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Original Research

Sink or Swim? Clinical Objective Tests and Measures Associated with Shoulder Pain in Swimmers of Varied Age Levels of Competition: A Systematic Review

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BACKGROUND

Swimming is enjoyed by athletes of all ages, and shoulder pain is a common problem. Clinicians identify impairments which impact shoulder pain and these impairments may differ depending on the swimmer's age competition level.

PURPOSE

The purpose of this study was to investigate objective measures utilized to assess swimmers and assess the relationship of test values to shoulder pain in distinct age groups/competition levels. A secondary aim was to report normative/expected values for these tests.

DESIGN

Systematic review

METHODS

PRISMA methodology was employed to assess studies evaluating clinical tests and measures associated with shoulder pain for swimmers in varied age competition levels. The Methodological Index for Non-Randomized Studies instrument was used to evaluate the quality of the included studies, and a qualitative synthesis of findings was conducted to determine the strength of the evidence in four age competition levels for nine objective measures. Distinct cut points for proposed measures were identified.

RESULTS

Twenty-seven studies were included in the analysis and the majority were of moderate quality in adolescent/adult swimmers. Youth swimmers had limited evidence for the development of shoulder pain associated with scapular position/dyskinesia, weakness of periscapular muscles, low endurance of core muscles, and moderate evidence for shoulder pain associated with laxity and altered range of motion (ROM). Adolescent/adult swimmers demonstrated limited evidence for a positive association between developing shoulder pain if there is a low eccentric ER:concentric IR ratio, and moderate evidence for pectoralis minor tightness and glenohumeral laxity. There were limited

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studies regarding masters swimmers to derive conclusive evidence. Cut points were identified from the included studies but these have not been validated in other studies.

CONCLUSION

Swimmers of various ages may have different objective clinical tests and measures associated with the risk for developing shoulder pain. More studies are needed to fully understand risk factors for shoulder pain in the masters swim competition level, and to validate recommended cut points for various tests and measures.

Key level of evidence

3, Systematic review of mostly Level 3 studies

INTRODUCTION

Shoulder pain in swimmers has consistently been noted to interfere with swimming training and competition. In 1993, McMaster and Troup published the first large scale United States survey documenting the prevalence of shoulder pain interfering with practice or competition to be 10-26% in a group of 1262 swimmers.[1] They also identified aspects of training that swimmers reported aggravated their pain, such as use of paddles, kickboards and stretching. Since that time, additional factors associated with shoulder pain and injury have been studied and the prevalence of shoulder pain in swimmers of varied ages and competitive levels has been well documented.[2,3] Given this high pain prevalence, it may not be surprising that a study of baseline shoulder function using the Kerlan-Jobe orthopedic clinic score reported that scores of NCAA swimmers are lower than those of athletes in other overhead sports, and are similar to injured athletes in other sports.[4] In addition, except for neurolysis for suprascapular neuropathy, arthroscopic surgery has had limited success in returning swimmers to prior competitive training volume and level.[5,6] Therefore, the mainstay of treatment for competitive swimmers is conservative management and Khodaee et al. report that most patients with shoulder pain shoulder cases can be treated with rehabilitation, a proper strengthening routine, and correction of stroke flaws.[7]

In order to provide appropriate rehabilitation, knowledge of the factors associated with shoulder pain and injury is important for health care providers treating competitive swimmers. Both intrinsic and extrinsic variables have been cited in etiology of shoulder pathology. Extrinsic variables include number of years of swum[4,8]prior history of shoulder pain or injury,[3,9,10] and training variables,[8,10] such as acute:chronic workload ratio, which is calculated using the current training volume in relation to the rolling average of the volume of training over the prior four weeks.[11-13] A recent systematic review explored the impact of swim volume on various age competition levels and determined that adolescent swimmers experienced the highest level of shoulder pain although adult swimmers had a comparatively higher swim volume.[14] Intrinsic factors are specific to the individual swimmer, such as stroke technique, muscle force capacity and endurance, posture and mobility, and, if appropriately identified, may be amenable to change.[15] Although stroke characteristics, such as hand entry crossover during freestyle swimming, have been associated with shoulder pain, the videotaping and complex stroke analysis techniques used by researchers may preclude their use in clinical practice.[11,12,16] The identification of clinical measures that assess possible contributors to shoulder pain in competitive swimmers is within the scope and ability of most clinicians. While authors have examined which clinical examination findings are related to pain and injury in the swimmers' shoulder, no systematic review has examined these tools in various age-group and competition levels. Changes in mobility and strength in the musculoskeletal system are inevitable across the lifespan; thus, it is reasonable to expect that risk factors for developing shoulder pain may change over time. Therefore, the purpose of this study was to investigate objective measures utilized to assess swimmers and assess the relationship of test values to shoulder pain in distinct age groups/competition levels. A secondary aim was to identify normative data and/or cut-off values which are associated with risk for swimmers to develop shoulder pain.

METHODS

STUDY DESIGN

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines, and was prospectively registered in Prospero (CRD42021224198)

SEARCH STRATEGY AND ELIGIBILITY

A literature search was conducted by a professional medical librarian (SH) using Medline (via OVID), Embase, CINAHL Complete, SPORTDiscus, and SCOPUS from inception through November 5, 2020. This literature search was updated on May 2, 2022 in order to capture any additional relevant research published since the onset of this project. Search keywords included swimming, shoulder, objective tests and measures. The full search strategy and outcome are summarized in Appendix A. Specific criteria for consideration in the literature search are outlined the Population Intervention Comparison Outcome Time (PICOT) chart in Table 1. Inclusion criteria were articles about swimmers which delineated the age group/competition level, objective tests or measures, and compared measures between groups with and without pain. Exclusion criteria were articles about non-swimming athletes, athletes with history of prior shoulder surgery, studies not reporting on a group

Table 1. Population Intervention Comparison Outcome Time (PICOT) chart

Key Concepts, Synonyms	Inclusion Criteria	Exclusion Criteria
Patient population / problem	**Swimmers; Age group, Elite (NCAA, National, Olympic), Masters**	**Non-swimming UE athletes, Water-polo, Triathletes, Synchronized Swimmers**
Interventions / prognostic factors	**Physical examination tests:** Rotator cuff and/or scapular strength in any test position (Isokinetic, HHD), Posterior Shoulder Endurance Test (PSET), Athletic Shoulder (ASH) test, ER/IR/ elevation PROM, pectoralis minor/latissimus dorsi length, core stability (e.g. side bridge), thoracic rotation ROM, YBT-UQ, Hypermobility (e.g. Beighton score), etc.	Subjective measures, Patient questionnaires only (no objective measures); Surgical interventions/ procedures
Comparison	**N/A**	**N/A**
Outcome	Values/results from tests listed above. Pain, Injury	
Time	Pre-season, in-season, post-season screens; other symptomatic/non-symptomatic assessments	
Study Types • Observational? • Experimental? • Qualitative? • Case reports? • Editorials, letters, comments?	Prospective and Retrospective Observational Studies Cohort Cross-sectional Case reports RCT Systematic Reviews Meta-Analyses	Qualitative studies Studies reported in a foreign language

UE= Upper Extremity, NCAA= National Collegiate Athletic Association, HHD= Hand Held Dynamometry, ER= External Rotation, IR= Internal Rotation, PROM= Passive Range of Motion, ROM= Range of Motion, YBT-UQ= Y-Balance Test of the Upper Quarter

that had pain, interventional studies, and non-English publications.

STUDY SELECTION

Two reviewers (JK and TO) used Covidence systematic review software (Veritas Health Innovation Ltd, Melbourne, Australia) to independently screen titles and abstracts that were identified in the literature search, and the same reviewers screened articles selected for full-text review. Disagreement at the title and abstract review stage as well as the full-text review stage was reached by a third party (AT) who was blinded to the two voters' selections. Following screening, a hand search of included references was performed to identify articles which may have been missed in the preliminary literature search.

QUALITY ASSESSMENT OF THE INCLUDED STUDIES

Two reviewers independently determined the study level of evidence using the Oxford Centre for Evidence-Based Medicine levels of evidence from I to V. These two reviewers also independently scored the risk of bias for non-randomized studies using the Methodological Index for Non-randomized Studies (MINORS) tool.[17] Consensus on disagreements in score was reached by discussion. The MINORS appraisal tool assigns a score of 0 (not reported), 1 (inadequately reported), or 2 (adequately reported) to eight items for non-comparative studies, and an additional four items for comparative studies. The scores are categorized regarding the quality of study in the following manner: 0-6 is very low; 7-10 is low, 11-16 is moderate, and >16 is strong.[18]

DATA EXTRACTION

A custom data extraction sheet was developed using Microsoft Excel (Microsoft Corporation, Redmond, WA), and extraction was performed by three of the investigators (JK, TO and AT). All of the articles underwent a second assessment of data extraction by one of the same three investigators to reach agreement on extracted data.

Extracted data included study characteristics (lead author, year of publication, time to final end point for follow-up, type of study, and sample size) and patient information (gender, age, competition level), all objective tests and measures associated with shoulder pain, and the what the association of objective tests and measures was to the presence of shoulder pain. The swimming competition age level was determined as follows based on a combination of recommended age divisions by the USA swimming competition levels[19] and age groupings in included studies was based on the mean reported age to arrive at the following breakdown of age levels of competition:

- Youth – less than 14 years of age
- Adolescent/Adult – 15-27 years of age
- Masters – over 27 years of age
- Various age levels – the reported ages studied included at least two of the above levels

Table 2. Strength of evidence for objective tests and measures.

Strong evidence	**Two or more studies with low risk of bias**
Moderate evidence	Two or more studies with moderate or high risk of bias, OR two studies with consistent findings in which one of the studies has a low risk of bias
Limited evidence	One study with low risk of bias, OR two studies with moderate or high risk of bias
Conflicting evidence	Studies demonstrating differing associations
No evidence	No study

DATA ANALYSIS

The agreeability between the two reviewers at the title/abstract and full-text review stages is reported as a Cohen's Kappa Correlation Coefficient (K).[20] A small correlation is said to exist if the K value is <0.4 moderate agreement 0.41-0.6, substantial agreement 0.61-0.8, and nearly perfect agreement 0.81-1.0.

Descriptive analysis was performed for each of the objective tests and measures due to high variance in the methods among studies, and high risk of bias/low quality of evidence for the majority of the studies. The strength of evidence was assigned to each objective test and measure based on publications reporting similar descriptive analysis as summarized in Table 2.[21,22]

RESULTS

The literature search identified 2180 articles from the data sources, which decreased to 918 studies screened after duplicates were removed. Full text review was conducted on 127 articles. The level of agreement between the two reviewers for the title and abstract phase and full-text review phase was 0.80 and 0.81, respectively, indicating substantial to nearly perfect agreement. Following title and abstract and subsequent full-text review, 22 articles were included for data extraction following the initial search and five additional articles were included after the updated search.[3,8,10,12,23-45] Figure 1 provides the PRISMA diagram.

QUALITY OF EVIDENCE

There were four Level IV noncomparative studies that were either case series or prospective cohorts with low numbers,[23,27,29,31] 12 Level III prospective case-controlled studies,[24-26,28,30,32-38] three Level III prospective correlational studies,[1,8,45] and seven Level II prospective cohort studies.[3,10,11,40,42-44] There were no Level I randomized controlled trials.

The MINORS score for the Level IV studies ranged from 7-10, indicating a low quality of evidence. The MINORS score for the 12 Level III prospective case-controlled studies ranged from 11-19 which indicates an overall strong level of evidence although four of the studies in this category were only moderate level. The three Level III prospective correlational studies had a MINORs score which ranged from 10-15 indicating a moderate level of evidence. The eight Level II prospective cohort studies had a MINORs score which ranged from 9-19 with the majority of the studies demonstrating moderate evidence, and one having strong evidence. The Oxford Levels of Evidence and the MINORs scores for all of the studies included for analysis in this systematic review are provided in Appendix B.

Due to heterogeneity amongst study methods, the overall recommendation for strength of evidence for each objective variable assessed for relationship to shoulder pain is swimmers is reported using the method described above to determine if the overall evidence is strong, moderate limited, conflicting, or no evidence. The summary of objective variables studied, risk of bias, and strength of evidence by age group is detailed in Table 3. The synthesis of the strength of evidence sorted by level of competition is summarized in Table 4.

INTERNAL AND EXTERNAL ROTATION STRENGTH

Seven studies evaluated the impact of internal and external rotation strength on shoulder pain with four using hand held dynamometry and three using isokinetic testing systems.[10,24,27,28,31,32,37] Patient position (eg. Supine or prone, and arm at neutral versus at 90 degrees of abduction) and speed of isokinetic testing were not standardized across the studies. Five of the studies were on adolescent/adult swim levels, and two were on varied age levels. Limited evidence from two low quality studies demonstrated that isokinetic testing of eccentric ER:concentric IR has a positive relationship to shoulder pain in both male and female adolescent swimmers.[24,31] The risk of developing shoulder pain was increased 4.5-fold when a preseason value of eccentric:ER:concentric IR was less than 0.68 in one low quality study.[31] In conflict with this evidence, three studies which all used hand held dynamometry demonstrated moderate evidence that there was no relationship between the internal:external rotator strength ratios and development of shoulder pain for swimmers in the adolescent/adult age group,[28,32,37] and in one study for swimmers of varied age groups including swimmers up to 77 years.[10]

SCAPULAR POSITION/DYSKINESIA

The influence of scapular position and/or scapular dyskinesia on shoulder pain in swimmers was assessed in seven studies.[10,11,23,35,36,44,46] Methods employed for analyzing the scapula position and dyskinesia included digital inclinometry of scapular position at various points of shoulder range of motion, the Kibler Test for distance from the spinous processes of the seventh and third thoracic vertebrae to the scapula, and visual inspection (dyskinesis pre-

Table 3. Summary of levels of evidence for each objective test and measure sorted by age level of competition.

Descriptive Characteristic	Study (Author, Year)	Age Competition Level	Gender	Method	Test Type/ Position	Pain/ Injury	Relationship	ROB	Strength of evidence
Assessment of External Rotation and Internal Rotation Strength	Bak Magnusson, 1997	Adolescent/ adult	Male/ Female	KinCom	90 Degree; ECC ER:CON IR	+	Decreased ratio	High	Moderate
	Drigny, 2020	Adolescent/ adult	Male/ Female	ConTrex Ioskinetic	45 Degree ECC ER:CON IR	+	Ratio Less Than 0.68	High	
	Tate, 2012	Varied age groups (8-77 years)	Male/ Female	HHD	90 degrees; Grouped by Age Level	-		Mod	Moderate
	Harrington, 2014	Adolescent/ adult	Female	HHD	90 Degrees	-		Mod	
	McLaine, *J Sci Med Sport*, 2018	Varied age groups (14-20 years)	Male/ Female	HHD	90 Degrees	-		Low	
	Boettcher, 2020	Adolescent/ adult	Male/ Female	HHD	Neutral	-		Mod	
	Beach, 1992	Adolescent/ adult	Male/ Female	Cybex	Prone (60, 240 degrees/ second)	-		High	Limited
Assessment of Scapular Position/ Dyskinesia	Brown, 2016	Adolescent/ adult	Male/ Female	Dual Inclinometer	4 Phases of Elevation	+	Decreased Scapular Upward Rotation	High	Conflicting
	McLaine, *Phys Ther Sport*, 2018	Varied age groups (14-20 years)	Male/ Female	Digital Inclinometer	90/140 degrees	-		Low	
	McKenna, 2012	Youth	Male/ Female	Kibler Test	Kibler Grades	+	Decreased Kibler Neutral	Low	Conflicting
	Welbeck, 2019	Adolescent/ adult	Male/ Female	Kibler Test	Kibler Grades	-		High	
	Bak Fauno, 1997	Adolescent/ adult	Male/ Female	Visual Inspection	Yes/No	+	Not Reported	High	Moderate
	Tate, 2012	Varied age groups (8-77	Male/ Female	Visual Inspection	Yes/No	-		Mod	

Descriptive Characteristic	Study (Author, Year)	Age Competition Level	Gender	Method	Test Type/ Position	Pain/ Injury	Relationship	ROB	Strength of evidence
		years)							
	Pollen, 2023	Adolescent/ adult	Male/ Female	Visual Inspection	Yes/No	-		Mod	
Assessment of Periscapular Strength	Tate, 2012	Varied age groups (8-77 years)	Male/ Female	HHD	Lower Trapezius, Middle Trapezius, Serratus Anterior	+	Decreased Middle Trapezius Strength in 8-11 year age group	Mod	Conflicting
	Harrington, 2014	Adolescent/ adult	Female	HHD	Scapular Depression/ Abduction	-		Mod	
	Lippincott, 2018	Adolescent/ adult	Female	HHD	Upper trapezius, Lower Trapezius, Serratus Anterior	-		Low	
	Tate, 2020	Adolescent/ adult	Male/ Female	PSET	3 Points in Season	-	Increased Endurance, No Effect on Pain	Mod	Moderate
	Thomas, 2021	Masters	Male/ Female	PSET		-		Mod	
	Feijen, 2021	Youth	Male/ Female	PSET		+		Mod	
	McLaine, 2019	Varied age groups (14-20 years)	Male/ Female	Unclear	Flexion: Extension Ratio	+	Males Only (Flexion: Extension strength ratio was higher for the shoulders with pain reported in questionnaire)	Low	Limited
Assessment of Core Stability/ Endurance	Harrington, 2014	Adolescent/ adult	Female	Side Bridge, Prone Bridge	Time	-		Mod	Conflicting
	Lippincott, 2018	Adolescent/ adult	Female	CKCUEST	Number of Taps	-		Low	
	Tate, 2020	Adolescent/ adult	Male/ Female	Prone Bridge, Side Bridge, CKCUEST	Time/ Number of Taps	+	Side Bridge Endurance < 8.5 seconds in 12-14 year age group	Mod	

Descriptive Characteristic	Study (Author, Year)	Age Competition Level	Gender	Method	Test Type/ Position	Pain/ Injury	Relationship	ROB	Strength of evidence
	Abdelmohsen, 2021	Youth	Male/ Female	Trunk extension strength at 60 and 180 deg/sec; Side Bridge and Static Back Endurance Tests, Ball Bridge and Unilateral Bridge Tests	Multiple Core Test	+		Mod	
	Pollen, 2023	Adolescent/ adult	Male/ Female	Unilateral Bridge, CKCUEST	Time/ Number of Taps	-		Mod	
Assessment of Thoracic Mobility	Welbeck, 2019	Adolescent/ adult	Male/ Female	Thoracic Rotation Inclinometer	Degrees	-		High	Limited
	Pollen, 2023	Adolescent/ adult	Male/ Female	Trunk Flexion/ Extension		-		Mod	
Assessment of ER/IR PROM	Bak Fauno, 1997	Adolescent/ adult	Male/ Female	Degrees	90 degrees	-		High	Conflicting
	Bansal, 2007	Varied age groups (17-35 years)	Male	Degrees	90 degrees	+	No Statistics Reported	Mod	
	Tate, 2012	Varied groups (8-77 years)	Male/ Female	Degrees	90 degrees	+	Decreased IR (8-11 years)	Mod	
	Walker, 2012	Varied age groups (11-27 years)	Male/ Female	Degrees	90 degrees	+	ER > 100 degrees, <93 degrees	Mod	
	Harrington, 2014	Adolescent/ adult	Female	Degrees	90 degrees	-		Mod	
	Cejudo, 2019	Adolescent/ adult	Male/ Female	Degrees	90 degrees	-		Low	
	Matsuura, 2020	Adolescent/ adult	Male/ Female	Degrees	90 degrees	-		Mod	
	Tate, 2020	Adolescent/ adult	Male/ Female	Degrees	90 degrees	-		Mod	
	Thomas, 2021	Masters	Male/ Female	Degrees	90 degrees	+	Decreased ROM: 10 degree IR; 8 degree ER; 18 degree total arc	Mod	

Descriptive Characteristic	Study (Author, Year)	Age Competition Level	Gender	Method	Test Type/ Position	Pain/ Injury	Relationship	ROB	Strength of evidence
	Mise, 2022	Youth	Male/ Female	Degrees	90 degrees	+	For males, Shoulder ER (right) was significantly lower in the pain group than the non-pain	High	
	Pollen, 2023	Adolescent/ adult	Male/ Female	Degrees	GIRD (yes/ no)	-		Mod	Conflicting
Assessment of Other ROM	Cejudo, 2019	Adolescent/ adult	Male/ Female	Degrees	Horizontal Adduction	+		Low	Moderate
	Thomas, 2021	Masters	Male/ Female	Degrees	Horizontal Adduction	+	7.8 degree horizontal adduction	Mod	
	Ozcaldiran, 2002	Youth	Male/ Female	Sum of flexion, extension, abduction, ER, IR, & functional ER	Total ROM Score	+	Increase in total flexibility index (r not reported)	Mod	Limited
	Mise, 2022	Youth	Male/ Female	Centimeters	Shoulder Rotation Width	+	Shoulder rotation width of the male higher in pain group and female lower in pain group	High	Limited
Assessment of Muscle Length	Harrington, 2014	Adolescent/ adult	Female	Length Centimeters at Rest/ Stretch	Pectoralis Minor Length	+	Decreased pectoralis minor length on dominant arm	Mod	Conflicting
	Tate, 2012	Varied age groups (8-77 years)	Male/ Female	Degrees Flexion; Centimeters at Rest/Stretch	Latissimus Dorsi Length/ Pectoralis Minor Length	++	Latissimus Dorsi 8-11 years, Pectoralis Minor 15-19 years	Mod	
	Lippincott, 2018	Adolescent/ adult	Female	Length Centimeters	Pectoralis Minor Length	-		Low	
	Matsuura, 2020	Adolescent/ adult	Male/ Female	Degrees Flexion	Latissimus Dorsi Length	-		Mod	
Assessment of Laxity	Bak Magnusson, 1997	Adolescent/ adult	Male/ Female	Yes/No	Anterior Drawer, Sulcus	+	6/7 Painful Shoulders	Low	High
	McMaster,	Adolescent/	Male/	Clinical Examination Shoulder	Sulcus, Ant/	+	Increase in total score	Low	

Descriptive Characteristic	Study (Author, Year)	Age Competition Level	Gender	Method	Test Type/ Position	Pain/ Injury	Relationship	ROB	Strength of evidence
	1998	adult	Female	Score	Post Translation		associated with interfering pain		
	Sein, 2010	Varied age groups (13-25 years)	Male/ Female	Yes/No	Sulcus, Ant/ Post Translation	+	Increase in laxity and extreme pain	Mod	
	Bak Fauno, 1997	Adolescent adult	Male/ Female		Carter/ Wilkinson, Anterior Drawer, Sulcus	unclear	No Statistical Analysis	High	Limited
	Bansal, 2007	Varied age groups (17-35 years)	Male	Yes/No	Sulcus	-		Low	
	Walker, 2012	Varied age groups (11-27 years)	Male/ Female	KT1000	Ant/Post Translation	-		Low	

ROM= Risk of Bias, HHD= Hand Held Dynamometry, ECC ER:CON IR= Eccentric External Rotation:Concentric Internal Rotation Ratio, PSET= Posterior Shoulder Endurance Test, CKCUEST= Closed Kinetic Chain Upper Extremity Stability Test, ROM=Range of Motion, GIRD= Glenohumeral Internal Rotation Deficit.

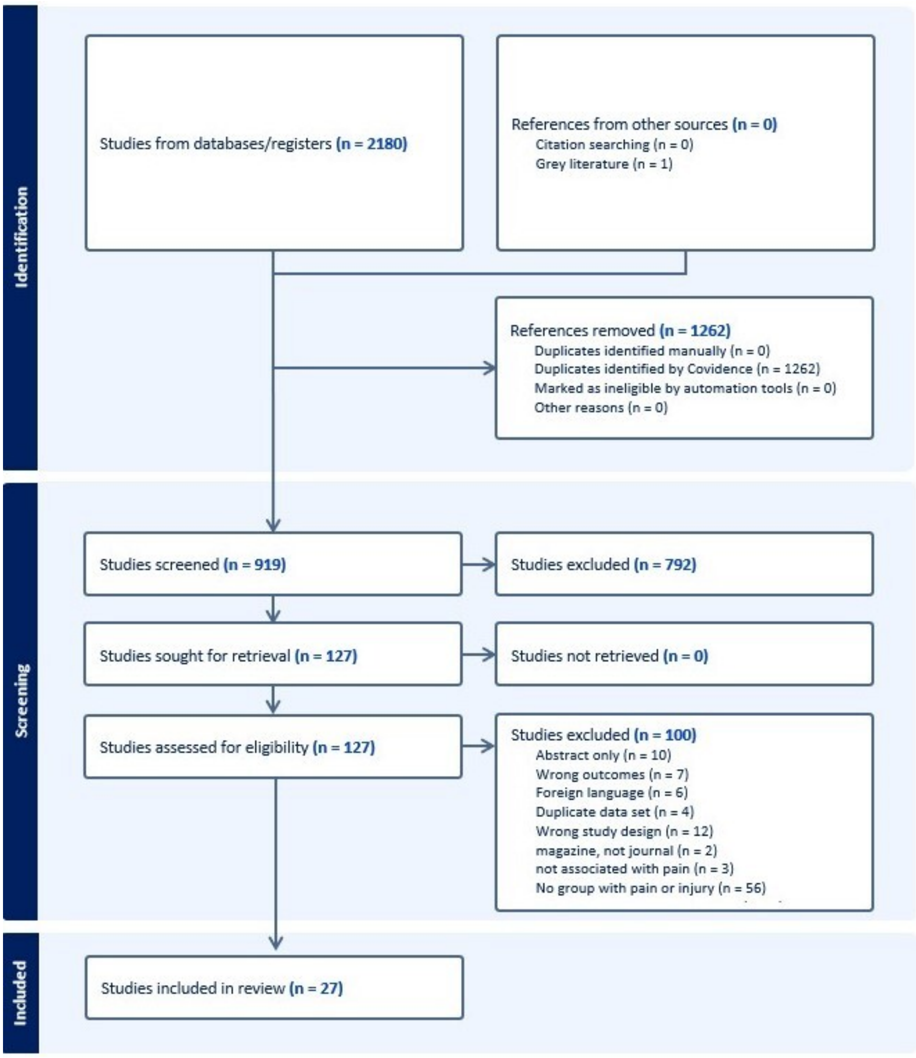

Figure 1. PRISMA diagram for study flow.

sent, yes or no). The age groups of the swimmers One study examined youth, four examined adolescents/adults, and two examined varied age ranges. There is limited evidence from only a single study of youth swimmers demonstrating greater shoulder pain with swimming if they did not have a neutral position of the scapula with the Kibler Test.[35] In conflict with this finding is limited evidence from one study using Kibler Test[44] and one using visual inspection[41] which both describe no relationship between scapular position/dyskinesia and shoulder pain for youth swimmers. Moderate evidence for no relationship between scapular position and shoulder pain was determined from two studies across age groups,[10,36] one including youth and adolescent/adult swimmers employed digital inclinometry for assessing the scapula at various intervals of elevation[36] and the other[10] used visual inspection for swimmers across all age levels (age 8-77).

PERISCAPULAR MUSCLE STRENGTH

Seven studies evaluated the influence of periscapular muscle strength on shoulder pain in swimmers.[10,12,32,33,38,42,43] Two studies were on youth swimmers, three were on adolescent/adult swimmers, one studied swimmers across the lifespan (8-77 years), one assessed masters swimmers, and one study assessed both youth and adolescent/adult ages. Handheld dynamometry was utilized to determine the strength of periscapular muscles in three studies, while the posterior shoulder endurance test was used in three studies, and one study did not clearly describe strength testing methods. Overall, there was moderate evidence for no relationship between scapular strength on shoulder pain in swimmers. There is limited evidence from two studies in youth swimmers to support the assertion that decreased scapular strength is associated with the development of shoulder pain.[10,12] One study found a decrease in lower and middle trapezius strength,[10] and one demonstrated poorer performance on the posterior shoulder endurance test for youth swimmers who developed shoulder pain.[12]

CORE STABILITY/ENDURANCE

Five studies utilized various methods for analyzing core stability and endurance as a risk factor for developing shoulder pain.[11,26,32,33,41,42] Methods included use of the closed kinetic chain upper extremity test (number of taps),

Table 4. Summary of synthesized strength of evidence for objective measures studied sorted by age level of competition.

Objective variable measured	Youth <14 years old	Adolescent/ Adult 15-27 years old	Masters >27 years old	Various Age Level
IR:ER strength ratio	No evidence	Limited + Ecc ER:Con IR (<0.68 risk) Moderate – ER:IR	No evidence	No evidence
Scapular position/dyskinesia	Limited +	Conflicting: Limited + 3 studies Limited – 2 studies	No evidence	No evidence
Periscapular muscle strength	Limited evidence + when weak scapular mm.	Moderate -	No evidence	No evidence
Core stability	Moderate + (<8.5 second side plank)	Moderate -	No evidence	No evidence
Thoracic mobility	Not reported	Moderate -	No evidence	No evidence
Internal Rotation (IR) and External Rotation (ER) Range of motion	Moderate + Decreased IR in 8-11 year olds Increased ER in males	Moderate -	No evidence	No evidence
Other Range of Motion (ROM)	Moderate + Increased ROM			
Flexibility	No evidence	Moderate + Pectoralis Minor tightness	No evidence	
Laxity	Moderate +	Moderate +	No evidence	Conflicting: Moderate + Strong -

EccER:ConIR = Eccentric external rotation to concentric internal rotation ratio
ER:IR = External rotation to Internal rotation ratio

the timed side bridge, timed prone plank, timed ball bridge, and isokinetic peak torque testing for trunk flexion/extension. One study reported on youth swimmers, three were on adolescent/adult swimmers, and one included various age groups There is moderate evidence from two studies in youth swimmers that decreased trunk endurance is associated with the development of shoulder pain.[26,42] One of these studies suggested that a time of less than 8.5 seconds for side plank in youth swimmers was a risk factor for developing shoulder pain.[42] In contrast, three studies on adolescent/adult swimmers demonstrated moderate evidence that there was no relationship between core endurance and the development of shoulder pain.[32,33,41]

THORACIC MOBILITY

Two studies assessed the impact of trunk mobility including thoracic rotation[44] and trunk flexion/extension[41] on the development of shoulder pain in adolescent/adult swimmers. These studies demonstrated limited evidence regarding the impact of trunk mobility as a risk factor for developing shoulder pain.

INTERNAL AND EXTERNAL ROTATION RANGE OF MOTION

The most widely studied objective variable as a risk factor for shoulder pain was shoulder internal and external range of motion which was reported in 11 studies.[3,10,24,25,30,32,34,40-43] One of the studies reports on youth swimmers, six report on adolescent/adult swimmers, one on masters, and three on swimmers of various ages. All of the studies except one used goniometry, and measured rotation at 90 degrees of abduction, while one study reported the presence or absence of glenohumeral internal rotation deficiency as "yes or no." In the adolescent/adult competition level, six studies demonstrated moderate evidence that there was not a relationship between shoulder rotation measures and the development of shoulder pain.[24,30,32,34,41,42] In contrast, Walker et al. suggest that excessive ER (>100 deg) or diminished ER (<93 deg) were risk factors for developing shoulder pain in 11-27 year old swimmers.[3] In comparison, there is moderate evidence demonstrating that youth swimmers have association between decreased range of motion and shoulder pain, including Tate et al. who examined 8-11 year olds and Mise et al. who examined 14 year-old boys and described that decrease IR and decreased ER, respectively were associated with greater risk for shoulder pain.[10,40]

OTHER RANGE OF MOTION

Moderate level evidence for having excessive mobility associated with shoulder pain was described in two studies of youth swimmers using novel range of motion methods: one used a total ROM index and found that pain was associated with higher summation of mobility[45]; the other used a shoulder rotation width index which was associated with shoulder pain if it was decreased in males, and increased in females.[40] This index is purported to be an index of comprehensive shoulder motion combining glenohumeral and scapulothoracic movements; it is a measure of the minimal distance between the two hands that are holding a dowel while raising the arms as high overhead as possible without elbow flexion. One study on masters swimmers[43] and one on adolescent/adult swimmers[30] associated decreased horizontal adduction with shoulder pain. Cejudo et al. propose that a cut point of having less than 39 degrees of horizontal adduction is associated with 3.6 times the risk of developing shoulder pain with swimming in the adolescent/adult age competition level.

MUSCLE LENGTH

The influence of flexibility of the pectoralis minor muscles on shoulder pain in adolescent/adult swimmers is reported in three studies[32-34] and across various age groups in one study.[10] There was moderate evidence to support that tightness of the pectoralis minor muscle is associated with shoulder pain in the adolescent/adult swimmer. Both studies reporting on pectoralis minor muscle length measured in centimeters the distance from the tip of the coracoid process to the base of the 4th rib.

LAXITY

Laxity was assessed for the glenohumeral joint in six studies by using the sulcus sign or the anterior/posterior drawer sign using a "yes or no" laxity score or using a KT1000 instrument.[1,3,8,23-25] Three studies reported on adolescent/adult swimmers and three report swimmers of various ages. There is strong evidence to support that laxity is associated with pain in adolescent/adult swimmers and in swimmers of various ages.[1,8,24] In contrast, two studies provided conflicting evidence demonstrating no association between laxity and shoulder pain for swimmers of various ages.[3,25]

DISCUSSION

The primary aim of this systematic review was to investigate objective measures utilized to assess swimmers and assess the relationship of these assessments to shoulder pain in distinct age groups/competition levels. The majority of the studies were prospective cohorts of moderate quality with several being high quality and several low quality. A qualitative synthesis of data was conducted due to heterogeneity of methods of obtaining the objective measures. The secondary aim of determining specific cut off values for risk factors in objective measures was achieved in that several values are reported; however, these have not been tested for validation in other studies.

YOUTH SWIMMERS

Youth swimmers had shoulder pain associated with scapular dyskinesis (limited evidence for positive relationship), decreased periscapular muscle strength (limited evidence for positive relationship), reduced core endurance (moderate evidence for positive relationship), internal and external rotation ROM (moderate evidence of relationship if decreased IR or increased ER); and laxity (moderate evidence for positive relationship). A cutoff of <8.5 seconds for side plank was proposed for associated of shoulder pain developing in one study, but this has not been tested for validity in other studies. The trend in these findings suggests that youth swimmers may benefit from more strengthening and neuromuscular control exercises to optimize shoulder stability which may be more lax in this skeletally developing age group.

ADOLESCENT SWIMMERS

The majority of studies reported objective measures on adolescent/adult swimmers. This age group had increased risk of shoulder associated with ER:IR strength ratio when eccentric ER and concentric IR were assessed using isokinetic equipment, with a proposed cut off ratio of <0.68 associated with risk of developing shoulder.[31] This cut-off ratio is also only reported in one study and has not been tested for validity. Moderate evidence for the adolescent/adult swimmers' ER and IR strength in one static position using handheld dynamometry demonstrated no relationship with shoulder pain development. The conflicting evidence between these strength tests in this age group is likely attributable to the differing methods of assessing strength. Isokinetic strength testing may be a more accurate reflection of the demands of strength needs for swimmers and a better objective test than handheld dynamometry since the testing demonstrates strength throughout the range of motion and can assess both eccentric and concentric muscle strength. It is possible that eccentric posterior cuff activity compared to the concentric internal rotator contractions reflects the swimmer muscle activation patterns more closely than static measures of strength in one position with handheld dynamometry. The role of the scapula in the development of shoulder pain remains unclear in this age group as noted with conflicting evidence. Tightness of the pectoralis minor was associated with shoulder pain, and this may be related to the pectoralis minor creating an anterior scapular tilt which can contribute to impingement of subacromial structures.[47]

MASTERS SWIMMERS

Masters swimmers were only represented in one study[43] and therefore the ability to synthesize evidence was not attempted for this age group.

SWIMMERS ASSESSED ACROSS VARIED AGE LEVELS OF COMPETITION

The discrepancy of the role of laxity for swimmers across varied age levels may be related to the wide spread of ages represented in these studies. It is possible that younger swimmers may struggle more with laxity as noted in the youth and adolescent age levels,[1,8,24] while older swimmers may not have as much trouble due to the glenohumeral joint becoming less lax with aging. A clinical inference from this could be that youth and adolescent swimmers would benefit from performing band stability exercises, while older swimmers might benefit more from stretching.

A recent systematic review assessed the association of symptom development with objective measures in all regions of the body in elite swimmers, however there was no delineation of age or competition level in that review.[48] The authors reported on 17 studies for the upper extremity with similar scores on the MINORs risk of bias assessment to findings in this review which reflect overall moderate levels of evidence. Similar conclusions are reported regarding insufficient evidence regarding scapular static and dynamic positioning on the influence of shoulder pain, and those authors relate the lack of conclusive evidence to the diverse methods of assessing scapular position. The ecc ER:con IR ratio was also supported by moderate evidence in the recent systematic review with one study reporting that a ratio of >1.08 is associated with injury risk[24]; however, this cut point has not been validated in any prospective studies.

LIMITATIONS

Limitations of this systematic review include that only studies in English were included which may have resulted in studies having been excluded. Also, the heterogeneity of data collection methods precluded data pooling in meta-analysis. However, the rigorous method of synthesizing evidence based on the quality of studies allows for meaningful conclusions regarding objective tests for the varied age levels of competition.

CONCLUSION

Objective tests and measures have been identified which are related to the development of shoulder pain in swimmers of distinct age/competition levels. These clinical tests may prove helpful to assist providers in considering interventions which may prevent the development of shoulder pain. Further research is needed to assess the validity of identified test cut points, and to add to the data pool for the masters level swimmer.

CONFLICTS OF INTEREST

The Authors report no conflicts of interest.

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SUPPLEMENTARY MATERIALS

Appendix A

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Appendix B

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