18.

De Vita, M., Panetta, V., Prattico, F., & Foti, C. (2015). Epidemiological study on artistic gymnastics injuries. *Medicina Dello Sport, 68*(3), 487–495.

Difiori, J. P., Benjamin, H. J., Brenner, J. S., Gregory, A., Jayanthi, N., Landry, G. L., et al. (2014). Overuse injuries and burnout in youth sports: A position statement from the American medical society for sports medicine. *British Journal of Sports Medicine, 48*(4), 287–288.

Dixon, M., & Fricker, P. (1993). Injuries to elite gymnasts over 10 yr. *Medicine & Science in Sports & Exercise, 25*(12), 1322–1329.

Federation Internationale De Gymnastique Women's Technical Committee. (2017-2020). *Women's artistic gymnastics Code of Points*, 2017 [Available from: https://www.gymogturn.no/wp-content/uploads/2015/10/CoP-2017-2020-1.pdf.

Fellander-Tsai, L., & Wredmark, T. (1995). *Injury incidence and cause in elite gymnasts, 114*(6), 344–346.

Flatow, E. L., & Warner, J. I. (1998). Instability of the shoulder: Complex problems and failed repairs: Part I. Relevant biomechanics, multidirectional instability, and severe glenoid loss. *Instructional Course Lectures, 47*, 97–112.

French, D. N., Gomez, A. L., Volek, J. S., Rubin, M. R., Ratamess, N. A., Sharman, M. J., et al. (2004). Longitudinal tracking of muscular power changes of NCAA Division I collegiate women gymnasts. *The Journal of Strength & Conditioning Research, 18*(1), 101–107.

Garrick, J. G., & Requa, R. K. (1980). Epidemiology of women's gymnastics injuries. *The American Journal of Sports Medicine, 8*(4), 261–264.

Gerber, C., & Ganz, R. (1984). Clinical assessment of instability of the shoulder. With special reference to anterior and posterior drawer tests. *Journal of Bone & Joint Surgery, British Volume, 66*(4), 551–556.

Homer, S., & Mackintosh, S. (1992). Injuries in young female elite gymnasts. *Physiotherapy, 78*(11), 804–808.

Jobe, F. W., & Pink, M. (1993). Classification and treatment of shoulder dysfunction in the overhead athlete. *Journal of Orthopaedic & Sports Physical Therapy, 18*(2), 427–432.

Kerr, Z. Y., Baugh, C. M., Hibberd, E. E., Snook, E. M., Hayden, R., & Dompier, T. P. (2015). Epidemiology of National Collegiate Athletic Association men's and women's swimming and diving injuries from 2009/2010 to 2013/2014. *British Journal of Sports Medicine, 49*(7), 465–471.

Kerr, Z. Y., Hayden, R., Barr, M., Klossner, D. A., & Dompier, T. P. (2015). Epidemiology of national collegiate athletic association women's gymnastics injuries, 2009-2010 through 2013-2014. *Journal of Athletic Training, 50*(8), 870–878.

Knowles, S. B., Marshall, S. W., & Guskiewicz, K. M. (2006). Issues in estimating risks and rates in sports injury research. *Journal of Athletic Training, 41*(2), 207–215.

Kochanowicz, A., Niespodzinski, B., Mieszkowski, J., Kochanowicz, K., & Sawczyn, S. (2018 Jul-Aug). The effect of gymnastic training on muscle strength and co-activation during isometric elbow and glenohumeral flexion/extension. *The Journal of Sports Medicine and Physical Fitness, 58*(7-8), 966–973.

Koh, T. J., Grabiner, M. D., & Weiker, G. G. (1992). Technique and ground reaction forces in the back handspring. *The American Journal of Sports Medicine, 20*(1), 61–66.

Kolt, G. S., & Kirkby, R. J. (1995). Epidemiology of injury in australian female gymnasts. *Sports Medicine, Training and Rehabilitation, 6*(3), 223–231.

Kolt, G. S., & Kirkby, R. J. (1999). Epidemiology of injury in elite and subelite female gymnasts: A comparison of retrospective and prospective findings. *British Journal of Sports Medicine, 33*(5), 312–318.

Mackie, S. J., & Taunton, J. E. (1994). Injuries in female gymnasts - trends suggest prevention tactics. *The Physician and Sportsmedicine, 22*(8), 40–45.

Manske, R., & Ellenbecker, T. (2013). Current concepts in shoulder examination of the overhead athlete. *International journal of sports physical therapy, 8*(5), 554–578.

Marshall, S. W., Covassin, T., Dick, R., & Nassar, L. G. (2007). Descriptive epidemiology of collegiate women's gymnastics injuries: National collegiate athletic association injury surveillance system, 1988-1989 through 2003-2004. *Journal of Athletic Training, 42*(2), 234–240.

McFarland, E. G., Torpey, B. M., & Curl, L. A. (1996). Evaluation of shoulder laxity. *Sports Medicine (Auckland, NZ), 22*(4), 264–272.

van Mechelen, W., Hlobil, H., & Kemper, H. C. (1992). Incidence, severity, aetiology and prevention of sports injuries. *A review of concepts. Sports medicine (Auckland, NZ), 14*(2), 82–99.

Meeusen, R., & Borms, J. (1992). *Gymnastic injuries. Sports medicine (Auckland, NZ), 13*(5), 337–356.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Journal of Clinical Epidemiology, 62*(10), 1006–1012.

National Institute of Health: US Department of Health and Human Services. (2017). *Quality assessment tool for observational cohort and cross-sectional studies*.

Nattiv, A., & Mandelbaum, B. R. (1993). Injuries and special concerns in female gymnasts. *The Physician and Sportsmedicine, 21*(7), 66–83.

Neer, C. S., 2nd, & Foster, C. R. (1980). Inferior capsular shift for involuntary inferior and multidirectional instability of the shoulder. A preliminary report. *Journal of Bone and Joint Surgery American Volume, 62*(6), 897–908.

Nelson, C. E., Rayan, G. M., Judd, D. I., Ding, K., & Stoner, J. A. (2017). Survey of hand and upper extremity injuries among rock climbers. *Hand, 12*(4), 389–394.

Purnell, M., Shirley, D., Nicholson, L., & Adams, R. (2010). Acrobatic gymnastics injury: Occurrence, site and training risk factors. *Physical Therapy in Sport, 11*(2), 40–46.

Saluan, P., Styron, J., Ackley, J. F., Prinzbach, A., & Billow, D. (2015). Injury types and incidence rates in precollegiate female gymnasts a 21-year experience at a single training facility. *Orthopaedic Journal of Sports Medicine, 3*(4), 6.

Sands, B., Eisenman, P., & Johnson, S. (1987). Getting ready for 1988: Research and athlete preparations project—junior elite gymnasts. *Technique, 87*, 12–18.

Sands, W. A., Newman, A. P., Harner, C., Paulos, L. E., & Shultz, B. B. (1987). Two year study of injury in collegiate women's gymnastics. *Technique, 7*(3), 4–10.

Sands, W. A., Shultz, B. B., & Newman, A. P. (1993). Women's gymnastics injuries. A 5-year study. *The American Journal of Sports Medicine, 21*(2), 271–276.

Shrier, I., Meeuwisse, W. H., Matheson, G. O., Wingfield, K., Steele, R. J., Prince, F., et al. (2009). Injury patterns and injury rates in the circus arts: An analysis of 5 years of data from cirque du Soleil. *The American Journal of Sports Medicine, 37*(6), 1143–1149.

Shuang, F., Hou, S.-X., Zhu, J.-L., Ren, D.-F., Cao, Z., & Tang, J.-G. (2014). Percutaneous resolution of lumbar facet joint cysts as an alternative treatment to surgery: A meta-analysis. *PLoS One, 9*(11), e111695.

Silvij, S., & Nocini, S. (1982). Clinical and radiological aspects of gymnast's shoulder. *The Journal of Sports Medicine and Physical Fitness, 22*(1), 49–53.

Singh, S., Smith, G. A., Fields, S. K., & McKenzie, L. B. (2008). Gymnastics-related injuries to children treated in emergency departments in the United States, 1990-2005. *Pediatrics, 121*(4), E954–E960.

Sleeper, M. D., Kenyon, L. K., & Casey, E. (2012). Measuring fitness in female gymnasts: The gymnastics functional measurement tool. *International journal of sports physical therapy, 7*(2), 124–138.

Snook, G. A. (1979). Injuries in women's gymnastics. A 5-year study. *The American Journal of Sports Medicine, 7*(4), 242–244.

Wadley, G. H., & Albright, J. P. (1993). Women's intercollegiate gymnastics. Injury patterns and "permanent" medical disability. *The American Journal of Sports Medicine, 21*(2), 314–320.

Weisenthal, B. M., Beck, C. A., Maloney, M. D., DeHaven, K. E., & Giordano, B. D. (2014). Injury rate and patterns among CrossFit athletes. *Orthop J Sports Med, 2*(4), 2325967114531177.

Westermann, R. W., Giblin, M., Vaske, A., Grosso, K., & Wolf, B. R. (2015). Evaluation of men's and women's gymnastics injuries: A 10-year observational study. *Sport Health, 7*(2), 161–165.