Assessing Shoulder Strength and Range of Motion in Normal and Symptomatic Swimmers

Kayla Botha

BHSc (Physiotherapy)

A thesis submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Master of Health Science Standard

School of Health and Environmental Sciences

2024

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Kayla Botha

18th April 2024

CANDIDATE CONTRIBUTIONS TO CO-AUTHORED PAPERS

Chapter 3 Botha, K. & Brughelli, M. Inter- and intra-session reliability of shoulder range of motion and strength in swimmers.	Botha 90% Brughelli 10%
Chapter 4 Botha, K. & Brughelli, M. Shoulder strength and range of motion in swimmers with and without shoulder pain: A cross-sectional study	Botha 90% Brughelli 10%

Kayla Botha **Matt Brughelli**

The concept investigated in Chapter 3 was developed by Kayla Botha based on the review of the literature. Kayla completed the recruitment and data collection. Dr Matt Brughelli reviewed and assisted with some of the statistical analysis and provided feedback on the discussion and recommendations made.

The study included in Chapter 4 was designed by Kayla Botha based on the review of the literature. Kayla completed the recruitment and data collection. Dr Matt Brughelli assisted with the statistical analysis of the data and provided feedback on the discussion, conclusion, and recommendations made.

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge and thank my supervisor, Dr Matt Brughelli. I am very grateful for your support and guidance through the process of planning, collecting data, and writing of my thesis. Your feedback and insight have been valuable, especially when it came to the analysis of the data. Thank you for your prompt responses to questions and providing feedback. It certainly helped keep me accountable and engaged in my writing.

I would also like to acknowledge my parents, Rina and Brandt, my sister, Kelly-Mari, and my husband, Adam, for their unwavering support during my research journey. Mom and dad, thank you for your belief in my capabilities and instilling “a never give up” attitude from a very young age. Kelly, I will be forever grateful for your late night texts of encouragement when the motivation to continue writing was at an all time low. Last but not least, Adam, thank you for your understanding and patience during my studies. Thank you for your endless support and words of encouragement when I was stressed and wanted to give up. Thank you for being the glue that held our household together during this time.

Lastly, I would like to thank the coaches and athletes that contributed to my thesis. Thank you for giving up your personal time to assist me in conducting my research. I hope that my findings provide more insight on managing shoulder pain.

ETHICS APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 22/150, with approval granted on 6th September 2022.

ABSTRACT

Swimming is a recreational and competitive sport that can be identified by its repetitive and coordinated movements between various parts of the body. Unlike other sports where the lower body initiates and contributes to the propulsive forces, this is the primary role of the upper body. Although the cause of shoulder pain in swimmers is believed to be multifactorial, some modifiable factors such as muscle strength imbalance, altered muscle endurance and coordination, and deficits in the shoulder joint mobility, can predispose swimmers to shoulder pain or injury. Chapter 2 of this thesis includes a literature review on shoulder strength and range of motion in swimmers with and without pain. The literature review highlighted the limited research using isokinetic dynamometry to assess shoulder concentric and eccentric strength in swimmers who experience pain. Also, most of the studies analyzed these strength measures using absolute strength values and the conventional concentric and eccentric (ER:IR) ratios. Literature examining shoulder strength in other overhead sports has found that using a functional ratio of eccentric versus concentric (eccER:conIR) to be more appropriate. This literature review also showed that shoulder ROM of swimmers has primarily been assessed in supine or standing. On the basis of the findings of this literature review, this thesis sought to examine the differences in shoulder rotational strength in swimmers who have pain or not using the Humac Norm isokinetic dynamometer. For additional analysis on the differences between the painful and non-painful side, the researcher aimed to use the functional ratio (eccER:conIR) which has previously been studied twice in this population. Additionally, this thesis intended to measure the shoulder internal and external rotation ROM of swimmers using an inclinometer in prone. This position was selected as it is specific to swimming. Three out of the four strokes are performed in prone. Since the cross-sectional study included in this thesis is the first to use the Humac Norm isokinetic dynamometer and the inclinometer in prone to assess the shoulder of swimmers, in particularly those with shoulder pain, this thesis also aimed to determine the inter- and intra-session reliability of these objective measures. The reliability study (chapter 3) found moderate to excellent inter-session reliability (ICC: 0.68-0.98; CV: 4.80-19.70; SEM: 1.71-5.36) and excellent intra-session reliability (ICC: 0.98-1.00; CV: 1.50-19.80; SEM: 0.00-1.84) for the use of an inclinometer in prone for swimmers with and without shoulder pain. Moderate to excellent inter-session reliability was found for the use of the Humac Norm isokinetic dynamometer to assess a swimmer’s shoulder strength (ICC: 0.60-1.00; CV: 6.80-60.50; SEM: 0.00-7.20). The Humac Norm isokinetic dynamometer showed excellent intra-session reliability (ICC: 0.99-1.00; CV: 2.20-8.20; SEM: 0.00-1.31). Although the Humac Norm isokinetic dynamometer showed moderate to excellent inter-session relative reliability, the high CV and SEM values indicated less adequate absolute reliability. Whereas the intra-session absolute reliability, during the second session, was

more adequate. This shows the importance of having at least one familiarization session, particularly for the eccentric testing protocol. Eccentric movement is unique and not performed on a daily basis hence the importance for participants to practice this movement to ensure testing proficiency. Future research using the Humac Norm isokinetic dynamometer to assess swimmers' shoulders should include at least one familiarization session. Chapter 4 included a cross-sectional study design to investigate strength hand ROM in swimmers with and without pain. The strength data indicated no significant side to side difference in shoulder external or internal rotation strength in asymptomatic swimmers; however, the external rotators were significantly stronger when working eccentrically than concentrically (R: p= 0.01, ES= -1.76; L: p=0.01, ES= -2.17). There was also no significant difference in functional eccER:conIR ratio between the left and right side (p=0.66). On the contrary, swimmers with shoulder pain were significantly weaker on their symptomatic side during concentric internal rotation (p=0.05, ES=-0.96). Additionally, swimmers who have painful shoulders had a significantly greater functional ratio on the symptomatic side (p=0.04). Lastly, there was no significant difference in internal and external rotation ROM regardless of pain being present or not. Further research is required to validate the findings of our study as it is the second study to use the functional ratio to evaluate the differences in shoulder strength in swimmers with shoulder pain. Also, it is the first study to assess shoulder ROM using an inclinometer in prone. On the basis of the findings in this thesis, practical implications include that health professionals or strength coaches working with swimmers should measure shoulder ROM in prone as they may get a more practical and reliable assessment of the shoulder's mobility. Lasty, health professionals involved in the management of shoulder injuries in swimmers should consider using the functional ratio (eccER:conIR) to evaluate the muscle balance around the shoulder joint as it is more appropriate and sport-specific, especially considering how the internal and external rotators interact during the propulsive phase in swimming.

CHAPTER 1: INTRODUCTION AND RATIONAL

Background

Swimming is a recreational and competitive sport that is characterized by its repetitive and coordinated movements between the different parts of the body, in particular the upper and lower limbs. Closed and continuous motor skills are necessary for strength, speed, and endurance during swimming (Lucas et al., 2021; Wiazewicz & Eider, 2020) and as a result an athlete's performance can be influenced by various factors such as physiological, biomechanical, and anthropometric (Lucas et al., 2021). Therefore, screening swimmers is essential since early detection of risk factors enables timely intervention and management. This helps to reduce future injuries or progression of injuries, missed training practices, and loss of competition time (Schlueter et al., 2021). These risk factors are both modifiable and non-modifiable and interact in a dynamic way which makes it challenging for a single clinical assessment tool to identify athletes' risk of injury (Schlueter et al., 2021).

The shoulder joint of a swimmer is the most common body part affected by injuries, accounting for 16 to 76 percent of injuries (Trinidad et al., 2021). Further statistics show that shoulder pain is responsible for 20 to 35 percent of swimmers' experiencing time-loss to injury each year (Gaunt & Maffulli, 2012).

Unlike other sports, where the legs initiate and contribute to propulsive forces, swimmers primarily use their upper extremities (Batalha et al., 2020). The majority of the swimming strokes have a high demand for shoulder adduction and internal rotation (IR) resulting in these muscles becoming stronger than their antagonists, which can potentially cause muscle imbalances (Batalha et al., 2013; Weldon & Richardson, 2001; West, Sole & Sullivan, 2005). Muscle strength imbalances are one of the many proposed risk factors that can contribute to shoulder pain amongst swimmers (Feijen et al., 2021; Schlueter et al., 2021). To further support this statement, a review of the literature by Schlueter and colleagues (2021) found moderate quality evidence supporting the relationship between the shoulder's rotator strength and endurance ratios and the presence of shoulder pain or injury. They also reported that current research supports the relationship between shoulder internal and external rotation range of motion (ROM) and the risk of shoulder injury or development of injury amongst swimmers (Schlueter et al., 2021). On the contrary, a systematic review by McKenzie and colleagues (2023) found no association between shoulder ROM, pain, and injuries. Similarly, a meta-analysis by Bradley and colleagues (2016) reported that although swimmers may have increased ER and reduced IR ROM, there is no clear evidence that these changes are a predictor for shoulder injuries in swimmers. While several studies support the association of ROM and shoulder pain, the current research is conflicting and limited by sample size and study design. This highlights the importance of standardization of protocols and in particular sport-specific considerations such as testing position.

The assessment of rotator cuff muscle imbalances, specifically with the use of isokinetic testing, can be an objective, useful, and reliable way to quantify muscular strength and imbalances (Drigny et al., 2020). Previously, muscle strength imbalances were determined using a conventional ratio between the peak torque of external rotation (ER) and internal rotation (IR) during either a concentric or an eccentric contraction (Bak, 2010; Batalha et al., 2013; Bradley et al., 2016). However, more recent studies found that evaluating the agonist muscle during a concentric contraction whilst the antagonist muscle acts eccentrically to be more appropriate. This is because the antagonist contributes to the dynamic stability of the glenohumeral joint (Andrade et al., 2013; Guney et al., 2016). To date, literature regarding rotator muscle imbalances and its association with shoulder pain or injuries has predominantly stemmed from conventional ratios (Drigny et al., 2020). In spite of this, ER muscles are less likely to engage concentrically during the swimming motion as it is mainly involved in the non-propulsive phase. During the propulsion phase, the pectoralis major initiates the powerful adduction and extension of the humerus and contributes to the internal rotation of the shoulder (Pink et al., 1991). Simultaneously, the teres minor works synergistically to extend the arm (Pink et al., 1991). Subsequent to the activity from the pectoralis major and teres minor, the humerus crosses the point where it is perpendicular to the body, and latissimus dorsi has the mechanical advantage (Pink et al., 1991). The activation of the latissimus dorsi causes the subscapularis muscle, which is a shoulder internal rotator, to contract and counteract the posterior translation of the humeral head (Wattanaprakornkul, Cathers, Halaki, & Ginn, 2011). The combination of full elevation with internal rotation and adduction is the typical position for shoulder impingement (Tovin, 2006). Consequently, the external rotator’s main role during propulsion is to reduce the anterior translation of the humeral head by contracting eccentrically to counteract the propulsive force of the internal rotators (Drigny et al., 2020) limiting anterior shoulder impingement.

Despite the amount of literature commenting on concentric and eccentric muscle strength of the shoulder internal and external rotators amongst other sports populations and even non-athletic people, there is extremely limited research conducted in the swimming environment. The understanding of both concentric and eccentric muscle strength amongst swimmers may add value to prescribing adequate and effective prevention and management protocols for swimmers whether they have a symptomatic shoulder or not.

As previously mentioned, there are several factors that may contribute to shoulder pain amongst swimmers. One modifiable factor, along with muscle imbalance, which could potentially influence a swimmer’s shoulder pain is poor biomechanics or technique (Feijen et al., 2021; Kubova et al., 2020; Schlueter et al., 2021). Walker and colleagues (2012) conducted a 12-month prospective cohort study investigating the incidence and risk factors of shoulder pain in swimmers and found that adequate rotational shoulder ROM is needed for correct technique whilst swimming and consequently to avoid shoulder impingement. This study showed the significant association between ER ROM and shoulder pain (Walker et al., 2012). Swimmers whose shoulder ER ROM measured high (≥100°) or low (≤93°) were at an increased risk of shoulder injuries compared to those in the mid-range, regardless of whether swim training exposure was adjusted for (Walker et al., 2012).

Although there is literature investigating shoulder ROM in swimmers, all the available studies assess ROM in the supine position. It has been suggested that clinicians may choose to use the prone position to assess or screen functional stability and structural restraints around the shoulder; especially since ER is assisted by gravity in supine (Furness et al., 2015). To date, there are no studies measuring shoulder ROM in prone amongst swimmers. It is thought that swimmers spend majority of their training time in a prone position hence assessing the shoulder in a similar way would provide more accurate and specific outcomes.

Purpose Statement

This thesis intends to contribute to the knowledge regarding shoulder strength and range of motion amongst swimmers and to examine its relationship with shoulder pain. Firstly, the literature investigating shoulder strength and range of motion amongst swimmers who experience shoulder pain will be reviewed. Furthermore, literature pertaining to the reliability of the diagnostic tools assessing these objectives will also be reviewed. Next, a comparison of maximal shoulder peak torque and active range of motion in swimmers who are symptomatic and asymptomatic will be explored. Finally, the reliability of the isokinetic dynamometer to assess peak torque and the inclinometer to measure range of motion in prone will be investigated. Practical recommendations for managing shoulder pain amongst swimmers will be suggested based on the research findings of this thesis.

Study Aims

The aims of this research were as follows:

1) To critically analysis the published literature on maximal shoulder strength and range of motion amongst swimmers with and without shoulder pain and the reliability of the diagnostic tools to assess these objectives.
2) To examine the reliability of diagnostic tools to assess the shoulder’s peak torque and active range of motion in prone.
3) To determine whether there is a difference in maximal peak torque and range of motion of the shoulder amongst symptomatic and asymptomatic swimmers.

Structure of the Thesis

This thesis is composed of 5 chapters which encompasses both original research and reviews with the intention of future publication. Therefore, each chapter is presented and worded in the journal format. References are presented as an overall reference list of the entire thesis at the end. The structure of the thesis is shown as a schematic in Figure 1.

The second chapter reviews literature that is investigating shoulder strength and range of motion amongst swimmers and its effects on shoulder pain. Furthermore, literature examining the reliability of diagnostic tools to assess these effects is also analysed.

The third chapter examines the reliability of the isokinetic dynamometer and the inclinometer to measure maximal shoulder peak torque and range of motion respectively.

The fourth chapter investigates maximal shoulder strength and range of motion in swimmers with and without shoulder pain.

The fifth and final chapter presents an overall discussion of the findings of the included research and provides some practical recommendations on how to manage shoulder pain amongst swimmers. Future considerations are also included in this chapter.

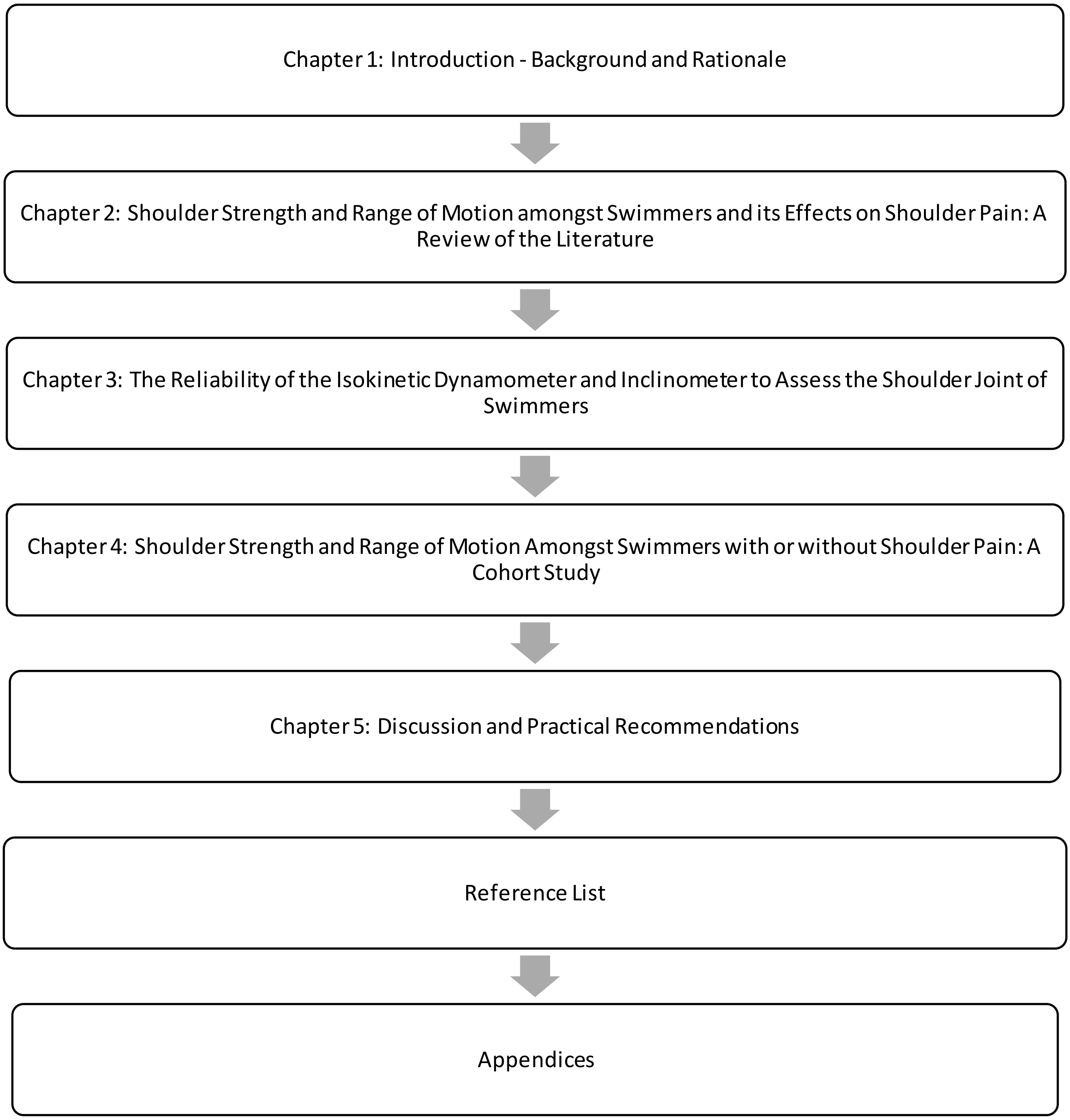


Figure 1. A Schematic of the Flow of Chapters in this Thesis

CHAPTER 2: Shoulder Strength and Range of Motion amongst Swimmers and its Effects on Shoulder Pain: A Review of the Literature

Abstract

This review examines the literature on maximal shoulder strength and range of motion (ROM) amongst swimmers with symptomatic and asymptomatic shoulders. During swimming, the majority of propulsive forces are generated by the upper body placing a significant amount of stress on the shoulders. Literature has indicated a high prevalence of shoulder injuries or pain amongst swimmers and that a ratio between the agonist and antagonist muscles of the shoulder joint is more important than their absolute strength.

Although this review did identify some differences in strength and ROM amongst swimmers who either experience shoulder pain or not, there are limitations to the literature that may potentially cause a risk of bias influencing the conclusions that were drawn. A limitation that was most frequently identified was the lack of testing randomisation and blinding of the researchers. Understandably with the cross-sectional and cohort type studies this can be challenging; however, blinding the researcher completing the statistical analysis from the testing order could be a way to reduce this risk of potential bias. Additionally, some studies did not acknowledge other factors that could influence findings such as previous shoulder surgeries or injuries unrelated to swimming, other medical conditions, and spinal conditions that refer pain into the shoulder. Not recognizing these factors could possibly put doubt on whether a swimmer's shoulder pain is influenced by strength, ROM, or other modifiable factors or are there alternative explanations for shoulder pain amongst swimmers. This review provides some recommendations on how future research could address these factors to limit the risk of bias and to add value to the literature.

Introduction

Swimming is a recreational and competitive sport that is characterised by its repetitive and coordinated movement between the different parts of the body, in particular the upper and lower limbs. The ability to swim fast is a complex skill that requires physical characteristics to maximise propulsive force whilst limiting the drag forces (Blanch, 2004). Unlike other sports, where the legs initiate and contribute to propulsive forces, swimmers primarily use their upper extremities (Batalha et al., 2020). Up to 90 percent of the total propulsive force is created by the upper body placing high loads through the shoulder joints (Batalha et al., 2020; De Martino & Rodeo, 2018). Both the internal and external rotators of the shoulder contribute significantly to the propulsive cyclical movements (Wiazewicz & Eider, 2021) as they work simultaneously to provide stability and mobility to the glenohumeral joint (Batalha et al., 2013; Codine et al., 1997; Wilk & Arrigo, 1993). Although, the propulsion predominantly relies on repetitive shoulder internal rotation (IR) and adduction resulting in stronger internal rotators and relatively weaker external rotators (Batalha et al., 2013; Weldon & Richardson, 2001; West, Sole & Sullivan, 2005).

There are four different types of strokes in swimming: freestyle, backstroke, breaststroke, and butterfly. Regardless of each swimmers' stroke specialty, the training is primarily freestyle resulting in excessive amounts of shoulder circumduction each day (Beach, Whitney & Dickoff-Hoffman, 1992; Virag et al., 2014; Weldon & Richardson, 2001; Wanivenhaus et al., 2012). Competitive swimmers can swim up to 18 000m each day, and they are frequently training 5-7 days a week and occasionally twice a day (Allegrucci, Whitney & Irrgang, 1994; Kluemper, Uhl & Hazelrigg, 2006; Lynch et al., 2010; McLaine et al., 2019; Seine et al., 2010), which equates to approximately 16 000-25 000 shoulder revolutions during a standard training week (Scovazzo et al., 1991). Therefore, the high prevalence of 40-91 percent (Bak, 2010; Matzkin et al., 2016; Seine et al., 2010) of shoulder pain amongst swimmers is no surprise.

Studies have analysed muscle strength during certain periods of the swimming calendar, such as competition and pre or post season (Bak & Fauno, 1997; Batalha et al., 2013; Ramsi et al., 2004; Batalha et al., 2020). The study by Batalha and colleagues (2013) included an in-season timepoint, as did Batalha and colleagues (2020); however, their study was not observational. Literature states that the balanced strength ratio between IR and ER is more important than their absolute strength (Ramsi et al., 2004). Drigny and colleagues (2020) supports this statement as they found a functional ratio between the peak torque of ER during an eccentric contraction and peak torque of IR during a concentric contraction to be more appropriate to evaluate injury risk as it assesses the eccentric contraction of the antagonist muscles which contribute to the dynamic GHJ stability (Drigny et al., 2020). Although it remains unclear whether muscle imbalance contributes to shoulder injuries in swimmers (Bradley et al., 2016), there is some evidence that strengthening the external rotators has a positive effect on decreasing shoulder pain in swimmers (Lynch et al., 2010).

With this in mind, the purpose of this review is to critically evaluate i) the reliability of using an isokinetic dynamometer and an inclinometer to measure maximal peak torque and range of motion of the shoulder and ii) the comparative studies examining shoulder strength, range of motion, and pain amongst swimmers. Additionally, practical recommendations that could contribute to our understanding of shoulder strength and ROM and its influence on a swimmer's shoulder pain will be provided.

1. Search Strategy

The author searched the electronic databases of MEDLINE, EBSCO, Science Direct, Taylor and Francis, PubMed, Google Scholar, Ovid, Scopus, CINAHL, and SPORTDiscus without any timeframe. The keywords used in various combinations when searching the databases included: 'shoulder pain', 'swimmers', 'range of motion', 'ROM', 'range of movement', 'flexibility', and 'strength'.

1.1. Selection Method of Comparative and Reliability Studies

The reviewer used a two-step screening method when selecting the comparative studies (Figure 2). Firstly, the titles and abstracts of the articles were reviewed. The second step applied the selection criteria to the articles. Studies were selected if they met the following selection criteria: (i) if the study investigated swimmers from any competitive level; ii) with shoulder pain; iii) specified what assessment tools were used; iv) observational studies, and (iv) the study must have been written in English language. The inclusion criteria for the reliability studies included: i) measuring internal and external rotation ROM, ii) using an inclinometer, and iii) the study must be written in English.

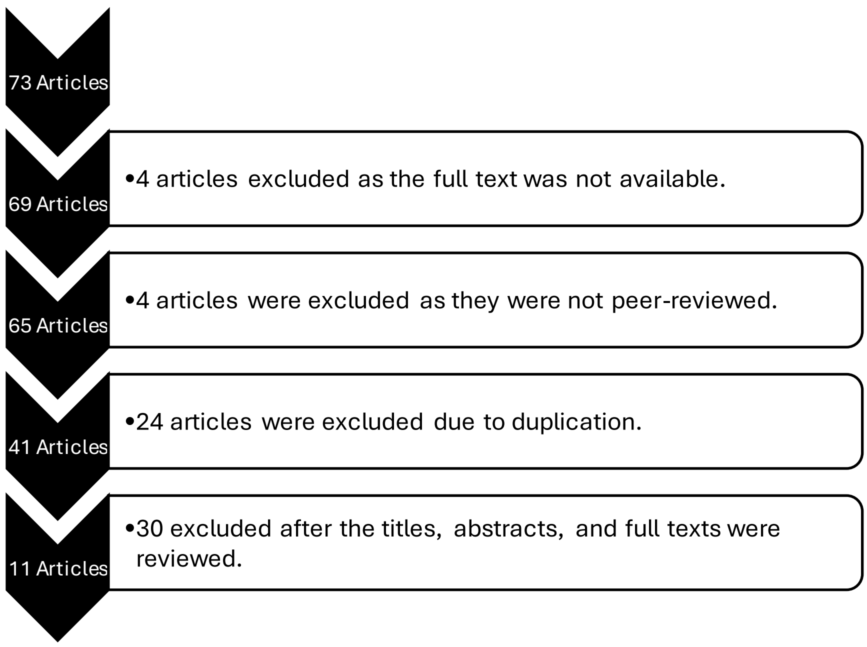


Figure 2. Schematic diagram of literature review process

1.2. Evaluation of Methodological Quality of the Studies

Critically appraising the included studies in Figure 1 is necessary to allow for a trustworthy review. Various appraisal tools, scales, and checklists have been developed to evaluate the methodological quality of observational and reliability studies (see table 1). Although the Downs and Black checklist and the NICE guidelines are commonly used to evaluate the quality of these studies, more current quality assessment tools have been developed.

Establishing the reliability of a physical examination is challenging due to the complex testing procedures, the variety of tests, and the lack of procedural standardisation (Lucas et al., 2013). With this in mind, the Quality Appraisal for Reliability Studies (QAREL) checklist (see appendix 4) was developed by a reference group of individuals, with proficiency in diagnostic research and quality appraisal, to evaluate the quality of diagnostic reliability studies (Lucas et al., 2010). QAREL is an 11-item checklist consisting of seven domains which include the spectrum of the participants, the spectrum of the assessors, blinding of assessors, the order of the examinations, the suitability of the timeframes between repeated measurements, appropriate test application and interpretation, and appropriate statistical analysis (Lucas et al., 2010). Lucas and colleagues (2013) found that majority of the items on the checklist to have moderate to good reliability. Each item is scored as “yes”, “no”, “unclear” and for some items a scoring of “not applicable” is available. The article by Lucas and associates (2010) provides a thorough explanation of how each item is assessed which helped guide the reviewer’s scoring (see table 2). An article was considered to be of a high quality if it received a “yes” score on at least 50% of the items (van Trijffel et al., 2005).

Table 1

Tools to evaluate Methodological Quality of Observational and Reliability Studies

Study type	Tools used
Cohort (observational)	CASP checklist
	SIGN critical appraisal checklist
	NIH quality assessment tool
	NOS
	JBI critical appraisal checklist
Cross-sectional (observational)	NIH quality assessment tool
	JBI critical appraisal checklist
	AXIS appraisal tool
Reliability	COSMIN checklist
	QAREL

Note. **AXIS** – Appraisal tool for Cross-sectional Studies; **CASP** – Critical Appraisal Skills Programme; **COSMIN** - COnsensus-based Standards for the selection of health Measurement Instruments; **JBI** – Joanna Briggs Institute; **NIH** – National Institute of Health; **NOS** – Newcastle-Ottawa Scale**; QAREL –** Quality Appraisal for Reliability Studies; **SIGN** – Scottish Intercollegiate Guidelines Network

The Joanna Briggs Institute (JBI) critical appraisal tools for cohort and cross-sectional studies are utilized to assess the methodological quality of the comparative studies. These checklists are specific to quantitative data and are primarily based on study design (Barker et al., 2023). For quantitative research, identifying the risk of bias in the publication is fundamental to reduce the possibility for including biased or misleading results (Porritt, Gomersall & Lockwood, 2014). JBI and collaborators are responsible for developing these appraisal checklists through an extensive peer-review process followed by the approval from the JBI Scientific Committee (Moola et al., 2020). The appraisal checklist for cross-sectional studies (see appendix 5) consists of eight questions and is scored “yes”, “no”, “unclear”, or “not applicable” (see table 2). The reviewer’s manual by Moola and colleagues (2020) provided an explanation on how to score each question. The JBI appraisal tool for cohort studies (see appendix 6) was also used with a similar scoring system, except there are 11 questions. Additionally, the JBI Levels of Evidence (see appendix 7) was used to determine the effectiveness of each study. The ranking of evidence of effectiveness is commonly associated with the study design and the ability to maximize internal validity (Porritt et al., 2014).

Table 2

The scoring of the quality appraisal checklists

Appraisal Checklist	Scoring	Quality of the Study
JBI	“yes”; “no”; “unclear”; “not applicable”	JBI Levels of Evidence (see appendix 7)
QAREL	“yes”; “no”; “unclear”; “not applicable”	QAREL score out of 11

Note. **JBI** – Joanna Briggs Institute; **QAREL** - Quality Appraisal for Reliability Studies

2. Reliability of the Isokinetic Dynamometer and Inclinometer for Assessing the Shoulder Joint

Various methods have been utilised to measure maximal peak torque and range of motion of the shoulder. These measures have evolved over the years by researchers and other health professionals. Table 3 shows the various tools that can be used to measure shoulder strength and ROM. Like any assessment methodology, it is essential that these measurements are valid and reliable to be meaningful and interpretable. The more reliable the measurement is, the greater the probability of adequately determining the sensitivity to identify small but clinically significant changes (Impellizzeri et al., 2008). Determining the validity and reliability of a specific measure is a fundamental part in assessing the quality of research (Taherdoost, 2016). In this section, we have included diagnostic studies (see table 4 and 5) to determine the reliability of isokinetic dynamometry to measure the maximal peak torque and an inclinometer to measure maximal range of motion in the shoulder. To establish a degree of methodological quality the QAREL checklist was used, and the individual quality scores are also documented (see appendix 8).

Table 3
Objective measures that are used in the research field to measure maximal shoulder peak torque and range of motion

Strength Measures	Range of Motion Measures
• Isokinetic dynamometer • Hand-held dynamometer	• Inclinometer • Digital levels • Goniometer • Ultrasound • Photography and digital programmes

2.1. Reliability of an isokinetic dynamometer to assess maximal peak torque of the shoulder

Earlier studies investigating the reliability of an isokinetic dynamometer to assess shoulder maximal peak torque have found it to have good to excellent reliability (Mandalidis et al., 2001; Plotnikoff & MacIntyre, 2002; van Meeteren, Roebroeck & Stam, 2002 & Dauty et al., 2003). Mandalidis and colleagues (2001) tested the IR and ER shoulder strength in 31 male students and reported ICC scores between 0.76 to 0.93 which is indicative of good reliability; however, they found that the IR SEM scores were higher than ER scores. These findings were further supported by Plotnikoff and colleagues (2001) who investigated 14 healthy adults and recorded SEM scores for IR (SEM: 2.44-3.73) was greater than for ER (SEM: 1.72-2.55). The ICC scores ranged from 0.87-0.94, similar to those of Mandalidis and colleagues (2001).

More recent studies by Eduardo and colleagues (2013) and Collado-Mateo and colleagues (2018) observed higher ICC scores (>0.85 and 0.97 respectively) than the previously mentioned studies. Although, there was a difference in SEM percentages between these two studies which needs to be considered. Eduardo and colleagues (2013) found that the SEM percentage for IR varied between 7.7% and 11 % and ER was 9.8% to 14.5%; whereas Collado-Mateo and colleagues (2018) reported a SEM percentage for ER 4.4% and 4.56%-6.79% for IR.

Most studies were of adequate quality, according to the QAREL checklist; however, two studies were of poor quality as there was no blinding of the examiners to the results or clinical information of the participants increasing the risk of bias (Eduardo et al., 2013; Collado-Mateo et al., 2018). Overall, it is evident that using the isokinetic dynamometer to measure the maximal peak torque of shoulder ER is more reliable than IR. Although, the high ICC values reported in these studies support the ability for the isokinetic dynamometer to measure peak torque accurately and reliably, the higher SEM scores and percentages limits these findings as it indicates less precision in the measurements or scores obtained. This makes it challenging to confidently state that the isokinetic dynamometer is a highly reliable tool to measure maximal shoulder peak torque.

Table 4
Reliability studies investigating the isokinetic dynamometer to measure maximal peak torque of the shoulder joint

Study	Participants	Measures	Findings		Quality of the Study
			ICC	SEM	QAREL Score
Mandalidis et al., (2001)	31 male students	A Kin Com II dynamometer was used to assess concentric and eccentric movements of bilateral shoulder IR and ER. The angular velocity speeds were set at 60°/s and 120°/s. The arm was at 45° abduction and 30° horizontal adduction.	The ICC values ranged between 0.76-0.93. Concentric data for both internal and external rotation of the shoulder were more reliable (ICC ≥ 0.80) than eccentric data (ICC ≥ 0.76).	The SEM values varied between 3.9Nm to 12.4Nm. The LOA values ranged between 4.0Nm and 13.3Nm. Both SEM and LOA showed the measurement of errors for peak torque, eccentric contractions, and internal rotation was greater than the average peak torque, concentric contractions, and external rotation.	5/11

Plotnikoff et al., (2002)	14 participants between the ages of 27 and 35 years.	The Kin Com dynamometer was used to assess concentric and eccentric internal and external rotation strength of the shoulder. The angular velocity of the tests was defined as 30°/s.	The ICC ranged from 0.87 to 0.91 for internal rotation and 0.89 to 0.94 for external rotation.	The SEM values varied between 2.44 and 3.73 for the internal rotation and 1.72 to 2.55 for the external rotation.	5/11
Van Meeteren et al., (2002)	20 healthy men and women varying ages without pain.	A Biodex dynamometer was used to assess abduction/adduction and external/internal rotation strength. The angular velocity of the tests was 60°/s and respectively 120°/s and 180°/s.	The ICC ranged from 0.69 to 0.92.	The SEM percentage ranged from 7% to 14%. The SEM percentage was smaller for the men than the women.	5/11
Dauty et al., (2003)	14 healthy males and females aged between 40 and 55 years.	A Cybex Norm isokinetic dynamometer was used to assess concentric and eccentric contractions of the shoulder internal and external rotators at an angular velocity of 60°/s and 120°/s.	For the external rotators, the peak torque ICC values varied between 0.91 and 0.96; the total work ranged from 0.91 and 0.95; and the average power varied between 0.88 and 0.94. For the internal rotators, the peak torque ICC values varied between 0.93 and 0.98; the total work ranged from 0.88 to 0.96; and the average power varied from 0.83 and 0.97.	For the external rotators, the peak torque SEM values varied from 3.3Nm to 6.3Nm; the total work SEM values ranged from 9Nm to 13Nm; and the average power SEM values varied between 5.2Nm and 13Nm. The internal rotators, the peak torque	6/11

				SEM values varied from 4.5Nm to 9.8Nm; the total work SEM values ranged from 10Nm to 16Nm; and the average power SEM values varied from 6.8Nm to 13Nm.	
Edouard et al., (2013)	46 healthy participants	Concentric and eccentric were performed in IR and ER using a Biodex dynamometer in a seated position (45° of shoulder abduction in the scapular plane). The angular velocities of the tests were 60°/s and 120°/s concentrically, and 30°/s eccentrically.	Most of the measurements showed high relative reliability (ICC> 0.90) at any speed. ER peak torque had moderate reliability particularly during the eccentric contraction (ICC > 0.85).	The SEM percentage ranged between 7.7% to 11.7% for the IR peak torque and 9.8% to 14.5% for the ER peak torque.	4/11
Collado-Mateo et al., (2018)	35 competitive swimmers age between 13 and 19 years.	A Biodex dynamometer was used to assess concentric movements were performed including IR and ER. The angular velocity of the test was defined at 60°/s.	For the dominant arm, the peak torque (ER: ICC= 0.977; IR: ICC= 0.972) and work (ER: ICC= 0.967; IR: ICC= 0.961) was higher than an ICC of 0.95. For the non-dominant arm, the ICC values	The SEM in both dominant and non-dominant was lower in the ER testing for both peak torque (D: 4.43%; ND: 4.49%) and work (D: 5.42%; ND:	3/11

			was slight less reliable. IR peak torque was 0.38 and ER was 0.972. The work ICC for IR was 0.917 and ER was 0.966.	5.39%); whereas the IR testing was slightly higher in peak torque (D: 4.56%; ND: 6.79%) and work (D: 5.55%; ND: 8.04%).	
Habets et al., (2018)	54 healthy and active subjects between the ages of 18 and 55 years.	A Humac Norm isokinetic dynamometer was used to assess both concentric and eccentric strength of the knee flexors and extensors and shoulder rotators were measured using the Humac NORM isokinetic dynamometer. The angular velocity of the test was defined at 60°/s and 180°/s for the knee movements and 60°/s and 120°/s for the shoulder movements.	The knee flexors and extensors measures have showed good to excellent reliability, with the ICC values ranging from 0.74 to 0.89. Additionally, the shoulder rotators measure also showed good to excellent reliability, with the ICC values ranging from 0.72 to 0.94.	The SEM percentage for knee flexors and extensors varied between 13% to 23.1%. the concentric measures were slightly higher than for the respective eccentric measures. The SEM percentage ranged from 6.9% to 14.4%. The SEM percentage was smaller for the shoulder external rotators than the internal rotators.	6/11

Note. **CV** – coefficient variation; **D** – dominant; **ICC** – intraclass coefficient correlation; **LOA** – limits of agreement; **ND** – non-dominant; **Nm** – Newton meter; **PCC** – Pearson's correlation coefficient; **QAREL** – Quality Appraisal for Reliability Studies; **SEM** – standard error of measurement

2.2. Reliability of an inclinometer to assess maximal range of motion of the shoulder joint

Even though an earlier study by Awan and colleagues (2002) assessing the reliability of using an inclinometer to measure shoulder IR ROM amongst 56 unimpaired school athletes found moderate intra-rater reliability (ICC: 0.58-0.71) and poor to moderate inter-rater reliability (ICC: 0.41-0.66), more recent reliability studies found an increase in both intra- and inter-rater reliability. Kolber and colleagues (2012) measured 30 asymptomatic adults' shoulder ROM and reported good to excellent intra-rater reliability (ICC: 0.83-0.94) and moderate to excellent inter-rater reliability (ICC: 0.58-0.95). Though, the SEM scores they recorded were quite varied for both intra- and inter-rater reliability (SEM: 1.64-4.27; 1.63-3.98 respectively) indicating greater variance in the observed scores which may be attributed to inadequate test design. These findings were supported by other recent studies by Cools et al., (2014), Furness et al., (2015) and Walker et al., (2016) who reported good to excellent intra- and inter-rater reliability. Cools and colleagues (2014) found good to excellent intra-rater reliability (ICC: 0.85-0.99) and excellent inter-rater reliability (ICC: 0.96-0.99) which was somewhat supported by adequate minimal detectable change (MDC) score of 4.02-7.48. Further, Furness and colleagues (2015) documented an excellent reliability both in prone (ICC: 0.98-0.99) and in supine (ICC: 0.93-0.98) positions and was strengthened by a good SEM score of 1.5-2.4. A final study by Walker and colleagues (2016) measuring shoulder IR and ER ROM amongst 17 competitive swimmers found good to excellent intra-reliability (ICC: 0.85-0.96) and good to excellent inter-rater reliability (ICC: 0.77-0.94) except for measuring the left shoulder IR (ICC: 0.65); however, the SEM scores for both intra- and inter-rater reliability is of an adequate level (SEM: 2-5).

Overall, the inclinometer had good to excellent intra- and inter-rater reliability. The good intra-rater reliability shows that examiners can be confident when using the inclinometer, several times on the same person, as they are likely to get similar results. Further support to use an inclinometer is the good inter-rater reliability. This shows the robustness of the measure to changes in examiners.

Table 5

Reliability studies investigating the inclinometer to measure maximal internal and external rotation of the shoulder joint

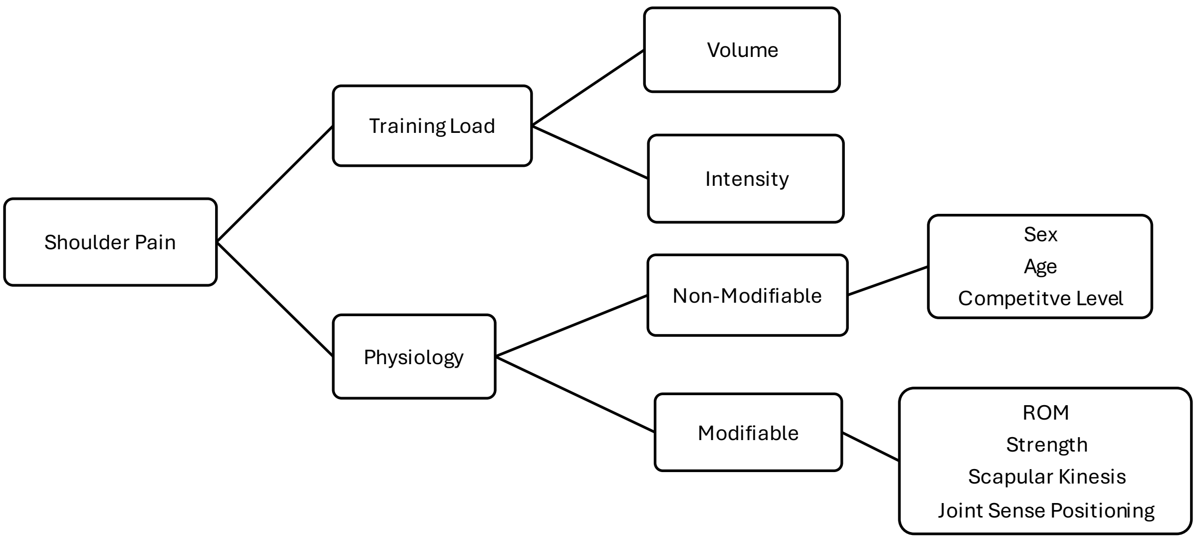
Study	Participants	Measures	Findings	
			ICC	SEM
Awan et al., (2002)	56 unimpaired high school athletes were assessed.	Shoulder IR was measured using a digital inclinometer in 3 different techniques – standard, manual scapular stabilisation and visual.	The ICC values for intra-rater reliability varied between 0.58 to 0.71. For the inter-rater reliability the ICC values ranged between 0.41 and 0.66.	Not reported.
Kolber et al., (2012)	30 asymptomatic adults (12 males and 18 females) were assessed.	Active shoulder ROM was measured using an Acumar digital inclinometer.	The ICC values for intra-rater reliability ranged between 0.83 and 0.94. The ICC values for the inter-rater reliability ranged between 0.58 to 0.95.	The SEM value for the intra-rater reliability ranged between 1.64° to 4.27°. For the inter-rater reliability the values varied between 1.63° and 3.98°.
Cools et al., (2014)	30 asymptomatic adults (15 women and 15 men) were assessed.	Shoulder ROM was measured using two instruments – a plastic Baseline goniometer and an Acumar Digital inclinometer.	The ICC values for intra-rater reliability ranged between 0.85 to 0.99 in the various testing positions and using the different instruments. For inter-rater reliability the ICC values ranged between 0.96 to 0.99.	The SEM was used to calculate the MDC. The MDC varied from 4.02° to 7.48° in the different testing positions and using the different instruments.
Furness et al., (2015)	15 subjects (8 males and 7 females) between the ages of 22 and 48 years were assessed.	Active shoulder IR and ER was measured using a standard gravity-dependent inclinometer and the HALO device in prone and supine positions.	Using the inclinometer to measure the ROM in prone and supine, the ICC value varied between 0.98 and 0.99 and 0.93 and 0.98 respectively. Using the HALO device to measure the ROM in prone and supine, the ICC values varied between 0.97 and 0.99 and 0.97 and 0.98 respectively.	Using the inclinometer in both prone and supine positions, the SEM value varied 1.5 and 2.4. Whereas, using the HALO device in these positions to measure ROM, the SEM values varied between 1.9 and 2.4.
Walker et al., (2016)	17 competitive swimmers aged between 12 and 24 years who completed a	Shoulder IR and ER was measured in supine using a Dualer inclinometer.	For inter-rater reliability, the ICC values for all the shoulder ROM measured ranged between 0.77 and 0.94, except for the left IR the ICC value was 0.65.	For the inter-rater reliability the SEM value ranged between 2° and 5°. The MDC ranged between 5° and 12°.

	minimum of 5 weekly swimming sessions.	For intra-rater reliability, the ICC values for all the shoulder ROM measures ranged between 0.85 and 0.96.	For the intra-rater reliability, the SEM value and MDC was the same as the inter-rater findings.

Note. **ER** – external rotation; **ICC** – intraclass coefficient correlation; **IR** – internal rotation; **MDC** – minimal detectable change; **ROM** – range of motion; **SEM** – standard error of measurement

3. Comparative Research

As stated previously, up to 90 percent of the total propulsive force in swimming is created by the upper extremities placing a great amount of repetitive stress through the shoulder joints. If we observe the model described in figure 3, we acknowledge that Hill, Collins & Posthumus (2015) anticipated that various of factors can contribute to shoulder pain in swimmers. For the purpose of this review, we focus on shoulder ROM, strength, and pain. One approach we can use to determine whether there is a significant difference in these factors is to do a comparative analysis. In this section, comparative studies that have been published in peer-review journals (see table 6 and 7) are critically evaluated and methodological qualities are established to provide some confidence in the conclusions drawn from these studies. To assist with the evaluation of the methodological qualities of this review, the individual quality appraisal scoring for the individual studies are also documented (see appendix 9 and 10). Inherent in comparing specific measures is ensuring certain statistical criteria are met, particularly adequate sample size, strategies to deal with confounding factors, and appropriate statistical tests being used. Some of the studies do not report the statistical criteria, so the reader needs to be cognizant of this limitation and the interpretation of the results herewith.



Note. Adapted from findings of a critical systematic review of risk factors for shoulder pain and injury amongst swimmers by Hill, Collins & Posthumus (2015).

Figure 3. Schematic diagram of risk factors associated with shoulder pain in swimmers

3.1. Delimitations and Limitations

Delimitations refers to the characteristics that limit the scope and describe the boundaries of a study providing clarity and ensuring the study remains focused. A total of 741 swimmers were used in the research cited in table 6 and 7 of which 502(~68%) were females. In terms of age, most studies used athletes in their teens or twenties, two studies included a younger age group of 8 to 77 years (Tate et al., 2012) and 11-27 years (Walker et al., 2012). Swimming was the only sport included in this sample. Training status varied from national to club level athletes. The results of the following analysis are most applicable to this demographic.

Limitations refer to the weakness of a study, based on issues that are often out of the researcher's control. Some of the limitations of the studies used in this review relate to the statistical criteria that was previously mentioned. For example, many studies do not account for confounding factors when completing their statistical analysis. It is important to consider confounding factors as they may conceal an actual association or falsely demonstrate an obvious association between variables where no real associations between them exist.

In regard to methodology, some variation was recognised in the equipment used to measure strength goniometer, ultrasound and the testing order (most studies used some form of randomisation). Many researchers have allowed for familiarisation in their studies, except for studies by McLaine and colleagues (2018), Tate and colleagues (2012) and Tate and colleagues (2020). The person who reads this review needs to be judicious about any conclusions made from the analysis given the delimitation and limitations mentioned.

3.2. Comparison between maximal peak torque and shoulder pain

Due to the limited number of studies using an isokinetic dynamometer to measure peak torque of the shoulder amongst swimmers, this review included studies using both an isokinetic and a handheld dynamometer. Majority of the studies assessed maximal shoulder strength in various movements such as flexion, abduction, extension, IR, and ER. However, the reviewers were only interested in the IR and ER strength measures.

Some contrasting findings have been reported on the difference between shoulder strength and shoulder pain. The more recent studies have found no significant difference between maximal peak torque of the shoulder and pain (Boettcher et al., 2020; Harrington, Meisel & Tate, 2014; McLaine et al., 2018). An earlier study by Bak and Magnusson (1997) found no difference in shoulder ER strength and the conventional ratio of concentric and eccentric IR:ER. Subsequent studies with similar population groups favoured these findings as they also found no significant differences between strength ratios (IR: p= 0.91; ER: p=

0.81) (McLaine et al., 2018) and maximal peak torque of ER ($p = 0.71$) or IR ($p = 0.79$) (Harrington et al., 2014).

Although Bak and Magnusson (1997) found no significant difference in maximal ER strength and the conventional ratios when comparing side to side, they did find a significant decrease in both concentric and eccentric IR strength ($p = 0.06$; $p = 0.07$ respectively) and a significantly greater functional ratio of eccIR:conIR ($p = 0.04$) when comparing side to side and pain was present. When comparing between an injured group and a control group, the conventional ratio of both concentric ER:IR and eccentric ER:IR were significantly higher ($p = 0.02$; $p = 0.02$ respectively). Additionally, the functional ratio of eccER:conIR between the injured and control groups indicated a significantly increased ratio amongst the injured swimmers ($p = 0.02$). Although the study by Tate and colleagues (2012) also found significant strength differences in maximal IR strength amongst swimmers, these findings were measured in the 12 to 14 year old group. On the contrary, Drigny and colleagues (2020) stated that the ROC curves for peak torque ratios to predict the risk of injury showed that conventional eccIR:eccER and functional eccER:conIR ratios less than 0.68 were indicative of a significant injury risk ($p < 0.05$).

Table 6
Comparison between shoulder maximal peak torque and shoulder pain in swimmers

Study	Participants	Assessment	Findings (*p*-value)	Quality of Study Level of Evidence for Effectiveness
Bak et al., (1997)	15 swimmers from the Danish National team between the ages of 15 and 25 years with and without shoulder pain	IR and ER isokinetic strength was assessed using the KinCom dynamometer. Shoulder flexion and abduction strength was measured using an HHD.	There was lower concentric (p = 0.06) and eccentric (p = 0.07) IR strength in the painful shoulder in comparison to the pain-free shoulder. Also, the functional eccER:conIR strength ratio was greater on the painful shoulder side than the pain-free side (p = 0.04). There was no significant difference in the ER strength measure and the conventional concentric and eccentric ER:IR ratios.	3.c
Tate et al., (2012)	236 competitive female swimmers aged 8-77 years with and without shoulder pain	Core endurance - side bridge test, prone bridge test, and closed kinetic upper extremity stability test PROM - inclinometer Muscle force production of IR, ER, and horizontal abduction in prone - HHD Pectoralis minor muscle length – PALM meter Scapular dyskinesis test	Between ages 8 and 11 there was only a significant difference in middle trapezius strength between those swimmers with and without pain (p= 0.05). Between ages 12 and 14 there was only a significant difference between internal rotation strength amongst the symptomatic and asymptomatic swimmers (p= 0.05).	4.b
Harrington et al., (2014)	37 NCAA Division I female swimmers with and without shoulder pain	Scapular depression and adduction, scapular adduction, IR, and ER measured using an HHD. Core endurance measured with a side and prone bridge.	No significant difference in IR (p= 0.79) and ER strength (p= 0.71)	4.b

McLaine et al., (2018)	85 swimmers without a recent history of shoulder pain	Shoulder flexion, extension, IR, and ER strength were measured using an HHD.	There was a significant difference in strength between the male and female groups (*p*< 0.002), but no significant difference between dominant and non-dominant side except for extension strength in males (*p*< 0.05). Swimmers with a history of shoulder pain did not show a significant difference in strength or strength ratios compared to those without pain (IR: *p*= 0.91; ER: *p*= 0.81).	4.b
Boettcher et al., (2020)	68 elite swimmers (16 years old or ≤ from both sexes)	Maximal shoulder IR and ER strength were measured using an HHD.	There was a significant difference between male and female IR strength (*p*= 0.002) but not for ER strength (*p*= 0.427). There were no significant differences in strength between hand dominance (*p*≥ 0.547) and pain status (*p*≥ 0.755). There are no significant associations between pain status and any shoulder strength parameters (*p*≥ 0.107).	3.e
Drigny et al., (2020)	18 adolescent elite swimmers without current or recent (<1 month) shoulder injury with time lost from sport participation or unable to do isokinetic test.	IR and ER shoulder strength measured using Con-Trex isokinetic dynamometer.	Both conIR and eccIR PTs were significantly greater in male than in female swimmers (*p*< 0.05). The years of practice explained a significant proportion of variance in the PTs under all conditions (*p*< 0.01) and in the functional eccER:conIR ratio (*p*< 0.05). The ROC curves for the PT ratios as predictors of the risk of shoulder injury IR. There was a significant relative risk when the participant had eccER:conIR < 0.68 (*p*< 0.05).	3.e

Note. **conER** – concentric external rotation; **conIR** – concentric internal rotation; **eccER** – eccentric external rotation; **eccIR** –eccentric internal rotation; **ER** – external rotation; **HHD** – handheld dynamometer; **IR** – internal rotation; **LT** – lower trapezius; **NCAA** – National Collegiate Athletic Association; **PALM** – palpation meter; **PROM** – passive range of motion

3.3. Comparison between maximal range of motion and shoulder pain

It has been proposed by Hill and colleagues (2015) that shoulder range of motion may be a modifiable physiological risk factor associated with shoulder pain in swimmers and is therefore of interest in this review. The studies included use various assessment tools to measure shoulder range of motion, for example an inclinometer, a goniometer, a digital level, and ultrasound.

To date, previous studies have examined the association between shoulder ROM and pain in swimmers. Three studies have found a significant difference in ROM amongst swimmers with shoulder pain. Walker and colleagues (2012) found a significant assocation between significant interefering pain and swimmers with both high and low external rotation ROM (p= 0.015) and met the multivariate model inclusion criteria for significant shoulder injury (p= 0.07). These findings were similar to that of Mise and colleagues (2022) where they found that external rotation is significantly decreased amongst those swimmers with pain (p= 0.02). To further support these positive findings, Tate and colleague (2012) reported a significant difference in passive range of motion amongst swimmers ages 8 to 11 years (flexion: p= 0.02; IR: p= 0.05). Conversely, there was no significant difference in ROM between the age 12 years to masters.

Other previous studies have failed to demonstrate a statistically significant difference in ROM amongst swimmers with shoulder pain. Earlier studies by Beach and colleagues (1992) and Bak and Magnusson (1997) found no significant difference in shoulder ROM (p >0.001). A more recent study by Harrington and colleagues (2014) further strengthens these previous findings as they also found no significant difference in ROM on the dominant side (ER: p= 0.40; IR: p= 0.21) nor on the non-dominant side (ER: p= 0.76; IR: p= 0.16). A multiple regression analysis by Holt and colleagues (2017) showed no association between current pain or history of pain with humeral torsion or any ROM changes (p= 0.46).

3.4. Summary of Comparison Research

These findings provide insight into whether there is a relationship between maximal shoulder strength and range of motion and pain amongst swimmers. Given the delimitations, limitations, and the variety of objective measures used to assess these variables, it is challenging to establish any association between a change in shoulder strength and ROM and pain with any real certainty from the studies reviewed in this section. Although comparative research attempts to discover a causal relationship between variables, it is fundamentally flawed by confounding factors such as sex, history of injury, training load, and the level of experience having various effects on the statistical model.

Table 7

Comparison between maximal range of motion and shoulder pain in swimmers

Study	Participants	Assessment	Findings (*p*-values)	Quality of Study Level of Evidence for Effectiveness
Beach et al., (1992)	32 swimmers (28 division I collegiate swimmers and 4 club swimmers).	Shoulder flexibility was measured using a goniometer. Strength and endurance ratios were measured bilaterally with a Cybex II isokinetic dynamometer and the upper body exercise table.	There was no significant correlation between shoulder flexibility, strength ratios, and shoulder pain ($p > 0.001$). A multiple regression analysis of 0.78 was found for the combination of ER and abduction endurance ratios to shoulder pain were significant ($p \leq 0.001$).	3.e
Bak et al., (1997)	15 swimmers from the Danish National team between the ages of 15 and 25 years with and without shoulder pain	Shoulder flexion and abduction strength was measured using an HHD. ROM was also assessed; however, the measuring tool was not stated.	Although the IR ROM was reduced in the painful shoulders in comparison to the pain-free swimmers, this difference was insignificant ($p = 0.14$). There was no difference in the ER ROM.	3.c
Tate et al., (2012)	236 competitive female swimmers aged 8-77 years with and without shoulder pain.	Core endurance - side bridge test, prone bridge test, and closed kinetic upper extremity stability test PROM - inclinometer Muscle force production of IR, ER, and horizontal abduction in prone - HHD Pectoralis minor muscle length – PALM meter Scapular dyskinesis test	There was a significant difference in PROM shoulder flexion ($p = 0.02$) and IR ($p = 0.05$) amongst swimmers aged 8 to 11. There were no significant differences in the PROM measures for swimmers aged 12 to masters ($p > 0.01$).	4.b

Walker et al., (2012)	74 competitive swimmers from both sexes aged 11 to 27.	Active shoulder IR and ER at 90° abduction was measured in supine using a Dualer inclinometer. Shoulder laxity was measured in prone at 90° abduction using an arthrometer. Anterior-posterior translation was applied to the shoulder joint when it was measured.	ER was significantly associated with significantly interfering shoulder pain (*p*= 0.015) and met the multivariate model inclusion criteria for significant shoulder injury (*p*= 0.07). Both ER ROM (SIP: *p*= 0.008; SSI: *p*= 0.02) and previous shoulder injury history (SIP: *p*= 0.02; SSI: *p*= 0.001) were significant independent predictors of shoulder injury.	3.e
Harrington et al., (2014)	37 NCAA Division I female swimmers with and without shoulder pain	PROM for shoulder IR and ER at 90° abduction using a digital inclinometer.	On the dominant arm there is no significant differences in ROM between those swimmers with and without shoulder pain (ER: *p*= 0.40; IR: *p*= 0.21). On the non-dominant arm there is also no significant differences in ROM between swimmers (ER: *p*= 0.76; IR: *p*= 0.16)	4.b
Holt et al., (2017)	70 elite Australian swimmers from both sexes and are ≥16 years old.	Humeral torsion was measured in supine using a non-invasive ultrasound technique. IR and ER shoulder PROM was measured in supine and AROM was measured in both supine and prone using digital photographs.	There was a significant main effect between IR and hand dominance (*p*= 0.046) and ER and hand dominance (*p*= 0.015). There were no differences between dominant and non-dominant shoulders for any individual rotation ROM measure (*p*≥ 0.120). IR PROM measured significantly greater than IR AROM (*p*< 0.001). ER PROM also measured significantly greater than ER AROM (*p*< 0.001). Multiple regression analysis showed no association between current shoulder pain or history of shoulder pain with humeral torsion or any shoulder ROM variables (*p*= 0.46).	3.e

Tate et al., (2020)	30 collegiate swimmers aged 18 or older from a division III university.	Passive shoulder IR, ER, and HADD were measured using a Precise Digital Level/Protractor digital. ROM was measured at three different times (T1 = week 3; T2 = week 8; T3 – week 20).	The ER ROM on the left shoulder was significantly greater from T1 to T2 (p= 0.014) and T1 to T3 (p= 0.005). However, there was no significant change on the right shoulder (p= 0.7). The IR ROM on left shoulder was significantly less from T1 to T3 (p= 0.0001) and between T2 and T3 (p= 0.004). On the right shoulder IR ROM was significantly less between T1 and T2 (p= 0.0001), T1 and T3 (p= 0.0001), and T2 and T3 (p= 0.009). HADD on the left was significantly reduced between T1 and T2 (p= 0.0001), T1 and T3 (p= 0.0001), and T2 and T3 (p= 0.011). For HADD on the right, there was a significant decrease in ROM between T1 and T2 (p= 0.0001) and T1 and T3 (p= 0.001).	3.e
Mise et al., (2022)	76 competitive swimmers from both sexes with a mean age of 14 in Japan.	Maximal shoulder IR and ER were measured with the elbow joint at 90° flexion and shoulder at 90° abduction using goniometry.	For males, the ER was significantly lower in those with shoulder pain than those without pain (p= 0.02). For females whose average distance of swimming per session longer had significantly more pain (p= 0.02).	3.e

Note. **AROM** – active range of motion; **ER** – external rotation; **HADD** – horizontal adduction; **HHD** – handheld dynamometer; **IR** – internal rotation; **NCAA** – National Collegiate Athletic Association; **PROM** – passive range of motion; **ROM** – range of motion; **SIP** – significant interfering shoulder pain; **SSI** – significant shoulder injury

4. Conclusions and Future Research Guidance

This review set out to critically evaluate the reliability of an isokinetic dynamometer to measure shoulder strength and an inclinometer to assess shoulder ROM. Additionally, the research investigating whether there is a difference between shoulder strength, ROM, and pain in swimmers was also critiqued. Given the limitations, it is challenging to draw a conclusion with any great certainty that changes in shoulder strength and ROM contributes to shoulder pain amongst swimmers. The model by Hills and colleagues (2015) is a simple illustration of the various influential factors on shoulder pain. Also given the high prevalence of shoulder pain reported amongst swimmers, higher quality correlational studies need to be done to further explore these influential factors on shoulder pain. Future studies must ensure that an inclusion criteria has been made clear and that strategies to address confounding factors during data analysis are in place.

The research presented in this review showed that an isokinetic dynamometer and an inclinometer can be effectively used by to measure an individual's concentric and eccentric strength and ROM within a session by different examiners and between different sessions following at least one familiarisation session for the eccentric contraction. Although, there is more variance in the observed scores which may be attributed to poor test design rather than an examiner's ability. It is essential to determine the accuracy of these tools to measure shoulder strength and ROM in swimmers. As previously stated, these factors can potentially contribute to shoulder pain in swimmers and therefore need to be reliable in order for researchers to draw trustworthy and accurate conclusions and make validated recommendations. Future research around reliability studies must ensure adequate blinding of the examiners to the results and clinical information of the participants and that the order of testing is randomised between sessions to limit the risk of potential bias. Also, future studies need to ensure that the time interval between the repeated measures are compatible with the stability of the variable being measured to limit a carry-over effect. Addressing these limitations, there is a possibility that the precision in the scores of the variables may improve allowing for more reliable and interpretable findings.

In addition, the study by Drigny and colleagues (2020) is the first to consider a longitudinal prospective study design to investigate the causal nature of the shoulder strength imbalance and injury. It is essential to acknowledge the limited number of injuries, the need for replicating this important work, and conducting an intervention study to determine whether improving the proposed factors do in fact decrease shoulder injuries in practice.

CHAPTER 3: Inter- and Intra-Session Reliability of Shoulder Range of Motion and Strength in Swimmers

Abstract

Background

Range of motion (ROM) and strength assessments are essential in the clinical environment to monitor patient status and progression over time. Such assessments help to identify risk factors for developing shoulder pain, particularly in the athletic population. The majority of studies that have assessed ROM in athletic populations have used the supine or seated positions. To date, no studies have assessed ROM in a prone position in swimmers. Also, isokinetic dynamometry is an established tool to measure joint strength and is regularly used as a gold standard for other strength evaluations. Though there is extensive research on isokinetic dynamometers to measure concentric and eccentric shoulder strength, there is limited research within the swimming population.

Aim

The present study aims to evaluate inter- and intra-session reliability of the i) inclinometer to measure shoulder rotational range of motion in prone position and the ii) Humac Norm isokinetic dynamometer to assess concentric and eccentric shoulder strength amongst swimmers.

Methods

Six female (average age 21.3 ± 4.6) and four male (average age 21.5 ± 2.96) swimmers completed experimental protocols on a Humac Norm isokinetic dynamometer and inclinometer. For the inclinometer, the participants were lying prone on a plinth with their arm at 90° abduction, the forearm at 90° flexion and a neutral wrist. A Humac Norm isokinetic dynamometer was used to assess concentric and eccentric peak torque during shoulder internal and external rotation. Relative reliability was determined by intraclass correlation coefficient (ICC). Absolute reliability was quantified by standard error of measurement (SEM) and the coefficient of variation (CV). Differences across trials or within a trial were analyzed with paired *t* tests.

Results

The inter-session relative reliability was moderate to excellent for both assessment tools where the inclinometer was shown to be more reliable (ICC: 0.69-0.98; CV: 4.80-19.70) than the Humac Norm isokinetic dynamometer (ICC: 0.60-0.99; CV: 6.80-60.50). The absolute reliability was less than adequate with SEM varying between 0.00 to 7.20 for the Humac Norm isokinetic dynamometer and 1.71 to 5.36 for the inclinometer. The intra-session relative reliability was excellent for both measuring tools with ICC ranging between 0.98 to 1.00. Absolute reliability was acceptable with the SEM values reported between 0.00

and 1.84. The Humac Norm isokinetic dynamometer (ICC: 0.99 – 1.00; CV: 2.20-8.20; SEM: 0.00-1.31) was shown to be more reliable than an inclinometer (ICC: 0.98-1.00; CV: 1.50-19.80; SEM: 0.00-1.45) when used numerous times within a session.

Conclusion

Both assessment tools showed acceptable reliability for clinical use. The higher intra-session reliability highlighted the importance of a familiarization session prior to the trials of testing.

Introduction

The changes in the status of patients over time are routinely assessed by clinicians and researchers. Strength and range of motion (ROM) assessments are essential for several athletic populations. Such assessments help the diagnosis of shoulder injuries or pathologies, assess the progression and effectiveness of treatment, and help to quantity the amount of change in movement quality and force produced over time (Streiner & Norman, 2008; van de Pol, van Trijffel & Lucas, 2010; Stark et al., 2011). Moreover, determining objective measures of ROM and strength is vital in identifying risk factors for shoulder pain, especially in the athletic population (Byram et al., 2010; Shanley et al., 2012). Hence the importance of establishing accurate and reliable objective measures to assess the functional status of the shoulder joint. Generally, shoulder ROM and strength are considered to be the necessary measures to evaluate shoulder function besides self-reported outcome scores and subjective findings (Roddey, Cook, O'Malley & Gartsman, 2005; Ginn, Cohen & Herbert, 2006; Rudiger, Fuchs, von Campe & Gerber, 2008).

It is worthwhile to recognize that the shoulder joint can be assessed in a position that is relevant and specific to the athlete. When considering swimming, the athlete spends the majority of their training session in a prone position regardless of their stroke specialization, therefore, considering a prone shoulder ROM assessment could be justified. Although there is a substantial amount of literature reporting on shoulder ROM amongst swimmers, current research is limited to assessments in predominantly supine (Beach, Whitney & Dickoff-Hoffman, 1992; Harrington, Meisel & Tate, 2014; Mise et al., 2023; Tate et al., 2012; Walker et al., 2012; Tate et al., 2020). Prior to completing a physical assessment of the shoulder in the swimming population, a reliable protocol for evaluating ROM in prone needs to be established. Competitive swimmers can swim up to 14 000m a day which equates to over 2500 shoulder rotations (Scovazzo et al., 1991) hence the importance of adequate shoulder rotation. Although there are various ways to assess ROM, an inclinometer seems to be superior as it can be calibrated based on the universal constant of gravity enabling the starting position to be consistently identified and repeated (Lea & Gerhardt, 1995). Additionally, ROM can be measured both actively and passively, however, active ROM is thought to be more reliable as it does not rely on the examiner's ability to determine the end feel of the joint (Muir, Corea & Beaupre, 2010). To date, there have been no studies investigating the reliability of using an inclinometer to assess swimmers' shoulder internal and external rotation in prone and within a swimming population.

The propulsion of a swimmer is predominantly generated by the upper body, especially the shoulder internal rotators and adductors (Batalha et al., 2013; Weldon & Richardson, 2001; West, Sole & Sullivan, 2005). Consequently, these muscles become stronger and hypertrophied unlike their antagonists which can lead to muscle imbalances

(Batalha et al., 2013). An adequate muscle balance is the basis of joint stabilization (Mulla et al., 2019). The ratio between internal and external rotator strength is commonly used to assess the proportional relationship between agonist and antagonist muscles (Collado-Mateo et al., 2018). Currently, isokinetic dynamometry is considered to be a valid tool to assess muscle strength and is often used as gold standard for other strength evaluations (Dvir, 1996; Pereira et al., 2019; Stark et al., 2011, van Dyk et al., 2016). Due to the constant angular velocity and accommodating resistance, the maximal force production of a muscle group can be assessed throughout a prescribed ROM (Perrin, 1993 & Perrin, 1994). Although there is extensive research investigating concentric and eccentric muscle strength around the shoulder joint, research within the swimming population is scarce. Moreover, limited studies utilize isokinetic devices and even less consider the functional ratio.

Methods

Purpose

This study investigated the inter- and intra-session reliability of the inclinometer to assess maximal active internal and external range of motion of the shoulder joint in prone. Also, the reliability of using a Humac NORM to assess maximal peak torque of the shoulder internal and external rotators during concentric and eccentric contractions was investigated. Testing was completed during the competitive season.

Participants

Six female (average age 21.3 ± 4.6) and four male (average age 21.5 ± 2.96) swimmers from various levels volunteered to participate in this research. All participants were healthy (no known medical conditions as determined by a health questionnaire), had no previous shoulder surgery or shoulder injuries unrelated to swimming, and had no history of cervical and thoracic pathology. The participants all swam a minimum of 3-5 sessions a week for the past six months. Most of them were national swimmers with the exception of one participant. The procedures of this study were approved by the Auckland University of Technology Ethics Committee. Participants were informed of the risks and benefits of partaking in the study and signed informed consent was gained.

Methodology

All participants completed two sessions on separate days which lasted approximately 30 minutes. The testing sessions were completed 1-2 weeks apart. Both ROM and strength measures were measured by a qualified physiotherapist with eight years of experience in musculoskeletal physiotherapy. The data collected from both testing sessions was used for inter-session reliability. The data from session two was used for intra-session reliability.

The active maximal shoulder range of motion was assessed using an inclinometer in a prone position. The participants were in prone with the arm being assessed over the edge of a plinth. The arm was taken into 90° abduction, the forearm flexed to 90°, and the wrist placed in neutral position (Clarkson, 2005). The angle of abduction was confirmed using a goniometer. A rolled towel was placed under the upper arm so that the humerus is visually in line with the acromion process to ensure a neutral horizontal position of the arm. Participants were instructed to actively rotate their arm as far as possible whilst light pressure was placed over the lateral epicondyle to ensure pure rotation. At the end of the available ROM, the inclinometer was placed on the anterior forearm adjacent to the radial styloid and the ROM measurement was taken. The examiner visually monitored for any thoracic extension or scapular retraction and corrected this with verbal cueing (appendix 11).

Participants were secured to a Humac Norm dynamometer (Lumex, Ronkonkoma, NY, USA) to evaluate the strength of a maximal isokinetic concentric and eccentric contraction of the shoulder internal and external rotators of both arms. The dynamometer was set up with the humerus at 90° forward flexion and 45° abduction (in the scapular plane), the elbow joint flexed to 90°, and the wrist in neutral. The elbow was placed in the elbow stabilizer pad and fixated by a velcro strap so that the humerus (the shoulder's axis of rotation) was in line with the dynamometer's axis of rotation (Habets et al., 2018). The ROM of the test was individualized depending on the participant's midrange and where they felt comfortable. The ROM for each participant was recorded and kept the same on both sides and for the re-test. To minimize any trunk movement, the trunk was secured by two straps across the chest and clipped together around the hips. A fixed sequence of testing was chosen due to practical considerations. The concentric followed by the eccentric contractions were performed at an angular velocity of 120°/s (Habets et al., 2018). During the re-test, the participants started with the same side as the initial test. Both concentric and eccentric tests kept the same protocols. The participants completed 3 sets of each contraction. The initial set consisted of 5 repetitions with a 25 second rest and was performed at 75% of maximal effort. The following 2 sets consisted of 4 repetitions with 45 seconds rest between each set and were performed at 80% and 100% of maximal effort respectively. During the eccentric testing, the participants were given verbal cues of “push” and “pull”.

Statistical Analysis

All data were recorded as means and standard deviations. The ROM was measured in degrees (°) and maximal strength (peak torque) was measured in newton-meters (Nm). Relative and absolute reliability indices were calculated under Will Hopkins (2016) recommendation. The intraclass correlation coefficient (ICC) and coefficient of variation (CV) were used to evaluate the relative reliability. Particularly, the $ICC_{2,1}$ (two-way mixed, single measures) with 95% confidence intervals was used (Shrout & Fleiss, 1979). ICC values less than 0.5 was indicative of poor reliability, 0.5-0.75 moderate reliability, 0.75-0.9 good reliability, and over 0.90 was indicating excellent reliability (Koo & Li, 2016). A CV value of 20 or less was considered acceptable (Reed, Lynne & Meade, 2002). The Standard Error of Measurement (SEM) was calculated to measure absolute reliability. The SEM was calculated as $SEM = SD\sqrt{1-ICC}$ where SD is the mean SD of both repetitions. A SEM value between 0.8-0.9 was considered an adequate demonstration of acceptable reliability (Tighe, McManus, Dewhurst, Chis & Mucklow, 2010).

Results

Table 8 summarizes the inter-session reliability analysis of the inclinometer and Humac Norm isokinetic dynamometer with ICC and CV values and SEM. ICC values ranged between 0.60-1.00 varying from moderate to excellent reliability for both devices. The CV values ranged between 4.80-60.50 indicating a wide range of variability between tests. Though, the CV values for the inclinometer were more acceptable (4.80-19.70) than the Humac Norm (6.80-60.50). Furthermore, the SEM values for both devices ranged from 0.00-7.20, which further indicates a less adequate demonstration of acceptable reliability. Peak torque (PT) of concentric ER on the right, eccentric ER on the left, and eccentric IR on the left showed excellent reliability with a lower CV value (8.00, 7.20, 6.80 respectively) and more acceptable SEM values (0.00, 1.35, 1.28 respectively). The inclinometer was shown to be more reliable than the Humac Norm isokinetic dynamometer with the ICC values varying from 0.69 to 0.98 and CV values within an acceptable range (4.80-19.70). The SEM values varied (1.71-5.36). The use of an inclinometer in prone to assess maximal IR, specifically on the left, was shown to be most reliable (ICC: 0.98; CV: 15.00; SEM: 1.71).

Table 9 showed the intra-session reliability of the inclinometer and Humac Norm isokinetic dynamometer. The ICC values for both devices ranged from 0.98 to 1.00 indicating excellent reliability. The CV values varied from 1.50-19.80, also showing adequate reliability. Likewise, the SEM values ranged from 0.00-1.84 demonstrating acceptable reliability of both devices. The Humac Norm isokinetic dynamometer (ICC: 0.99 – 1.00; CV: 2.20-8.20; SEM: 0.00-1.31) was a more reliable assessment tool than the inclinometer (ICC: 0.98-1.00; CV: 1.50-19.80; SEM: 0.00-1.45) when used multiple times within a session.

Table 8

The inter-session reliability of the Humac Norm and Inclinometer to assess maximal peak torque and range of motion of the shoulder joint

Variables	Trial 1		Trial 2				
	Mean	SD	Mean	SD	CV	ICC	SEM
PT con ER on L)	25.75	13.40	25.05	8.88	60.50	0.60	7.05
PT con ER on R)	29.05	13.56	27.48	11.02	8.00	1.00	0.00
PT con IR on L)	33.84	16.16	33.00	14.54	57.50	0.78	7.20
PT con IR on R)	38.58	19.03	40.05	21.96	17.00	0.99	2.05
PT ecc ER on L)	58.60	14.25	54.83	12.82	7.20	0.99	1.35
PT ecc ER on R)	60.80	19.44	53.09	15.85	15.70	0.93	4.67
PT ecc IR on L)	47.45	12.43	47.41	13.08	6.80	0.99	1.28
PT ecc IR on R)	49.08	15.09	49.13	18.53	23.00	0.82	7.13
ROM ER on L)	101.37	10.18	100.33	9.09	4.80	0.69	5.36
ROM ER on R)	106.70	9.46	100.40	8.98	5.90	0.68	5.21
ROM IR on L)	30.50	12.42	32.37	11.82	15.00	0.98	1.71
ROM IR on R)	35.77	13.69	32.70	11.25	19.70	0.95	2.79

Note. **Con** - concentric; **CV** - coefficient of variation; **Ecc** - eccentric; **ER** - external rotation; **ICC** - intraclass correlation coefficient; **IR** - internal rotation; **L** - left; **PT** - peak torque; **ROM** - range of motion; **R** - right; **SD** - standard deviation; **SEM** – standard error of mean (measured in Newton-metres for PT and degrees for ROM)

Table 9

The intra-session reliability of the Humac Norm and Inclinometer to assess maximal peak torque and range of motion of the shoulder joint

Variables	Test 1		Test 2		Test 3				
	Mean	SD	Mean	SD	Mean	SD	CV	ICC	SEM
PT con ER on L)	25.65	9.65	26.69	9.24	25.26	7.95	5.40	1.00	0.00
PT con ER on R)	30.31	11.40	30.13	11.27	29.46	11.78	3.60	1.00	0.00
PT con IR on L)	35.69	15.06	35.78	15.71	36.31	13.94	5.80	1.00	0.00
PT con IR on R)	40.29	23.60	40.98	24.05	41.32	24.65	8.20	1.00	0.00
PT ecc ER on L)	54.50	14.96	54.79	15.24	53.42	12.95	4.20	1.00	0.00
PT ecc ER on R)	50.51	13.09	50.61	13.41	51.14	14.32	6.40	1.00	0.00
PT ecc IR on L)	52.54	14.90	50.29	14.43	49.51	9.87	7.10	0.99	1.31
PT ecc IR on R)	51.67	22.67	55.09	24.85	50.15	18.07	2.20	1.00	0.00
ROM ER on L)	101.8	11.67	103.0	10.43	100.30	8.59	2.40	0.98	1.45
ROM ER on R)	103.8	7.74	106.4	8.87	106.90	8.81	1.50	1.00	0.00
ROM IR on L)	31.40	13.34	31.30	12.54	28.60	12.67	19.80	0.99	1.29
ROM IR on R)	37.80	13.51	35.80	12.94	35.70	12.50	11.90	0.98	1.84

Note. **Con** - concentric; **CV** - coefficient of variation; **Ecc** - eccentric; **ER** - external rotation; **ICC** - intraclass correlation coefficient; **IR** - internal rotation; **L** - left; **PT** - peak torque; **ROM** - range of motion; **R** - right; **SD** - standard deviation; **SEM** – standard error of mean (measured in Newton-metres for PT and degrees for ROM)

Discussion

This study aimed to evaluate the inter- and intra-session reliability of shoulder range of motion and strength in swimmers using an inclinometer and a Humac Norm isokinetic dynamometer. To our knowledge this is the first study to determine the reliability of an inclinometer to assess shoulder rotational ROM in swimmers in prone. Additionally, only two prior studies (Bak & Magnusson, 1997; Drigny et al., 2020) have used isokinetic dynamometers to assess maximal concentric and eccentric peak torque in swimmers; however, these studies did not use the Humac Norm isokinetic dynamometer. Therefore, this study is the first to evaluate the reliability of the Humac Norm isokinetic dynamometer to measure maximal concentric and eccentric peak torque in swimmers. The main findings showed that both the inclinometer and Humac Norm isokinetic dynamometer were reliable tools to assess shoulder ROM and concentric and eccentric peak torque in swimmers.

Inter- and intra-session reliability is vital to ensure correct interpretation of the measurement results within a clinical environment. Various statistical methods have been used to measure the reliability of assessment tools. A review by Zaki and colleagues (2012) reported that the intraclass correlation coefficient (ICC) was the most popular method to evaluate reliability. Other methods used to assess reliability include means comparison, Bland-Altman limits of agreement (LoA), and Pearson's correlation coefficient (*r*).

The present study used ICC to determine relative reliability of the two assessment tools - i.e. the Humac Norm isokinetic dynamometer and the inclinometer. ICC values range from 0.00 to 1.00. Generally, ICC close to 1.00 shows high similarity between values from the same group. Whereas ICC close to 0.00 means that values from the same group are not similar. Koo and Li (2016) proposed that the reliability of a certain assessment tool is considered good if the computed ICC value is greater than 0.75. The ICC value is a proportional index of reliability where the error variance is compared to the between-subject variance (van Meeteren, Roebroeck & Stam, 2002); however, in a clinical setting proportional reliability is not informative. Therefore, absolute reliability focusing on the error variance can be used to interpret two consecutive measures in individuals. Thus, the standard error of measurement (SEM) was calculated in this study. SEM is indicative of errors within the test procedures and can be dependent on the action, side, or direction of the movement being assessed. Consequently, ensuring a standardized protocol for all measurements is essential for reliability. Other potential factors of error that can influence the reproducibility of test findings and contribute to reduced consistency of the results include but not limited to the equipment used, data processing, the examiners, and participant-linked variations (Dvir, 1995).

The Reliability of the Inclinometer

While there are several ways to measure shoulder range of motion (ROM) in the clinical setting, the most used tools are the goniometer and inclinometer (Roy & Esculier, 2011). Earlier research has documented the use of an inclinometer to assess active shoulder internal (IR) and external rotation (ER) (Green, Buchbinder, Forbes, & Bellamy, 1998; Awan et al., 2002; Hoving et al., 2002; Kolber, Slatzman, Beekhuizen & Cheng, 2009; Kolber et al., 2011; Kolber & Hanney, 2012; Cools et al., 2014; Furness et al., 2015; Walker et al., 2016). Although only two of these studies investigated ROM in a prone position (Kolber et al., 2009; Kolber & Hanney, 2012). The most recent study by Furness and colleagues (2015) also investigated the reliability of an inclinometer and HALO device in both prone and supine position. It is more logical to assess ROM in a sport-specific position.

An aim of this study was to determine the inter- and intra-session reliability of an inclinometer to assess active shoulder internal and external rotation amongst swimmers in a prone position. This position was selected as swimmers spend majority of their time in the pool in prone. Also, three out of the four strokes are done in a prone position. Previous studies reported moderate to excellent inter-rater (ICC: 0.58-0.99) and intra-rater (ICC: 0.58-0.99) reliability of the inclinometer (Awan et al., 2002; Kolber et al., 2011; Cools et al., 2014; Furness et al., 2015; Walker et al., 2016). One study did report poor to moderate inter-rater reliability (ICC: 0.41-0.66) (Awan et al., 2002). However, the present study only documented the intra-rater reliability between sessions and within a session. 1. The findings of intra-session reliability are consistent with that of Furness et al. (2015) where the ICC ranged from 0.93 to 0.99. The inter-session reliability was slightly higher (ICC: 0.82-0.96) in Furness et al. (2015) study than in the present one (ICC: 0.68-0.98). The study by Walker and colleagues (2016) was the only study to measure the reliability of an inclinometer in swimmers; however, the measuring position was in supine. It is also important to acknowledge that the participants in this present study were both symptomatic and asymptomatic, whereas in all the previous studies the participants had no shoulder pain.

The Reliability of the Humac Norm Isokinetic Dynamometer

The review by Edouard and colleagues (2011) highlights the limited data available on the inter-session reliability of isokinetic dynamometry of the shoulder joint. Only five studies that were identified had similar testing procedures to the current study (Dauty et al., 2003; Kimura et al., 1996; Frisiello et al., 1994; Kramer & Ng, 1996; Malerba et al., 1993). The specific protocol chosen for this study was a preset testing position for measuring shoulder internal and external rotators peak torque on the Humac Norm isokinetic dynamometer. Participants were in a seated position with the shoulder in 45° abduction in the scapular plane and the testing speed was set to 120°per second. Peak torque during concentric and eccentric contractions were assessed. Methodologically high-quality studies have supported this position of testing (Dauty et al., 2003; Davies, 1992; Codine et al., 2005; van Meeteren et al., 2002; Plotnikoff & MacIntyre, 2002). Movement in the scapular plane allows the glenohumeral joint to be near its loose-packed position optimizing the potential for peak torque during rotation and it is more physiological, safe, and comfortable for the participants. On average, competitive swimmers complete 63.08 strokes per minute which equates to 1.05 strokes per second (Hyodo, Koga, Sengoku & Wada, 2023). If one stroke is almost 360° of shoulder rotation, the angular velocity of a swimmer's shoulder during the freestyle stroke can be considered as 360° per second. This measure of angular velocity cannot be mimicked by the Humac Norm isokinetic dynamometer, therefore a testing speed of 120° per second was used. This is a favorable velocity due to the challenges and consequences associated with higher speed (Dvir, 1995).

Although there are some studies investigating the reliability of isokinetic dynamometry to assess shoulder strength, there is only one study that considered the swimming population (Collado-Mateo et al., 2018). These researchers used the Biodex dynamometer to assess concentric internal and external rotation at an angular velocity of 60° per second (Collado-Mateo et al., 2018). To our knowledge, this current study was the first to evaluate the inter- and intra-session reliability of the Humac Norm isokinetic dynamometer to measure the concentric and eccentric peak torque of a swimmer's shoulder. We found good to excellent relative inter-session reliability, with ICC values ranging from 0.78 to 1.00 for shoulder rotation during both concentric and eccentric contractions. The only measure which had adequate reliability was concentric external rotation on the left (ICC: 0.60). Our findings were consistent with other studies where their ICC values also varied from 0.69 to 0.97 indicating adequate to excellent reliability (Mandalisdis et al., 2001; Plotnikoff et al., 2002; van Meeteren et al., 2002; Dauty et al., 2003; Edouard et al., 2013; Collado-Mateo et al., 2018; Habets et al., 2018). However, some differences were noted from the studies by Mandalisdis and colleagues (2001) and more recently Edouard and colleagues (2013) who reported reliability for isokinetic dynamometry to assess eccentric contractions was slightly lower. Whereas our study found lower reliability for the concentric contractions on the left side only.

While good to excellent relative inter-session reliability for isokinetic dynamometry has been found, it is still important to consider the coefficient of variation (CV) values. The CV value is a type of measure of dispersion used to gauge the extent of the variability of the data. Depending on the specific contraction type and side of the test, the CV values varied from 4.80 to 60.50. As CV values were not included in other studies, there is nothing to compare our results to. Our results did show an unacceptable CV value for concentric external rotation (CV: 60.50) and internal rotation (CV: 57.50) on the left, and for eccentric internal rotation on the right (CV: 23.00). Despite not being able to compare CV values, a comparison between SEM can be made to determine absolute inter-session reliability and is also considered to be more clinically relevant. Previous studies reported adequate SEM values demonstrating acceptable reliability for isokinetic dynamometry (Mandalisdis et al., 2001; Plotnikoff et al., 2002; Van Meeteren et al., 2002; Dauty et al., 2003; Edouard et al., 2013; Collado-Mateo et al., 2018; Habets et al., 2018). This differs from the findings presented in this study where the SEM values were relatively high varying from 0.00 to 7.20. One possible explanation for this could be the lack of familiarization especially for the eccentric contractions. Eccentric movements are not typical actions in daily life which may contribute to the inter-session variability increasing the measure of error. Also, when comparing the reliability of eccentric contractions in other studies the SEM values were greater than the concentric values (Mandalisdis et al., 2001; Plotnikoff et al., 2002; Van Meeteren et al., 2002; Dauty et al., 2003; Edouard et al., 2013; Collado-Mateo et al., 2018; Habets et al., 2018). This is similar to our findings where the eccentric SEM values varied from 1.28 to 7.13 and the concentric SEM values were from 0.00 to 7.20.

On the contrary to these findings of ICC, CV, and SEM values for the inter-session reliability, intra-session reliability values were notably more reliable. The ICC values ranged from 0.99 to 1.00, the CV values were between 2.20 and 8.20, and the SEM values varied from 0.00 to 1.31. All these values indicated excellent relative intra-session reliability and adequate absolute intra-session reliability. These findings further support the need for a familiarization session prior to formal testing commencing to limit the measurement of error.

Limitations and Future Research

This study did have some limitations that need to be acknowledged. Despite the utmost effort to standardize the protocol for measurement and stabilization, no external fixation was used for reasons of clinical relevance. Also, the end of range during the ROM assessments were determined by subjective criteria rather than objectively controlled. No familiarization sessions prior to testing were completed. Although moderate to excellent inter-session reliability was found for both assessment tools, the values improved with intra-session reliability highlighting the importance for familiarization to get more accurate and consistent values. Lastly, this present study did not measure inter-rater reliability. This needs to be recognized when applying the findings in a clinical setting, especially when there is more than one health professional managing the same patient.

As previously acknowledged, this is the first study to evaluate the inter-session and intra-session reliability of both the inclinometer in prone and the Humac Norm isokinetic dynamometer to assess the ROM and strength of the shoulders in swimmers who have shoulder pain or not. Further research is required to confirm and validate the findings of this study.

Conclusion

The purpose of this study was to identify the inter- and intra-session reliability of the inclinometer and the Humac Norm isokinetic dynamometer to measure the strength and rotational ROM of a swimmer's shoulder. The study found moderate to excellent inter-session reliability and good to excellent intra-session reliability for both assessment tools. Also, the need for at least one familiarization session was highlighted. Clinicians can consider using these assessment methods on swimmers as it is sport-specific and reliable.

CHAPTER 4: Shoulder Strength and Range of Motion in Swimmers with and without Shoulder Pain: A Cross-Sectional Study

Abstract

Background

Shoulder pain in swimmers is very common and can be attributed to the high volume of shoulder rotations during swimming. Also, it has been found that shoulder internal rotators and adductors are the primary muscles to produce the propulsive forces during a stroke (Hibberd & Myers, 2013). Consequently, they become stronger than their antagonists and potentially cause muscle imbalances around the glenohumeral joint. Further, the external rotators act eccentrically to help prevent the anterior translation of the humeral head during a swimming stroke (Gaudet et al., 2018). Though there is extensive research regarding muscle strength and shoulder pain, more specifically in overhead sports, there is limited evidence in the swimming population. There is also no other study investigating shoulder range of motion (ROM) in the prone position in swimmers. This testing position is more sport-specific and has potential to add value to the existing research investigating whether altered ROM can influence shoulder pain in swimmers.

Aim

The present study aims to measure the maximal shoulder internal and external rotation strength (concentric and eccentric) and range of motion in swimmers, and to determine whether there is a difference in these measurements between swimmers who experience shoulder pain and those who do not.

Methods

Seven female (average age 20.86 ± 4.42) and four male (average age 21.5 ± 2.96) swimmers from local clubs participated in this study. They completed experimental protocols on a Humac Norm isokinetic dynamometer and an inclinometer. Both concentric and eccentric maximal shoulder internal and external rotation strength were measured. For the inclinometer, participants were instructed to lie prone on a plinth with their arm abducted to 90°, elbow flexed to 90°, and wrist in neutral.

Results

In the asymptomatic group, no significant difference in strength between side to side was found, regardless of whether it was a concentric or eccentric contraction. Although when comparing concentric with eccentric movements in this group, there was a significant difference between concentric and eccentric external rotation. The swimmers' external rotators were significantly stronger when working eccentrically (Left: p= 0.01, ES = -2.17; Right: p= 0.01, ES= -1.76). Despite these findings, the symptomatic group has no significant difference in strength when comparing the painful and non-painful sides, except when the

internal rotators work concentrically. The non-painful shoulder internal rotators were significantly stronger than the painful side during a concentric contraction (p= 0.05, ES= -0.96). Although there was no significant difference in the functional ratio (eccER:conIR) in the asymptomatic group, in the symptomatic group the ratio was significantly greater for the painful shoulder compared to the pain free side (p= 0.04). No significant difference in range of motion was found regardless of pain being present or not.

Conclusion

There is no difference in shoulder range of motion in swimmers regardless of hand dominance and whether they experience shoulder pain or not. Furthermore, swimmers who do not experience shoulder pain were found to have stronger external rotators when working eccentrically regardless of hand dominance. On the contrary, their internal rotators are stronger during concentric contractions. Despite these findings, swimmers who have painful shoulders had significantly weaker internal rotators on the painful side during concentric movements. Furthermore, in the symptomatic group, the painful shoulder did have a greater functional ratio than the asymptomatic side. This study's findings highlight some of the muscle imbalances (concentric vs. eccentric and painful vs. non-painful side) around the shoulder of swimmers. The functional ratio to compare strength measurements has previously primarily been studied in other overhead and upper limb dominant sports. As this is the second study to use the functional ratio (eccER:conIR) to analyze the shoulder strength of swimmers, further research is needed to improve the validity and reliability of the ratio being used in the swimming community. Additionally, this study is among the few to measure both concentric and, in particular, eccentric shoulder strength in swimmers, hence more studies are required to either confirm or challenge our findings. Future research is needed to validate the findings of the ROM assessment as it is the first study to measure a swimmer's shoulder ROM in prone.

Introduction

Swimming is a unique activity that requires motor skills driven by muscle strength, endurance and control in a non-weight bearing position (Struyf et al., 2017; Wiazewicz & Eider, 2021). The majority of the propulsive forces are primarily generated by the upper body, unlike other sports where the legs initiate and contribute to these forces (Batalha et al., 2020; Pink & Tibone, 2000). Up to 90 percent of the driving force is predominantly produced by the torque of the shoulder (Pink & Tibone, 2000). For the shoulder to produce this torque, several different shoulder motions are involved, particularly in a clockwise and counterclockwise direction with varying degrees of shoulder internal and external rotation and scapular protraction and retraction (Tovin, 2006). Fundamentally, swim strokes place the shoulder joint in extreme ranges of motion whilst a tremendous amount of muscular force is exerted simultaneously (Bak, 2010; Ceccon et al., 2013; Heinlein & Cosgarea, 2010; Tate et al., 2012; Yanai & Hay, 2000).

Shoulder internal rotators and adductors are the main muscle groups to produce the power for propulsion in majority of the strokes (Hibberd & Myers, 2013) which can result in these muscles becoming stronger than their antagonists, thus potentially causing muscle imbalances (Batalha et al., 2013; Weldon & Richardson, 2001; West, Sole & Sullivan, 2005). Moreover, muscle strength changes may occur especially in the internal and external rotators as they assist with performance. Although measuring the absolute strength of the shoulder muscles may be useful in determining the risk of injury or pain in swimmers, developing a balanced strength ratio could be more appropriate (Ramsi et al., 2004) as the rotators of the shoulder contribute to the stability and mobility of the glenohumeral joint particularly in overhead athletes (Batalha et al., 2013; Codine et al., 1997; Ramsi et al., 2004; Wilk & Arrigo, 1993).

Regardless of the stroke specialization during swimming, most of the training involves freestyle. On average, a swimmer will complete 60 000m to 80 000m a week with a stroke count of 8 to 10 per 25m equating to approximately 30 000 shoulder rotations in a week (Heinlein & Cosgarea, 2010). This places an incredible amount of stress on the shoulder. It is with no surprise that the prevalence of shoulder pain in swimmers varies between 40 and 91 percent (Bak, 2010; Matzkin et al., 2016; Sein et al., 2010). It accounts for 20 to 35 percent of swimmers' experiencing time-loss to injury each year (Gaunt & Maffulli, 2012). Determining the contributing factors to shoulder pain in swimmers can potentially aid their rehabilitation and help reduce the time-loss to injury. A clear consensus regarding the etiology of shoulder pain in swimmers is lacking. A previous study by Bak (2010) found an absolute or sudden increase in training volume and poor technique resulting from insufficient muscle strength to be the most common contributor to shoulder pain. On the contrary, a retrospective epidemiological study by Tessaro and colleagues (2017) found no statistical significance between shoulder pain and years of swimming; training frequency, duration, or volume; or current or history of participation in other overhead activities. It is believed that the cause of shoulder pain in swimmers is multifactorial making it challenging to isolate specific contributing factors (Rodeo, 2004; Rupp, Berninger & Hopf, 1995; Wanivenhaus et al., 2012; Weldon & Richardson, 2001; Zemek & Magee, 1996). Some of the modifiable factors that can predispose swimmers to shoulder pain include muscle strength imbalances, altered muscle endurance and coordination, and deficits in glenohumeral mobility (Hibberd & Myers 2013; Struyf et al., 2017). A study by Walker and colleagues (2012) found that adequate rotational ROM is required for correct swimming technique to avoid any shoulder impingement. Previous research has found a significant difference in internal and external rotation ROM in swimmers with shoulder pain or not (Mise et al., 2022; Walker et al., 2012). More specifically, those swimmers whose external rotation ROM measure high (≥100°) or low (≤93°) were more at risk of developing shoulder pain or injury, regardless of swimming training exposure (Walker et al., 2012).

Although there is extensive research examining concentric and eccentric muscle strength in overhead athletes, there are limited studies investigating the internal and external rotation strength using isokinetic dynamometry in swimmers (Bak et al., 1997; Tate et al., 2012; Harrington et al., 2014; McLaine et al., 2018; Boettcher et al., 2020; Drigny et al., 2020), especially those experiencing shoulder pain (Bak et al., 1997; Tate et al., 2012; Harrington et al., 2014; Boettcher et al., 2020). Furthermore, to the best of our knowledge, there is no study measuring shoulder rotational range of motion in prone in swimmers regardless of them being symptomatic or not.

Methods

Purpose

This cross-sectional study aimed to assess the maximal strength of the shoulder internal and external rotators during concentric and eccentric contractions. Additionally, maximal active shoulder internal and external rotation were measured in a prone position. The differences between these strength and ROM measures between swimmers who experience shoulder pain or not was also determined. Testing occurred during the competition season.

Participants

Seven female (average age 20.86 ± 4.42) and four male (average age 21.5 ± 2.96) athletes from local swimming clubs volunteered to participate in this study. The swimmers' competitive levels varied; however, they all swam a minimum of 3-5 sessions a week for the past 6 months as a requirement to take part in this study. All participants were healthy (no known medical conditions verified by a health questionnaire), had no previous shoulder surgeries or injuries unrelated to swimming, and had no history of cervical or thoracic spine pathologies. The procedures of this study were approved by Auckland University of Technology Ethics Committee. Participants were given an information sheet prior to the testing sessions. The testing procedures were also verbally explained to the participants and an opportunity to ask questions prior to the testing was given. The participants gave written informed consent. The Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire and Swimmer Functional Pain Scale (SFPS) (appendix 12) score ≥ 4/10 and a DASH score of > 6/20.

Methodology

Prior to the formal testing, all participants attended a familiarization session which took approximately 30 minutes to complete. All testing sessions were performed between 1-2 hours after a training session. Both the strength and ROM measures were taken during the familiarization session and again at the formal testing session. All the tests were completed by a qualified physiotherapist. Only the data from the formal testing session was analyzed for this study.

A Humac Norm isokinetic dynamometer (Lumex, Ronkonkoma, NY, USA) was used to measure the maximal strength of the shoulder internal and external rotators. Maximal strength during both a concentric and an eccentric contraction was measured. The strength testing was completed on both arms. The arm being measured was set up at 90° forward flexion, 45° abduction (in the scapular plane), 90° elbow flexion, and the wrist was in the neutral position. The elbow was supported by the elbow stabilizer pad and fixated by a velcro strap. This allowed the humerus (the shoulder's axis of rotation) to be in line with the dynamometer's axis of rotation (Habets et al., 2018). The ROM of the tests were individually set depending on what the participant felt comfortable with. The ROM was kept the same for both arms and during the familiarization and formal testing sessions. To minimize any trunk movement, the trunk was secured by two straps across the torso that clipped together over the hips. A fixed sequence of testing was used due to practical considerations. First the concentric contractions were performed followed by the eccentric contractions at a set angular velocity of 120°/s (Habets et al., 2018). During the familiarization and formal testing sessions, the participants started with the same side. Both concentric and eccentric tests kept the same protocols. The testing protocol consisted of 3 sets of each contraction type. The sets consisted of 1) 5 repetitions at 75% of maximal effort with 25 seconds rest, 2) 4 repetitions at 80% of maximal effort with 45 seconds rest, and 3) 4 repetitions at 100% maximal effort with 45 seconds' rest. During the eccentric testing, verbal cues of "push" and "pull" were given.

Maximal active internal and external rotation of both shoulders were assessed in a prone position using an inclinometer (Baseline Bubble 360° inclinometer). The participants were instructed to lie prone on a plinth with their arms over the edge. The arm being tested was placed into 90° abduction with the elbow flexed to 90°, and the wrist in the neutral position (Clarkson, 2005). The angle of abduction was measured using a goniometer. To ensure a neutral horizontal position of the arm, a rolled towel was placed under the upper arm so that the humerus was visually in line with the acromion process. Participants were asked to actively rotate their arm as far as possible whilst the tester placed light pressure over the lateral epicondyle to ensure pure rotation. At the end of the available ROM, the inclinometer was placed on the anterior forearm adjacent to the radial styloid and the ROM was recorded. Any thoracic extension and scapular retraction were visually monitored by the tester and corrected with verbal cueing.

Statistical Analysis

All data are presented as means and standard deviation. Paired *t*-tests were used to compare i) the maximal shoulder strength between side to side and also concentric versus eccentric contractions and ii) ROM measures of swimmers with shoulder pain or not. The magnitude of the differences was determined using the effect size and Cohen's *d* coefficient (Cohen, 1988). This was interpreted as follows: small difference ($0.15 < d < 0.4$), medium difference ($0.5 < d < 0.7$), and large difference ($d > 0.8$). The level of statistical significance was set as $p < 0.05$. To analyze the strength balance of the shoulder rotators, a functional ratio (eccER:conIR) was calculated according to the following equation (Bak & Magnusson, 1997): eccER/conIR.

Results

Table 10 documents the maximal peak torque and ROM of the shoulder joint in swimmers who were asymptomatic with means and standard deviations. The concentric tests revealed a peak torque of 24.38 ± 10.38 and 25.13 ± 13.38 for external rotation and 28.86 ± 17.36 and 33.73 ± 25.30 for internal rotation on the left and right respectively. The eccentric tests showed a peak torque of 28.86 ± 17.36 and 33.73 ± 25.30 for internal rotation and 53.22 ± 16.22 and 54.52 ± 20.01 for external rotation on the left and right respectively. There was no significant side to side difference between maximal peak torque from both concentric and eccentric tests.

Table 11 shows the difference between concentric and eccentric contractions during internal and external shoulder rotation in swimmers with no shoulder pain. No statistically significant differences were found between concentric and eccentric contractions during internal rotation on both the right and the left side. In comparison to internal rotation peak torques, there was a significant difference between the external rotators peak torques during concentric and eccentric contractions on both sides. The external rotators of the shoulder were significantly stronger when working eccentrically than concentrically (R: p= 0.01, ES= -1.76; L: p=0.01, ES= -2.17). No significant difference in the functional eccER:conIR ratio between the left and right side was found (p= 0.70).

Table 10

Maximal peak torque, range of motion, and functional ratio of the shoulder joint amongst swimmers without shoulder pain

Variables	Left		Right			
	Mean	SD	Mean	SD	*p*-value	Effect Size
PT con ER	24.38	10.38	25.13	13.38	0.65	-0.06
PT con IR	28.86	17.36	33.73	25.30	0.31	-0.23
PT ecc ER	53.22	16.22	54.52	20.01	0.71	-0.07
PT ecc IR	45.68	13.16	43.79	14.39	0.47	0.14
ROM ER	100.33	12.51	102.47	7.09	0.55	-0.22
ROM IR	31.47	8.31	29.67	11.67	0.54	0.18
EccER:conIR	1.55	0.97	1.37	0.89	0.70	-

Note. **Con** - concentric; **Ecc** - eccentric; **ER** - external rotation; **IR** - internal rotation; **PT** - peak torque; **ROM** - range of motion; **SD** - standard deviation

Table 11

The difference between maximal peak torque of the shoulder during concentric and eccentric contractions in swimmers without shoulder pain.

Variables	Concentric		Eccentric			
	Mean	SD	Mean	SD	*p*-value	Effect Size
PT ER on L)	24.38	10.38	53.22	16.22	* 0.01	2.17
PT ER on R)	25.13	13.38	54.52	20.01	* 0.01	1.76
PT IR on L)	28.86	17.36	45.68	13.16	0	1.1
PT IR on R)	33.73	25.3	43.79	14.39	0.21	0.51

Note. **ER** - external rotation; **IR** - internal rotation; **L)** - left; **PT** - peak torque; **R)** - right; **SD** - standard deviation; ***** - statistical significance $p \leq 0.05$

Table 12 summarizes the maximal peak torque and ROM of the shoulder joint in swimmers experiencing shoulder pain. An average peak torque for concentric external rotation was 26.30 ± 6.45 on the painful and 29.84 ± 6.57 on the non-painful side. For eccentric external rotation, the peak torque was 37.72 ± 7.57 and 47.89 ± 13.56 on the painful and non-painful side respectively. No statistically significant difference in external rotation strength was found between the painful and non-painful sides for both concentric and eccentric contractions. Similarly, the eccentric test of internal rotation revealed a peak torque of 49.55 ± 12.64 on the painful side and 55.47 ± 20.82 on the non-painful side. There was no significant difference in internal rotation strength during eccentric contractions despite the shoulder being painful or not. On the contrary, internal rotation during a concentric contraction showed a peak torque of 37.72 ± 7.57 and 47.89 ± 13.56 on the painful and non-painful side respectively. The asymptomatic side was significantly stronger than the painful side (p=0.05, ES=-0.96). Furthermore, there was no significant difference in shoulder ROM between the painful and non-painful shoulder during both internal and external rotation movements.

Table 13 presents the difference between concentric and eccentric contractions during internal and external rotation in symptomatic swimmers. Although there was no significant difference in internal and external rotation strength on the asymptomatic side regardless of them contracting concentrically or eccentrically, the external rotators on the painful side were significantly stronger when working eccentrically than concentrically (p= 0.01, ES= -4.27). No significant difference between concentric and eccentric contractions during internal rotation on the painful side was found. The functional eccER:conIR ratio was significantly greater in symptomatic shoulders than pain free shoulders (p= 0.04).

Table 12
Maximal peak torque, range of motion, and functional ratio of the shoulder joint amongst swimmers with shoulder pain

Variables	Painful		Non-Painful			
	Mean	SD	Mean	SD	*p*-value	Effect Size
PT con ER	26.30	6.45	29.84	6.57	0.12	-0.54
PT con IR	37.72	7.57	47.89	13.56	*0.05	-0.96
PT ecc ER	56.00	7.47	52.14	7.60	0.29	0.51
PT ecc IR	49.55	12.64	55.47	20.82	0.37	-0.35
ROM ER	103.67	8.51	109.67	9.33	0.31	-0.67
ROM IR	36.33	12.51	35.07	17.90	0.90	0.08
EccER:ConIR	1.56	0.43	1.15	0.27	*0.04	-

Note. **Con** - concentric; **Ecc** - eccentric; **ER** - external rotation; **IR** - internal rotation; **PT** - peak torque; **ROM** - range of motion; **SD** - standard deviation; ***** = statistical significance $p \leq 0.05$

Table 13

The difference between maximal peak torque of the shoulder during concentric and eccentric contractions in swimmers with shoulder pain.

Variables	Concentric		Eccentric			
	Mean	SD	Mean	SD	*p*-value	Effect Size
PT ER on painful	26.3	6.45	56	7.47	* 0.01	4.27
PT ER on non-painful	29.84	6.57	52.14	7.6	0	3.15
PT IR on painful	37.72	7.57	49.55	12.64	0.1	1.17
PT IR on non-painful	47.89	13.56	55.47	20.82	0.17	0.44

Note. **ER** - external rotation; **IR** - internal rotation; **PT** - peak torque; **SD** - standard deviation; ***** - statistical significance $p \leq 0.05$

Discussion

This study set out with two primary objectives of assessing i) maximal shoulder rotational strength using a Humac Norm isokinetic dynamometer and ii) maximal shoulder internal and external rotational ROM using an inclinometer in prone in swimmers with or without shoulder pain. To the best of our knowledge, this is the first study to evaluate the shoulder ROM of swimmers in prone. Also, there are only two prior studies (Bak & Magnusson, 1997; Drigny et al., 2020) that measure maximal concentric and eccentric strength in swimmers using isokinetic dynamometry. These studies did not use a Humac Norm isokinetic dynamometer, making this the first study to use this type of isokinetic dynamometer to evaluate the concentric and eccentric rotational strength of swimmers with shoulder pain. Another objective of this study was to compare the difference in maximal shoulder rotational strength (concentric versus eccentric) and ROM in symptomatic and pain free swimmers. Only one previous study (Bak & Magnusson, 1997) used isokinetic dynamometry to assess swimmers' shoulder strength who were symptomatic. Further, only two previous studies (Bak & Magnusson, 1997; Drigny et al., 2020) used a functional ratio (eccER:conIR) to assess the muscle balance of a swimmer's shoulder. This study is the second to use this ratio to analyze the muscle strength of a swimmer's shoulder that is painful and comparing it to the non-painful side. The key findings showed that regardless of shoulder pain being present or not, swimmers were stronger during eccentric external rotation than concentrically. The internal rotation strength in asymptomatic swimmers had no significant difference between concentric and eccentric contractions or side to side. On the other hand, swimmers with painful shoulders had stronger concentric internal rotation on their asymptomatic side compared to their symptomatic side. Moreover, swimmers who had a painful shoulder had a significantly greater functional ratio (eccER:conIR) than swimmers who were pain free. Also, there was no significant difference in shoulder ROM whether shoulder pain was present or not. Overall, shoulder external rotation ROM was greater than internal rotation.

Difference in Shoulder Strength

Although this study found no significant difference between concentric internal and external rotation strength, the internal rotators were overall stronger than their antagonists. On the other hand, the external rotators of the shoulder were significantly stronger during an eccentric contraction than a concentric contraction (p=0.01). In overhead sports, the eccentric strength of the shoulder external rotators is important as this muscle group acts as a decelerator during overhead throwing by resisting shoulder internal rotation (Laudner, Stanek & Meister, 2006). Similarly, this finding highlights that shoulder external rotation is the least used motion in swimming and is primarily used in the non-propulsive phase hence they are less likely to act concentrically (Manske et al., 2015). Thus, their main role during the propulsion phase is to work eccentrically to counteract the propulsive internal rotation in order to limit the anterior translation of the humeral head (Gaudet, Tremblay & Dal Maso, 2018).

Similar findings were observed in the swimmers experiencing shoulder pain, except for internal rotation during a concentric movement. The internal rotators of the painful shoulder were significantly weaker during a concentric movement than the asymptomatic side (p=0.05). Similar findings have been previously observed by Tate and colleagues (2012) in 12- to 14-year-old swimmers where a significant difference in concentric internal rotation strength between symptomatic and asymptomatic swimmers were measured (p=0.05). Furthermore, a review of the literature by Struyf and colleagues (2017) had similar findings where competitive swimmers were stronger during internal rotation than external rotation. However, it was unclear whether the reduced internal rotation strength on the painful side was due to pain inhibition or if the muscle imbalance was an attempt to remain pain free. Swimmers with symptomatic shoulders tend to have lower concentric and eccentric internal rotation strength (Bak & Magnusson, 1997); however, this study found only concentric internal rotation strength to be significantly weaker on the painful side. On the contrary, our results are partially supported by other studies investigating concentric shoulder strength and pain using isometric dynamometry in swimmers (Beach, Whitney & Dickoff-Hoffman, 1992; Harrington, Meisel & Tate, 2014) where they found no difference in strength between swimmers who experience shoulder pain or not. Additionally, swimmers who experience pain in the shoulder tend to reduce their internal rotation by dropping their elbow during the recovery of freestyle to decrease the rotational demand on the shoulder and consequently reduce the shoulder pain (Pink & Tibone, 2000). If swimmers are doing this repetitively during their training, it could be a potential explanation for the reduced internal rotation strength.

Until recently, the research investigating the muscle imbalance of the shoulder rotators and its association with injury in swimmers has primarily been based on conventional concentric ratios (Bak, 2010; Batalha et al., 2013; Bradley et al., 2016). However, as previously stated, the external rotators are less likely to work concentrically which is a finding of this current study where the external rotators were not as strong during concentric contractions compared to eccentric contractions. More current literature has found that the functional eccER:conIR ratio is more appropriate to assess the strength of the antagonist muscles contributing to the dynamic stability of the shoulder joint; however, this ratio has predominantly been studied in other overhead sports. Although the literature review (Chapter 2) acknowledges the study by Drigny and colleagues (2020) where they investigated the functional strength ratio of the shoulder internal and external rotators in swimmers, it was challenging to compare their findings to our findings. The main reason being that our study was a retrospective study investigating the functional ratio in swimmers who were both symptomatic and asymptomatic. On the contrary, Drigny and colleagues' (2020) study design is prospective hence their recommendation of a value below 0.68 indicates an increased risk of injury was opposite to the recommendation by Andrade and colleagues (2013) and Guney and colleagues (2016) where a ratio above 1.0 is indicative of a risk of shoulder pain. Also, the participants in the Drigny and colleagues' (2020) study were all asymptomatic swimmers. The findings of our study showed a similar pattern to Bak and Magnusson (1997) where the ratio for the painful shoulder was significantly greater than the asymptomatic shoulder. Further research is required to validate the ratio 1.0 as a reference value for swimmers as the studies (Andrade et al., 2013; Guney et al., 2016) investigating this reference value did not include swimmers.

Difference in Shoulder Range of Motion

Another finding of the current study was that there was no difference in shoulder rotational ROM regardless of whether pain was present or not. This finding is consistent with that of Bak and Magnusson (1997) and Harrington and colleagues (2014) where they also found no significant difference in rotational ROM side to side despite having a symptomatic shoulder or not. On the contrary, a prospective cohort study by Walker and colleagues (2012) assessing active shoulder internal and external rotation ROM found a significant association between external rotation and significant interfering pain (p=0.015). They identified an increased risk of injury in swimmers with shoulder external rotation ROM <93° or ≥ 100° (Walker et al., 2012). Additionally, when assessing ROM in male and female swimmers, a prospective study by Mise and colleagues (2022) found that external rotation on the right was significantly lower in males who had shoulder pain (p=0.02); however, there was no significant difference found in the female group (p=0.84).

Limitations and Future Research

The results from this study must be interpreted with caution because of the limitations that it presents. Firstly, the number of participants in the current study was limited, and further studies are needed to confirm the results with larger samples. Secondly, this study is one of the few studies to investigate the functional ratio of the shoulder rotators in athletes that participate in overhead sport. Although there are two prior studies investigating the functional ratio of the shoulder rotators in swimmers (Bak & Magnusson, 1997; Drigny et al., 2020), this study is the second to use the functional ratio to evaluate the shoulder rotator strength in symptomatic swimmers. Drigny and colleagues (2020) conducted a prospective study investigating the functional ratio of asymptomatic swimmers.

Therefore, comparing our findings to any reference value needs to be interpreted with caution. Further studies are required to validate the reference value for the functional ratio to indicate a risk of injury in swimmers whether shoulder pain is present or not.

As previously stated, this is the first study to assess and compare maximal shoulder rotational strength using a Humac Norm isokinetic dynamometer in swimmers with shoulder pain or not. Also, it is the first to measure shoulder rotational ROM in prone in this population group. Future research needs to confirm and validate the findings of this study.

Conclusion

The aim of this study was to determine whether there is a difference in maximal strength and range of motion amongst symptomatic and asymptomatic swimmers. The results of this study showed that the external rotators of a swimmer's shoulder, regardless of it being symptomatic or not, were stronger during eccentric contractions than when the muscles were working concentrically. Further, asymptomatic swimmers had no significant difference in internal rotation strength regardless of contraction type (concentric vs. eccentric) or side to side. However, swimmers who did experience shoulder pain were significantly stronger during internal rotation on the unaffected side when working concentrically. Lastly, there was no significant difference in any shoulder ROM despite having shoulder pain or not. In spite of the current study's limitations of a small sample size and comparing to a reference value that has yet to be validated in the swimming population, the study certainly adds to our understanding of potential factors that can be contributing to shoulder pain in swimmers. Additional studies need to be done to firstly validate the findings of this current study and also to further investigate functional ratios and their role in identifying, managing, and preventing shoulder pain in swimmers moving forward.

CHAPTER 5: Discussion, Practical Implications and Conclusions

Discussion

Shoulder pain is the most common musculoskeletal complaint accounting for the most time-loss to injury. Research has shown that muscle imbalances around the shoulder joint are common characteristics that may contribute to the shoulder pain that swimmers experience (Feijen et al., 2021; Schlueter et al., 2021). Moderate quality evidence exists supporting the association between shoulder internal and external rotation strength and endurance (Bak et al., 1997; Beach et al., 1992). On the contrary, there are conflicting findings in the ROM research. Some studies found a significant difference in the shoulder ROM in symptomatic swimmers (Tate et al., 2012; Walker et al., 2012; Mise et al., 2022); however, other studies found no significant difference in ROM (Beach et al., 1992; Bak et al., 1997; Harrington et al., 2014; Holt et al., 2017).

Shoulder Strength in Swimmers

In reviewing the literature, varied evidence was found on the differences between shoulder strength in symptomatic and asymptomatic swimmers. Furthermore, there is limited evidence using an isokinetic dynamometer to measure maximal shoulder strength in swimmers. Most of the studies used handheld dynamometers (Boettcher et al., 2020; Harrington et al., 2014; McLaine et al., 2018; Tate et al., 2012). Only two previous studies used isokinetic dynamometry in the swimming population (Bak & Magnusson, 1997; Drigny et al., 2020) of which one study compared swimmers with a painful shoulder to those without pain (Bak & Magnusson, 1997). Until recently, research exploring the rotational muscle imbalances and its relationship with shoulder pain has primarily been based on conventional ratios (concentric:concentric or eccentric:eccentric) (Bak, 2010; Batalha et al., 2013; Bradley et al., 2016). Yet, more current research has commented that measuring the agonist when it contracts concentrically whilst the antagonist acts eccentrically to be more appropriate (Drigny et al., 2020). This is due to the antagonist (external rotators) working eccentrically during propulsion to help decelerate the humeral head to prevent it from translating anteriorly (Andrade et al., 2013; Drigny et al., 2020; Guney et al., 2016). Even though there is substantial literature investigating concentric and eccentric muscle strength of the shoulder rotators in other sports, there is very limited research done in the swimming population. Having a clearer understanding of both the concentric and eccentric muscle strength in swimmers could add value to adequate and effective prevention and management programs whether they have shoulder pain or not. Hence, the importance of using an isokinetic dynamometer to determine the strength profile of swimmers rather than handheld dynamometers. Handheld dynamometers can only measure isometric strength while the use of an isokinetic dynamometer can allow us to measure both concentric and eccentric strength of the shoulder rotators. To the best of our knowledge, the study conducted in this thesis is the first to use the Humac Norm isokinetic dynamometer to assess shoulder internal and external rotation strength in swimmers who experience shoulder pain or not and it is the second study to evaluate the functional ratios of shoulder rotational strength in symptomatic swimmers. Thus, the goal of this thesis was to add value and provide further insight into the assessment of swimmers' shoulders and to determine whether the presence of pain can influence the assessment findings. This thesis also aimed to explore a more sport-specific assessment that health professionals working with swimmers could implement. Consequently, health professionals could provide coaches, athletes, and trainers with sport-specific advice.

Even though the absolute strength measures for the asymptomatic group showed no significant side to side difference in concentric or eccentric shoulder strength despite hand dominance, the external rotators were significantly stronger during an eccentric contraction than a concentric contraction. As previously mentioned, the external rotators contract eccentrically during the propulsive phase in swimming to help reduce the anterior translation of the humeral head decreasing the risk of anterior shoulder impingement (Drigny et al., 2020). When comparing the shoulder strength in the symptomatic group, the swimmers who experienced shoulder pain had significantly weaker internal rotators when working concentrically than the pain free shoulder. This finding is supported by other studies where weaker internal rotators in swimmers with a painful shoulder was reported (Bak and Magnusson, 1997; Tate et al., 2012). Yet other studies found contradicting evidence where no significant difference in strength between swimmers who have pain or not was found (Beach, Whitney & Dickoff-Hoffman, 1992; Harrington, Meisel & Tate, 2014). This difference in internal rotation strength could be due to swimmers adjusting their stroke to limit the pain they experience by dropping their elbows during the recovery phase of freestyle to minimize the internal rotation demand on the shoulder (Pink & Tibone, 2000). If the swimmers are doing this regularly during training, it could be a possible explanation for the reduced internal rotation strength on the painful side.

The work by Pink and colleagues (1991) shows how the internal rotators of the shoulder work concentrically to produce the strong propulsive forces to move the body forward in the water. Even though the external rotators work simultaneously, they contract eccentrically to counteract the internal rotators preventing the anterior translation of the humeral head (Pink et al., 1991). This highlights the importance of using a functional ratio (eccER:conIR) to explore muscle imbalances of the shoulder joint in swimmers, rather than conventional concentric and eccentric ratios (ER:IR). Though there is a significant amount of research using this functional ratio in other overhead sports such as softball and baseball, there are only two prior studies using this ratio in the swimming community (Bak &

Magnusson, 1997; Drigny et al, 2020). When comparing this thesis' findings to these studies, our findings showed greater ratios than those reported by Bak and Magnusson (1997) and Drigny and colleagues (2020). However, the functional ratio of swimmers with painful shoulders were significantly greater than the asymptomatic side which was similar to that found by Bak and Magnusson (1997). This difference in ratios, particularly when compared to the study by Drigny and colleagues (2020), could be due to our study including swimmers who are symptomatic whereas Drigny and colleagues (2020) had only asymptomatic subjects. Also, the majority of the participants in our study were New Zealand representative swimmers, whereas the studies by Bak and Magnusson (1997) and Drigny and colleagues (2020) did not include national level athletes.

The findings of this thesis and other research reflect the need to alter the way in which health professionals and researchers assess and interpret shoulder strength in swimmers. This thesis suggests that moving away from using absolute strength measures and conventional ratios and using the functional ratio more frequently to be of better value and more appropriate especially seeing the way the shoulder rotational muscles interact. The study included in this thesis is the second to use the functional ratio to assess the rotational muscle imbalances of the shoulder in swimmers with shoulder pain or not, more research is needed to further validate the ratio in the swimming population and also validate our findings.

Reliability of the Humac Norm Isokinetic Dynamometer and Inclinometer

Another objective of this thesis was to investigate the inter- and intra-session reliability of the Humac Norm isokinetic dynamometer and the inclinometer to assess shoulder strength and ROM in swimmers. The Humac Norm isokinetic dynamometer has not previously been used to measure shoulder rotational strength and neither has an inclinometer been used in a prone position to assess rotational ROM in the swimming population. Therefore, secondary to assessing the difference in shoulder strength and ROM in swimmers, this thesis aimed to assess the reliability of the objective measures that were used.

Despite reliability studies showing good ICC values for using an isokinetic dynamometer to measure maximal strength of the shoulder accurately and reliably, higher SEM values have been reported for between sessions indicating that measurements being recorded are less precise. Though, the SEM values recorded for within a session were adequate. This indicated the need for at least one familiarization session. It can be concluded that isokinetic dynamometers are appropriate tools to objectively measure the concentric and eccentric strength of a swimmer's shoulder. Furthermore, the use of an inclinometer has been found to have good to excellent intra- and inter-rater reliability;

however, the reliability of the inclinometer to measure ROM in prone has yet to be determined in the previous literature.

For the Humac Norm isokinetic dynamometer, the findings showed good to excellent inter-session reliability; however, the CV values were unacceptable. Although other studies did not use CV values, the researcher was still able to compare SEM values. Previous research found adequate SEM values indicating acceptable reliability for isokinetic dynamometry to measure shoulder strength (Mandalisdis et al., 2001; Plotnikoff et al., 2002; Van Meeteren et al., 2002; Dauty et al., 2003; Edouard et al., 2013; Collado-Mateo et al., 2018; Habets et al., 2018). On the contrary, although this thesis reported good to excellent inter-session reliability, the SEM values were relatively high. Nonetheless, values reported for intra-session reliability were notably more reliable. The Humac Norm isokinetic dynamometer had excellent intra-session reliability with acceptable CV and SEM values. The higher values reported for intra-session reliability compared with the inter-session reliability can indicate that a familiarization session is important especially for eccentric testing protocols.

Additionally, this thesis found moderate to excellent inter- and intra-session reliability for the inclinometer to assess shoulder internal and external rotation ROM in prone. These findings were similar to those reported by Furness and colleagues (2015) and Walker and colleagues (2016). It is important to note that the study in this thesis used both symptomatic and asymptomatic swimmers and also measured ROM in prone, whereas the previous studies used asymptomatic participants and ROM was assessed in supine.

As previously stated, this thesis is the first to use both the Humac Norm isokinetic dynamometer and inclinometer to measure shoulder strength and ROM in prone in swimmers who have shoulder pain or not. Therefore, further research is needed to confirm and validate the findings of this study. Further research on these objective measures can add value to the shoulder assessment of swimmers. Firstly, testing ROM in prone is very specific to swimming and may be a more accurate way to measure shoulder ROM than in supine. Secondly, the Humac Norm isokinetic dynamometer assesses both concentric and eccentric shoulder muscle strength which is, as mentioned before, important for evaluating the muscle imbalances of the shoulder in swimmers. Hence, additional studies are essential to further support the use of the Humac Norm isokinetic dynamometer to measure shoulder strength in swimmers.

Shoulder ROM in Swimmers

Most of the research investigating shoulder ROM in swimmers was done in the supine position or standing. Yet, it has been suggested that using a prone position to assess or screen a swimmer’s shoulder may be more appropriate (Furness et al., 2015). This makes sense as swimmers spend the majority of their training time in a prone position so testing in prone may be more accurate and specific. To the best of our knowledge, the study included in this thesis is the first to evaluate shoulder rotational ROM using an inclinometer in prone. As a result, this thesis sought to measure shoulder rotational ROM in swimmers using an inclinometer in prone and to hopefully be the instigator for using this method and position of assessment for swimmers in future research.

This thesis did not find any significant differences in shoulder rotational ROM in swimmers regardless of shoulder pain being present or not which supports the results of Bak and Magnusson (1997) and Harrington and colleagues (2014). These findings are unlike other studies, where external rotation ROM was found to be significantly associated with interfering shoulder pain (Walker et al., 2012), and significantly lower in males with shoulder pain (Mise et al., 2022). It is important to acknowledge that the findings of this thesis have been compared to studies measuring ROM in the supine position. When measuring external rotation ROM in supine gravity provides some assistance unlike when measuring it in prone. As this is the first study to measure ROM using an inclinometer in prone amongst swimmers, further research is needed to validate the findings of this thesis.

In conclusion, there were no significant differences in shoulder internal and external rotational ROM regardless of pain being present or not. Additionally, this thesis found that the internal rotators of the painful shoulder were significantly weaker than the internal rotators of the non-painful shoulder. Furthermore, the external rotators of the painful shoulder were significantly stronger during an eccentric contraction. Similarly, the external rotators of swimmers who were pain free were also significantly stronger during an eccentric movement. Finally, the functional ratio was significantly greater for the painful shoulder. Future research should continue to explore the functional ratio (eccER:conIR) to determine the shoulder strength profile of swimmers as well as measuring shoulder ROM in prone as both these measures are swimming-specific. These measures can provide a clearer and more accurate picture of a swimmer's shoulder. As the majority of propulsion during swimming is generated by the upper body, a better understanding of the functional ratio in swimmers has the potential to enhance the athlete's performance if the shoulder muscle balance is correct.

Limitations

Although this thesis aimed to provide some useful insight into differences in shoulder rotational strength and ROM in swimmers with and without shoulder pain, a few limitations need to be acknowledged. The sample size of participants was relatively small which can increase the risk of bias. There is also a lack of generalizability of the research as there is limited heterogeneity. Participants were all national level athletes who have been swimming for over 10 years. Even though swimming is considered an overhead sport, it is challenging to compare it to other overhead sports as a swimmer's position is different. In most overhead sports the athlete is in an upright position whereas swimmers are horizontal in water when producing propulsive forces. Additionally, the participants displayed various learning abilities to the eccentric testing protocols. A potential consequence of this variability in learning abilities is the variation in the study outcomes. This was evident in the reliability study where the intra-session reliability was greater than the inter-session reliability for the isokinetic dynamometer. The difference in inter- and intra-session reliability highlights the need for familiarization sessions as the eccentric movement is unique and not commonly used in isolation in daily life. The higher intra-session reliability indicates that when participants did the eccentric motion repetitively, their ability to perform the test was better as there was less variability in the strength outcomes.

Taking these limitations into consideration, it is recommended that future research include a larger sample size to improve the generalizability and reliability of the research findings. Also, ensuring that sufficient familiarization has occurred will enhance the participant's ability to perform the unique backward eccentric movement. Adopting these approaches would facilitate more robust and generalizable findings.

Practical Recommendations

- It is suggested that assessing a swimmer's shoulder ROM, particularly internal and external rotation, in prone is more appropriate. This testing position is very specific to swimming as most of the time in the pool is spent in prone and not to mention that three out of the four strokes are performed in this position. The assessment of ROM in prone could give health professionals working with swimmers a more accurate and reliable evaluation of how the shoulder moves.
- The implementation of a functional ratio of eccER:conIR in conjunction with traditional measures can provide a more complete picture of a swimmer's shoulder health. This could potentially assist health professionals, coaches, and trainers in exercise prescription for their athletes.

Overall Conclusion

This thesis evaluated the differences in shoulder strength and ROM in swimmers who have shoulder pain or not. Additionally, it aimed to determine the reliability of the Humac Norm isokinetic dynamometer and the inclinometer in prone to assess a swimmer's shoulder strength and ROM. Although there was no significant difference in internal and external rotation strength in the asymptomatic group, there was a significant difference in concentric internal rotation strength in the symptomatic group. The concentric internal rotation strength of swimmers with shoulder pain was significantly lower than the pain free shoulder.

Additionally, external rotators were significantly stronger when contracting eccentrically. These findings highlight the roles of the rotational muscle groups during swimmer where the internal rotators work concentrically to generate enough force to propel the body forwards in the water. While the external rotators work eccentrically to limit the anterior translation of the humeral head reducing the risk of anterior shoulder impingement. Also, the painful shoulder of a swimmer had significantly greater functional ratio than the pain free side. No difference in shoulder rotational ROM was found despite pain being present or not. Furthermore, moderate to excellent inter-and intra-session reliability of the Humac Norm to assess shoulder strength and the inclinometer to measure shoulder ROM in prone amongst symptomatic and asymptomatic swimmers was found. Despite the significant findings of the study, the limitations of a small sample size and a single familiarization session could have affected the generalizability and proficiency of the findings. Future studies should address these limitations for more robust results. Also, this thesis is the second study to evaluate a swimmer's shoulder strength using the functional ratio and the first to measure shoulder ROM in prone in swimmers. Thus, further research is required to validate the findings of our research.

REFERENCES

Allegrucci, M., Whitney, S. L., & Irrgang, J. J. (1994). Clinical implications of secondary impingement of the shoulder in freestyle swimmers. *Journal of Orthopaedic and Sports Physical Therapy, 20(6),* pp. 307-318. doi:10.2519/jospt.1994.20.6.307.

Andrade, M. S., Vancini, R. L., de Lira, C. A., Mascarin, N. C., Fachina, R. J., & da Silva, A. C. (2013). Shoulder isokinetic profile of male handball players of the Brazilian national team. *Brazilian Journal of Physical Therapy, 17(6),* pp.572–578. doi:10.1590/S1413-35552012005000125

Awan, R., Smith, J., & Boon, A. J. (2002). Measuring shoulder internal rotation range of motion: A comparison of 3 techniques. *Archives of Physical Medicine and Rehabilitation, 83(9),* pp. 1229-1234. doi:10.1053/apmr.2002.34815

Bak, K., & Fauno, P., (1997). Clinical findings in competitive swimmers with shoulder pain. *American Journal of Sports Medicine,25(2),* pp. 254-260. doi:10.1177/036354659702500221.

Bak, K., & Magnusson, S. P. (1997). Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Journal of Sports Medicine, 25(4),* pp. 454-459. doi:10.1177/036354659702500407

Bak. K. (2010). The practical management of swimmer's painful shoulder: Etiology, diagnosis, and treatment. *Clinical Journal of Sports Medicine, 20(5),* pp. 386-390. doi:10.1097/JSM.0b013e3181f205fa.

Barker, T. H., Stone, J. C., Sears, K., Klugar, M., Tufanaru, C., Leonardi-Bee, J., Aromataris, E., & Munn, Z. (2023). The revised JBI critical appraisal tool for the assessment of risk of bias for randomized controlled trials. *JBI Evidence Synthesis, 21(3),* pp. 494-506. doi:10.11124/JBIES-22-00430

Batalha, N. M., Raimundo, A. M., Tomas-Carus, P., Barbosa, T. M., & Silva, A. J. (2013). Shoulder rotator cuff balance, strength, and endurance in young swimmers during a competitive season. *Journal of Strength and Conditioning Research, 27(9),* pp. 2562-2568. doi:10.1519/JSC.0b013e31827fd849

Batalha, N., Paixão, C., Silva, A. J., Costa, M. J., Mullen, J., & Barbosa, T. M. (2020). The effectiveness of a dry-land shoulder rotators strength training program in injury prevention in competitive swimmers. *Journal of Human Kinematics, 71,* pp. 11-20. doi:10.2478/hukin-2019-0093

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 and Sports Physical Therapy, 16(6),* pp. 262-268. doi:10.2519/jospt.1992.16.6.262.

Blanch, P. (2004). Conservative management of shoulder pain in swimming. *Physical Therapy in Sport, 5(3),* pp. 109-124. doi:10.1016/j.ptsp.2004.05.002

Boettcher, C., Halaki, M., Holt, K., & Ginn, K. A. (2020). Is the normal shoulder rotation strength ratio altered in elite swimmers?. *Medicine and Science in Sports and Exercise, 52(3),* pp. 680-684. doi:10.1249/MSS.0000000000002177.

Bradley, J., Kerr, S., Bowmaker, D., & Gomez, J. (2016). Review of shoulder injuries and shoulder problems in competitive swimmers. *American Journal of Sports Science and Medicine, 4(3),* pp. 57-73. doi:10.12691/ajssm-4-3-1

Byram, I. R., Bushnell, B. D., Dugger, K., Charron, K., Harrell, F. E. Jr., & Noonan T. J. (2010). Preseason shoulder strength measurements in professional baseball pitchers: Identifying players at risk for injury*. American Journal of Sports Medicine, 38(7),* pp. 1375-1382. doi:10.1177/0363546509360404.

Ceccon, S., Ceseracciu, E., Sawacha, Z., Gatta, G., Cortesi, M., Cobelli, C., & Fantozzi, S. (2013). Motion analysis of front crawl swimming applying CAST technique by means of automatic tracking. *Journal of Sports Sciences, 31(3),* pp. 276-287. doi:10.1080/02640414.2012.729134

Clarkson, H. M. (2005). *Joint Motion and Function Assessment: A Research-Based Practical Guide.* Lippincott Williams & Wilkins.

Codine, P., Bernard, P. L., Pochelle, M., Benaim, C., & Brun, V. (1997). Influence of sports discipline on shoulder rotator cuff balance. *Medicine and Science in Sports and Exercise, 29(11),* pp. 1400-1405. doi:10.1097/00005768-199711000-00002

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences.* Lawrence Erlbaum Associates.

Collado-Mateo, D., Dominguez-Muñoz, F. J., Batalha, N., Parraça, J., Tomas-Carus, P., & Adsuar, J. C. (2018). Test-retest reliability of isokinetic arm strength measurements in competitive swimmers. *Journal of Human Kinetics, 65,* pp. 5-11. doi:10.2478/hukin-2018-0035

Cools, A. M., De Wilde, L., Van Tongel, A., Ceyssens, C., Ryckewaert, R., & Cambier, D. C. (2014). Measuring shoulder external and internal rotation strength and range of motion: Comprehensive intra-rater and inter-rater reliability study of several testing protocols. *Journal of Shoulder and Elbow Surgery, 24*, pp. 1454-1461. doi:10.1016/j.jse.2014.01.006

Dauty, M., Delbrouck, C., Huguet, D., Rosseau, B., Potiron-Josse, M., & Dubois, C. (2003). Reproducibility of concentric and eccentric isokinetic strength of the shoulder rotators in normal subjects 40 to 55 years old. *Isokinetics and Exercise Science, 11(2),* pp. 95-100. doi:10.3233/IES-2003-0134

Davies, G. A. (1992). *Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques.* S &S Publishers.

De Martino, I., & Rodeo, S. A. (2018). The swimmer's shoulder: Multi-directional instability. *Current Reviews in Musculoskeletal Medicine, 11(2),* pp. 167-171. doi:10.1007/s12178-018-9485-0

Drigny, J., Gauthier, A., Reboursière, E., Guermont, H., Gremeaux, V., & Edouard, P. (2020). Shoulder muscle imbalance as a risk for shoulder injury in elite adolescent swimmers: A prospective study. *Journal of Human Kinetics, 75,* pp. 103-113. doi:10.2478/hukin-2020-0041

Dvir, Z. (1995). *Isokinetics: Muscle testing, interpretation and clinical application.* Churchill Livingstone.

Edouard, P., Codine, P., Samozino, P., Bernard, P., Hérisson, C., & Gremeaux, V. (2013). Reliability of shoulder rotators isokinetic strength imbalance measured using the Biodex dynamometer. *Journal of Science and Medicine in Sport, 16(2),* pp. 162-165. doi:10.1016/j.jsams.2012.01.007

Edouard, P., Samozino, P., Julia, M., Cervera, S. G., Vanbiervliet, W., Calmels, P., & Gremeaux, V. (2011). Reliability of isokinetic assessment of shoulder-rotator strength: A systematic review of the effect of position. *Journal of Sport Rehabilitation, 20(3),* pp. 367-383. doi:10.1123/jsr.20.3.367

Feijen, S., Struyf, T., Kuppens, K., Tate, A., & Struyf, F. (2021). Prediction of shoulder pain in youth competitive swimmers: The development and internal validation of a prognostic prediction model. *The American Journal of Sports Medicine, 49(1),* pp. 154-161. doi:10.1177/0363546520969913

Frisello, S., Gazaille, A., O'Halloran, J., Palmer, M. L., & Waugh, D. (1994). Test-retest reliability of eccentric peak torque values for shoulder medial and lateral rotation using the Biodex isokinetic dynamometer. *Journal of Orthopaedic and Sports Physical Therapy, 19(6),* pp. 341-344. doi:10.2519/jospt.1994.19.6.341

Furness, J., Johnstone, S., Hing, Wayne, Abbott, A., Climstein, M. (2015). Assessment of shoulder active range of motion in prone versus supine: A reliability and concurrent validity study. *Physiotherapy Theory and Practice, 31(7),* pp. 489-495. doi:10.3109/09593985.2015.1027070

Gaudet, S., Tremblay, J., & Dal Maso, F. (2018). Evolution of muscular fatigue in periscapular and rotator cuff muscles during isokinetic shoulder rotations. *Journal of Sports Sciences, 36(18),* pp. 2121-2128. doi:10.1080/02640414.2018.1440513

Gaunt, T., & Maffulli, N. (2012). Soothing suffering swimmers: A systematic review of the epidemiology, diagnosis, treatment and rehabilitation of musculoskeletal injuries in competitive swimmers. *British Medical Bulletin, 103(1),* pp. 45-88. doi:10.1093/bmb/ldr039.

Ginn, K. A., Cohen, M. L., & Herbert, R. D. (2006). Does hand-behind-back range of motion accurately reflect shoulder internal rotation?. *Journal of Shoulder and Elbow Surgery, 15(3),* pp. 311-314. doi:10.1016/j.jse.2005.08.005

Green, S., Buchbinder, R., Forbes, A., & Bellamy, N. (1998). A standardized protocol for measurement of range of movement of the shoulder using the Plurimeter-V inclinometer and assessment of its intrarater and interrater reliability. *Arthritis Care and Research: The Official Journal of Arthritis Health Professions Association, 11(1),* pp. 43-52. doi:10.1002/art.1790110108

Guney, H., Harput, G., Colakoglu, F., & Baltaci, G. (2016). The effect of glenohumeral internal-rotation deficit on functional rotator-strength ratio in adolescent overhead athletes. *Journal of Sports Rehabilitation, 25(1),* pp. 52-57. doi:10.1123/jsr.2014-0260

Habets, B., Staal, J. B., Tijssen, M., & van Cingel, R. (2018). Intrarater reliability of the Humac NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles. *BMC Research Notes, 11(1),* pp. 15-20. doi:10.1186/s13104-018-3128-9

Harrington, S., Meisel, C., & Tate, A. (2014). A cross-sectional study examining shoulder pain and disability in division I female swimmers. *Journal of Sport Rehabilitation, 23(1),* pp. 65-75. doi:10.1123/jsr.2012-0123.

Heinlein, S. A., & Cosgarea, A. J. (2010). Biomechanical considerations in the competitive swimmer's shoulder. *Sports Health, 2(6),* pp. 519-525. doi:10.1177/1941738110377611

Hibberd, E. E., & Myers, J. B. (2013). Practice habits and attitudes and behaviours concerning shoulder pain in high school competitive club swimmers. *Clinical Journal of Sports Medicine, 23(6),* pp. 450-455. doi:10.1097/JSM.0b013e31829aa8ff

Hill, L., Collins, M., & Pothumus, M. (2015). Risk factors for shoulder pain and injury in swimmers: A critical systematic review. *The Physician and Sportsmedicine, 43(4),* pp. 412-420. doi:10.1080/00913847.2015.1077097.

Holt, K., Boettcher, C., Halaki, M., & Ginn, K. A. (2017). Humeral torsion and shoulder rotation range of motion parameters in elite swimmers. *Journal of Science and Medicine in Sport, 20(5),* pp. 469-474. doi:10.1016/j.jsams.2016.10.002.

Hoving, J. L., Ryan, P., Stockman, A., Buchbinder, R., Green, S., Forbes, A., Bellamy, N., Brand, C., Buchanan, R., Hall, S., & Patrick, M. (2002). How reliably do rheumatologists measure shoulder movement? Annals of the Rheumatic Disease, 61(7), pp. 612-616. doi:10.1136/ard.61.7.612

Hyodo, H., Koga, D., Sengoku, y., & Wada, T. (2023). Relationship between swimming velocity and trunk twist motion in short-distance crawl swimming. *Biomechanics, 3(2),* pp. 193-203. doi:10.3390/biomechanics3020017

Impellizzeri, F. M., Bzzini, M., Rampinini, E., Cereda, F., & Maffiuletti, N. (2008). Reliability of isokinetic imbalance ratios measured using the Cybex NORM dynamometer. *Clinical Physiology and Functional Imaging, 28(2),* pp. 113-119. doi:10.1111/j.1475-097X.2007.00786.x

Kimura, I. F., Gulick, D. T., Alexander, D. M., & Takao, S. H. (1996). Reliability of peak torque values for concentric and eccentric shoulder internal and external rotation on the Biodex, Kinetic Communicator, and Lido dynamometers. *Isokinetics and Exercise Science, 6(2),* pp. 95-99. doi:10.3233/IES-1996-6204

Kluemper, M., Uhl, T., Hazelrigg, H. (2006). Effect of stretching and strengthening shoulder muscles on forward shoulder posture in competitive swimmers. *Journal of Sport Rehabilitation, 15(1),* pp. 58-70. doi:10.1123/jsr.15.1.58.

Kolber, M. J., & Hanney, W. J. (2012). The reliability and concurrent validity of shoulder mobility measurements using a digital inclinometer and goniometer: A technical report. *The International Journal of Sports Physical Therapy, 7(3),* pp. 306-313. Available from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3362980/

Kolber, M. J., Saltzman, S. B., Beekhuizen, K. S., & Cheng, M. S. (2009). Reliability and minimal detectable change of inclinometric shoulder mobility measurements. *Physiotherapy Theory and Practice, 25(8),* pp. 572-581. doi:10.3109/09593980802667995

Kolber, M. J., Vega, F., Widmayer, K., & Cheng, M. S. (2011). The reliability and minimal detectable change of shoulder mobility measurements using a digital inclinometer. Physiotherapy Theory and Practice, 27(2), pp. 176-184. doi:10.3109/09593985.2010.481011

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15(2),* pp. 155-163. doi:10.1016/j.jcm.2016.02.012.

Kramer, J. F., & Ng, L. R. (1996). Static and dynamic strength of the shoulder rotators in healthy, 45- to 75-year-old men and women. *Journal of Orthopaedic and Sports Physical Therapy, 24(1),* pp. 11-18. doi:10.2519/jospt.1996.24.1.11.

Kubová, S., Pavlů, D., Pánek, D., Hoika, V., Jebavý, R., & Kuba, K. (2020). The effect of short-term strength intervention on muscle activity of shoulder girdle during simulated crawl in elite swimmers. *Acta Gymnica, 50(4).* doi:10.5507/ag.2020.012

Laudner, K. G., Stanek, J. M., & Meister, K. (2006). Assessing posterior shoulder contracture: The reliability and validity of measuring glenohumeral joint horizontal adduction. *Journal of Athletic Training, 41(4),* pp. 375-380. https://pubmed.ncbi.nlm.nih.gov/17273461/

Lea, R. D., & Gerhardt, J. J. (1995). Current concepts of review: Range of motion measurements. *Journal of Bone and Joint Surgery. American Volume, 77(5*), pp. 784-798. doi:10.2106/00004623-199505000-00017

Lucas, D., Neiva, H. P., Marinho, D., Ferraz, R., Rolo, I., & Duarte-Mendes, P. (2021). Functional Movement Screen evaluation: Comparison between elite and non-elite young swimmers: FMS and performance in swimming. *Cuadernos de Psicología del Deporte, 21(2)*, pp. 163-173. doi:10.6018/cpd.438401

Lucas, N. P., Macaskill, P., Irwig, L., & Bogduk, N. (2010). The development of a quality appraisal tool for studies of diagnostic reliability (QAREL). *Journal of Clinical Epidemiology, 63(8),* pp. 854-861. doi:10.1016/j.jclinepi.2009.10.002.

Lynch, S. S., Thigpen, C. A., Mihalik, J. P., Prentice, W. E., & Padua, D. (2010). The effects of an exercise intervention on forward head and rounded shoulder postures in elite swimmers. *British Journal of Sports Medicine, 44(5),* pp. 376-381. doi:10.1136/bjsm.2009.066837.

Malerba, J. L., Adam, M. L., Harris, B. A., & Krebs, D. E. (1993). Reliability of dynamic and isometric testing of shoulder external and internal rotators. *Journal of Orthopaedic and Sports Physical Therapy, 18(4),* pp. 543-552. doi:10.2519/jospt.1993.18.4.543

Mandalidis, D. G., Donne, B., Regan, M. O., & O'Brien, M. (2001). Reliability of isokinetic internal and external rotation of the shoulder in the scapular plane. *Isokinetics and Exercise Science, 9(1),* pp. 65-72. doi:10.3233/IES-2001-0066

Manske, R. C., Lewis, S., Wolff, S., & Smith, B. (2015). Effects of a dry-land strengthening program in competitive adolescent swimmers. *International Journal of Sports Physical Therapy, 10(6),* pp. 858-867. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4637920/

Matzkin, E., Suslavich, K., & Wes, D. (2016). Swimmer's shoulder: Painful shoulder in the competitive swimmer. *Journal of American Academy of Orthopaedic Surgeons, 24(8),* pp. 527-536. doi:10.5435/JAAOS-D-15-00313.

McKenzie, A., Larequi, S-A., Hams, A., Headrick, J., Whiteley, R., & Duhig, S. (2023). Shoulder pain and injury risk factors in competitive swimmers: A systematic review. *Scandinavian Journal of Medicine and Science in Sports, 33(12),* pp. 2396-2412. doi:10.1111/sms.14454

McLaine, S. J., Bird, M., Ginn, K. A., Hartley, T., & Fell, J. W. (2019). Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers?. *Journal of Science and Medicine in Sport, 22(5),* pp. 516-520. doi:10.1016/j.jsams.2018.11.008

McLaine, S. J., Ginn, K. A., Fell, J. W.& Bird, M. (2018). Isometric shoulder strength in young swimmers. *Journal of Science and Medicine in Sport, 21(1),* pp. 35-39. doi:10.1016/j.jsams.2017.05.003.

McMaster, W. C. (1999), Shoulder injuries in competitive swimmers. *Clinics in Sports Medicine, 18(2),* pp. 349-359. doi:10.1016/s0278-5919(05)70150-2.

McMaster, W. C., Long, S. C., & Caiozzo, V. J. (1992). Shoulder torque changes in the swimming athlete. *American Journal of Sports Medicine, 20(3),* pp. 323-327. doi:10.1177/036354659202000315.

Mise, T., Mitomi, Y., Mouri, S., Takayama, H., Inoue, Y., Inoue, M., Akuzawa, H., & Kaneoka, K. (2022). Hypomobility in males and hypermobility in females are risk factors for shoulder pain among young swimmers. *Journal of Sport Rehabilitation, 31(1),* pp. 17-23. doi:10.1123/jsr.2020-0488.

Moola, S., Munn, Z., Tufanaru, C., Aromataris, E., Sears, K., Sfetcu, R., Currie, M., Qureshi, R., Mattis, P., Lisy, K.,& Mu, P-F. (2020). Chapter 7: Systematic reviews of etiology and risk. In: Aromataris E, Munn Z (Eds). *JBI Manual for Evidence Synthesis.* Available from https://synthesismanual.jbi.global

Muir, S. W., Corea, C. L., & Beaupre, L., (2010). Evaluating change in clinical status: Reliability and measures of agreement for the assessment of glenohumeral range of motion. *Northern American Journal of Sports Physical Therapy, 5(3),* pp. 98-110. Available from https://pubmed.ncbi.nlm.nih.gov/21589666/

Mulla, D. M., Hodder, J. N., Maly, M. R., Lyons, J. L., & Keir, P. J. (2019). Glenohumeral stabilizing roles of the scapulohumeral muscles: Implications of muscle geometry. *Journal of Biomechanics, 100(2020)*. doi:10.1016/j.jbiomech.2019.109589

Pereira, J.C., Neri, S.G.R., Vainshelboim, B., Gadelha, A.B., Bottaro, M., & Lima, R.M. (2019). A reference equation for normal standards for knee extensor isokinetic strength in Brazilian older women. *Aging Clinical and Experimental Research, 31(10),* pp.1531–1537. doi:10.1007/s40520-018-1084-9

Perrin, D. H. (1993). *Isokinetic exercise and assessment.* Human Kinetics

Perrin, D. H. (1994). Open chain isokinetic assessment and exercise of the knee. *Journal of Sport Rehabilitation, 3(3),* pp. 245-254. doi:10.1123/jsr.3.3.245

Pink, M., Perry, J., Browne, A., Scovazzo, M. L., & Kerrigan, J. (1991). The normal shoulder during freestyle swimming. An electromyographic and cinematographic analysis of twelve muscles *The American Journal of Sports Medicine, 19(6),* pp. 569-576. doi:10.1177/036354659101900603

Pink, M. M., & Tibone, J. E. (2000). The painful shoulder in the swimming athlete. *Orthopedic Clinics of North America, 31(2),* pp. 247-261. doi:10.1016/s0030-5898(05)70145-0.

Plotnikoff, N. A., & MacIntyre, D. L. (2002). Test-rest reliability of glenohumeral internal and external rotator strength. *Clinical Journal of Sport Medicine, 12(6),* pp.367-72. doi:10.1097/00042752-200211000-00008

Porritt, K., Gomersall, J., & Lockwood, C. (2014). JBI's systematic reviews: Study selection and critical appraisal. *American Journal of Nursing, 114(6),* pp. 47-52. doi:10.1097/01.NAJ.0000450430.97383.64

Ramsi, M., Swanik, K. A., Straub, S., & Mattacola, C. G. (2004). Shoulder-rotator strength of high school swimmers over the course of a competitive season. *Journal of Sport Rehabilitation, 13(1),* pp. 9-18. doi:10.1123/jsr.13.1.9

Reed,G. F., Lynn, F., & Meade, B. D. (2002). Use of coefficient of variation in assessing variability of quantitative assays. *Clinical and Diagnostic Laboratory Immunology, 9(6),* pp. 1235-1239. doi:10.1128/cdli.9.6.1235-1239.2002.

Roddey, T. S., Cook, K. F., O'Malley, K. J., & Gartsman, G. M. (2005). The relationship among strength and mobility measures and self-report outcome scores in persons after rotator cuff repair surgery: Impairment measures are not enough. *Journal of Shoulder and Elbow Surgery, 14(1),* pp. 95-98. doi:10.1016/j.jse.2004.09.023

Rodeo, S. A. Swimming. In S. G. Krishnan, R. J. Hawkins & R. F. Warren (Eds.), *The shoulder and the overhead athlete* (pp. 350). Lippincott Williams & Wilkins.

Roy, J. S., & Esculier, J. F. (2011). Psychometric evidence for clinical outcome measures assessing shoulder disorders. *Physical Therapy Reviews, 16(5),* pp. 331-346. doi:10.1179/1743288X11Y.0000000043

Rudiger, H. A., Fuchs, B., von Campe, A., & Gerber, C. (2008). Measurements of shoulder mobility by patient and surgeon correlate poorly: A prospective study. *Journal of Shoulder and Elbow Surgery, 17(2),* pp. 255-260. doi:10.1016/j.jse.2007.07.012.

Rupp, S., Berninger, K., & Hopf, T. (1995). Shoulder problems in high level swimmers: Impingement, anterior instability, muscular imbalance?. *International Journal of Sports Medicine, 16(8),* pp. 557-562. doi:10.1055/s-2007-973054

Schlueter, K. R., Pintar, J. A., Wayman, K. J., Hartel, L. J., & Briggs, M. S. (2021). Clinical evaluation techniques for injury risk assessment in elite swimmers: A systematic review. *Sports Health, 13(1),* pp. 57-64. doi:10.1177/1941738120920518

Scovazzo, M. L., Brown, A., Pink, M., Jobe, F. W., & Kerrigan, J. (1991). The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. *American Journal of Sports Medicine, 19(6),* pp. 577-582. doi:10.1177/036354659101900604.

Seine, M. L., Walton, J., Linklater, J., Appleyard, R., Kirkbride, B., Kuah, D., & Murrell, G. A. (2010). Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *British Journal of Sports Medicine, 44(2),* pp. 105-113. doi:10.1136/bjsm.2008.047282

Shanley, E., Thigpen, C. A., Clark, J. C., Wyland, D. J., Hawkins, R. J., Noonan, T. J., & Kissenberth, M. J. (2012). Changes in passive range of motion and development of glenohumeral internal rotation deficit (GIRD) in the professional pitching shoulder between spring training in two consecutive years. *Journal of Shoulder and Elbow Surgery, 21(11), pp*. 1605-1612. doi:10.1016/j.jse.2011.11.035.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin, 86(2),* pp. 420–428. doi:10.1037/0033-2909.86.2.420

Stark, T., Walker, B., Phillips, J. K., Fejer, R., & Beck, R. (2011). Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: A systematic review. *PM & R: The Journal of Injury, Function, and Rehabilitation, 3(5),* pp. 472-479. doi:10.1016/j.pmrj.2010.10.025

Streiner, D. L., & Norman, G. R. (2008). *Health measurement scales: A practical guide to their development and use.* Oxford University Press.

Struyf, F., Tate, A., Kuppens, K., Feijen, S., & Michener, L. A. (2017). Musculoskeletal dysfunctions associated with swimmers' shoulder. *British Journal of Sports Medicine, 51(10),* pp. 775-780. doi:10.1136/bjsports-2016-096847

Swanik, K. A., Lephart, S. M., Swanik, C. B., Lephart, S. P., Stone, D. A., & Fu, F. H. (2002). The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics. *Journal of Shoulder and Elbow Surgery, 11(6),* pp. 579-586. doi:10.1067/mse.2002.127303.

Taherdoost, H. (2016). Validity and reliability of the research instrument; How to test the validation of a questionnaire/survey in a research. *International Journal of Academic Research in Management, 5(3),* pp. 28-36. doi:10.2139/ssrn.3205040

Tate, A., Sarver, J., DiPaola, L., Yim, J., Paul, R.,& Thomas, S. J. (2020). Changes in clinical measures and tissue adaptations in collegiate swimmers across a competitive season. *Journal of Shoulder and Elbow Surgery, 29(11),* pp. 2375-2384. doi:10.1016/j.jse.2020.03.028.

Tate, A., Turner, G. N., Knab, S. E., Jorgensen, C., Strittmatter, A., & Michener, L. A. (2012). Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *Journal of Athletic Training, 47(2),* pp. 149-158. doi:10.4085/1062-6050-47.2.149.

Tessaro, M., Granzotto, G., Poser, A., Plebani, G., & Rossi, A. (2017). Shoulder pain in competitive teenage swimmers and it's prevention: A retrospective epidemiological cross sectional study of prevalence. *The Internation Journal of Sports Physical Therapy, 12(5),* pp. 789-811. doi:10.16603/ijspt20170798

Tighe, J., McManus, I. C., Dewhurst, N. G., Chis, L., & Mucklow, J. (2010). The standard error of measurement is a more appropriate measure of quality for postgraduate medical assessments than is reliability: An analysis of MRCP(UK) examinations. *BMC Medical Education, 10(40).* doi:10.1186/1472-6920-10-40

Tovin, B. J. (2006). Prevention and treatment of swimmer's shoulder. *North American Journal of Sports Physical Therapy, 1(4),* pp. 166-175. https://pubmed.ncbi.nlm.nih.gov/21522219/

Trinidad, A., Gonazález-Garcia, H., & López-Valenciano, A. (2021). An updated review of the epidemiology of swimming injuries. *PM & R Journal, 13(9),* pp. 1005-1020. doi:10.1002/pmrj.12503

van de Pol, R. J., van Trijffel, E., & Lucas, C. (2010). Inter-rater reliability for measurement of passive physiological range of motion of upper extremity joints is better if instruments are used: A systematic review. *Journal of Physiotherapy, 56(1),* pp. 7-17. doi:10.1016/s1836-9553(10)70049-7

van Dyk, N., Bahr, R., Whiteley, R., Tol, J.L., Kumar, B.D., Hamilton, B., Farooq, A., & Witvrouw E. Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: A 4-year cohort study. *American Journal of Sports Medicine, 44(7),* pp. 1789–1795. doi:10.1177/0363546516632526

van Meeteren, J. Roebroeck, M. E., & Stam, H. J. (2002). Test-retest reliability in isokinetic muscle strength measurements of the shoulder. *Journal of Rehabilitation Medicine, 34(2),* pp. 91-95. doi:10.1080/165019702753557890.

Van Trijffel, E., Anderegg, Q., Bossuyt, P. M. M., & Lucas, C. (2005). Inter-examiner reliability of passive assessment of intervertebral motion in the cervical and lumbar spine: A systematic review. *Manual Therapy, 10(4),* pp. 256-269. doi:10.1016/j.math.2005.04.008.

Virag, B., Hibberd, E. E., Oyama, S., Padua, D. A., & Myers, J. B. (2014). Prevalence of freestyle biomechanical errors in elite competitive swimmers. *Sports Health, 6(3),* pp. 218-224. doi:10.1177/1941738114527056

Walker, H., Gabbe, B., Wajswelner, H., Blanch, P., & Bennell, K. (2012). Shoulder pain in swimmers: A 12-month prospective cohort study of incidence and risk factors. *Physical Therapy in Sport, 13(4),* pp. 243-249. doi:10.1016/j.ptsp.2012.01.001.

Walker, H., Pizzari, T., Wajswelner, H., Blanch, P., Schwab, L., Bennell, K., & Gabbe, B. (2016). The reliability of shoulder range of motion measures in competitive swimmers. *Physical Therapy in Sport, 21,* pp. 26-30. doi:10.1016/j.ptsp.2016.03.002

Wanivenhaus, F., Fox, A. J. S., Chaudhury, S., & Rodeo, S. A. (2012). Epidemiology of injuries and prevention strategies in competitive swimmers. *Sports Health, 4(3),* pp. 246-251. doi:1177%2F1941738112442132

Wattanaprakornkul, D., Cathers, I., Halaki, M., & Ginn, K. A. (2011). The rotator cuff muscles have a direction specific recruitment pattern during shoulder flexion and extension exercises. *Journal of Science and Medicine in Sport, 14(5),* pp. 376-382. doi:10.1016/j.jsams.2011.01.001

Weldon, E. J., & Richardson, A. B. (2001). Upper extremity overuse injuries in swimming. A discussion of swimmer's shoulder. *Clinics in Sports Medicine, 20(3),* pp.423-438. doi:10.1016/s0278-5919(05)70260-x.

West, D., Sole, G., & Sullivan, S. J. (2005). Shoulder external- and internal-rotation isokinetic strength in master's swimmers*. Journal of Sport and Rehabilitation, 14(1),* pp. 12-19. doi:10.1123/jsr.14.1.12

Wiażewicz, A., & Eider, J. (2020). The relationship between swimming performance and isokinetic shoulder strength of elite swimmers. *Human Movement, 22(4),* pp. 10-19. doi:10.5114/hm.2021.103285

Wilk, K. E., & Arrigo, C. (1993). Current concepts in the rehabilitation of the athletic shoulder. *Journal of Orthopaedic and Sports Physical Therapy, 18(1*), pp. 365-378. doi:10.2519/jospt.1993.18.1.365

Yanai, T., & Hay, J. G. (2000). Shoulder impingement in front-crawl swimming: II. Analysis of stroking technique. *Medicine and Science in Sports and Exercise, 32(1),* pp. 30-40. doi:10.1097/00005768-200001000-00006.

Zaki, R., Bulgiba, A., Ismail, R., & Ismai, N. A. (2012). Statistical methods used to test for agreement of medical instruments measuring continuous variables in method comparison studies: A systematic review*. PLoS One, 7(5).* doi:10.1371/journal.pone.0037908

Zemek, M. J., & Magee, D. J. (1996). Comparison of glenohumeral joint laxity in elite and recreational swimmers. *Clinical Journal of Sport Medicine, 6(1),* pp. 40-47. doi:10.1097/00042752-199601000-00009

APPENDICES

Appendix 1: Ethics Approval, Auckland University of Technology Ethics Committee

AUT

Auckland University of Technology Ethics Committee (AUTEC)

22 September 2023

Matt Brughelli
Faculty of Health and Environmental Sciences

Dear Matt

Ethics Application: **22/150 Assessing shoulder strength and range of motion in normal and symptomatic swimmers**

On 6 September 2022 you were advised that your ethics application was approved.

We would like to remind you, that it was a condition of this approval that you submit to AUTEC the following:

- A brief annual progress report using the EA2 Research Progress Report / Amendment Form, available at http://www.aut.ac.nz/research/researchethics/forms, or
- A brief Completion Report about the project using the EA3 from, which is available online through http://www.aut.ac.nz/research/researchethics/forms. This report is to be submitted either when the approval expires on 6 September 2025 or when the project is completed;

It is also a condition of approval that AUTEC is notified if the research did not proceed or any adverse events occurring during the research. If there has been any alteration to the research, (including changes to any documents provided to participants) then AUTEC approval must be sought using the EA2 form.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please contact us at ethics@aut.ac.nz.

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: Botha.kayla@gmail.com

Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand
T: +64 9 921 9999 ext. 8316: E: ethics@aut.ac.nz: www.aut.ac.nz/researchethics

Appendix 2: Participant Information Sheet

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet

Study One

Date Information Sheet Produced:

11/05/2022

Project Title

Assessing the reliability of peak torque and active range of motion in prone for assessing the shoulder joint.

An Invitation

Hi, my name is **Kayla Botha**, and I am a Master's student at AUT University. I would like to personally invite you participate in our research project. The study aims to assess maximal shoulder strength and range of motion in normal and symptomatic swimmers.

What is the purpose of this research?

Swimming is a recreational and competitive sport that involves both the upper and lower body. Majority of the propulsion of the swimmers in the water originates from their upper extremities. Hence the occurrence of shoulder pain in swimmers is high. Research have found significant differences in shoulder range of motion (ROM) and strength in swimmers with and without shoulder pain. However, no studies have included ROM testing in the prone position in swimmers, and none have included eccentric shoulder strength in swimmers. The measurement of ROM in prone is sport specific as swimmers spend majority of their swimming training doing freestyle. This proposed study aims to determine the reliability of peak torque and active range of motion in prone for assessing the shoulder joint. The findings of this study will assist in developing a sport specific screening method of the shoulder for swimmers that would be beneficial for researchers and practitioners managing these athletes. Additionally, the findings of this research may be used for academic publications and presentations.

How was I identified and why am I being invited to participate in this research?

I (the lead research) was put in contact with your swimming coach via a colleague who has worked with Swimming New Zealand for several years. Based on the study outline and requirements of participation, the lead researcher identified your training group for a presentation. You are eligible to participate in this study if you are (1) male and female between the ages of 16 and 30 years; (2) are healthy (no known medical conditions), (3) have no history of previous shoulder surgery; (4) have no history of shoulder injuries unrelated to swimming; (5) have no history of cervical and thoracic pathology; (6) English speaking; (7) able to complete questionnaires and give informed consent; (8) and have been participating in regular swimming sessions (3-5 sessions a week) for the past six months.

How do I agree to participate in this research?

If you agree to participate in this research, you can email me on kayla.botha.physio@gmail.com expressing your interest to participate. You will be asked to report to the AUT-Millennium SPRINZ laboratory space where you will be given written information about the testing procedure. Before signing the consent form, you will be given an opportunity to ask me any questions about the research study. Following this opportunity for questions or queries, you will be required to sign and date the consent form.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Once you have decided to participate in the study you will be asked to complete a 1-1.5 hour familiarisation session at the AUT-Millennium SPRINZ laboratory space and repeat identical study procedures one week following the initial testing session (if able). The study procedures are as follows:

Initially, you will complete a subscale of the Penn Shoulder Score (strenuous pain score) and the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire (sports module). Following this, the researcher will give a complete verbal explanation of the testing procedures and equipment. You will then complete a 5-10 minute shoulder warm-up. The warm-up will include active shoulder internal and external rotation using a stick, shoulder internal and external rotation with arm at your side using a yellow theraband, and push ups. The testing procedures will consist of maximal shoulder internal and external rotation using the Humac Norm dynamometer at 120°/s and measuring shoulder active range of motion in prone using an inclinometer. You will complete three strength tests with a 1 minute passive rest periods (i.e., 6 resisted tests on each shoulder).

If you wish to continue your participation, you will be invited to return to our testing facility for a second testing session approximately one week later at the same time of day. This session will follow the same procedures as the first testing session to determine the reliability and validity of the test variables. Additionally, the findings of the retest will be included in Study Two.

The below pictures are of the equipment that will be used to assess your shoulder strength and range of motion.

Humac Norm Isokinetic Dynamometer

Inclinometer

What are the discomforts and risks?

You will be asked to perform maximal (very heavy intensity) exercises during the data collection. Therefore, you could potentially experience discomfort for a short period of time towards the concluding moments of these maximal assessments. The intensity of these exercises will be similar to what you experience during training and competition situations.

How will these discomforts and risks be alleviated?

Being an experienced swimmer who regularly competes and is familiar with training at high intensities, the exercise trials will be similar to what you experience within a typical week of training and competition. If you experience discomfort at any stage during the testing, you are encouraged to inform the researcher with you at the time so that they can best address the problem. If you have any questions regarding the risk of discomfort you may experience, please feel free to address these concerns to the researcher so that you always feel comfortable throughout this research process.

What are the benefits?

You will receive a sport-specific assessment of your shoulder joints. This will include an assessment of the shoulders' active range of motion (ROM) in prone and maximal shoulder internal and external strength. This information can be used to provide insight into muscle imbalances and reduced ROM that can be impacting your training capacity and race performance and contribute to potential injuries. The researchers will also benefit from this study as this sport-specific screening is a novelty. The results of this study will assist how health professionals assess and manage a swimmer's shoulder.

The results of this research are intended for publication and will contribute to part of my Master's Thesis and will also be submitted to peer-reviewed journals for publication.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Testing procedures and subsequent data collection may occur in small groups resulting in limited confidentiality during this period between those performing testing within the same session. No results will be imparted during the testing session. Your individual data will be protected and confidential from other participants in your testing group. Outside of the data collection, your privacy will be protected by the data being de-identified (your name will be replaced by a code, e.g., Swim 1, Swim 2 etc.), and the research will not disclose any person's participation in this study. No names or pictures will be used in the reporting (unless the participant gives explicit additional written consent for media purposes following AUT protocols and organised via the AUT university relations team). During the study, only the applicant and named researchers will have access to the data collected. The results of the study may be used for submission to peer-reviewed journals or submitted at conferences.

All data will be stored on password protected computers or in locked files. Following completion of data analysis your data will be stored by the AUT University SPRINZ research officer in the AUT University SPRINZ secure Ethics and Data facility at AUT Millennium campus. Given the progressive nature of research in this field, data will be kept indefinitely for the purposes of reanalysis (should future analysis methods arise) for purposes similar to that collected; however (as per above) all forms of data will be de-identified and kept secure for the entirety of the data's storage lifetime.

What are the costs of participating in this research?

Other than your time and effort, there will be no financial cost for you participating in this study. You will need to attend a 1-1.5 hour familiarisation session prior to testing sessions. The testing sessions will take approximately 1.5-2 hours.

You will receive a $20 petrol voucher for each testing session as koha for your time and travel.

What opportunity do I have to consider this invitation?

We would appreciate it if you could let us know within two weeks whether you would be available to take part in the study or not. After consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, upon completion each participant will receive a report regarding their shoulder range of motion and maximal strength. The report will indicate where there is muscle imbalance or reduced shoulder range of motion. It is your choice whether you share this information with your coach or other people.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Matt Brughelli, matt.brughelli@aut.ac.nz, (+649) 921 9999 ext 7025 or (+64) 27 221 7777.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, ethics@aut.ac.nz , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Kayla Botha, kayla.botha.physio@gmail.com

Project Supervisor Contact Details:

Dr. Matt Brughelli, Sport Performance Research Institute New Zealand (SPRINZ), School of Sport and Recreation, Faculty of Health and Environmental Sciences, AUT University, Private Bag 92006, Auckland 1020, matt.brughelli@aut.ac.nz, 09 921 9999 ext 7025 or 027 221 7777.

Approved by the Auckland University of Technology Ethics Committee on ***type the date final ethics approval was granted*****, AUTEC Reference number** ***type the reference number*****.**

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet

Study Two

Date Information Sheet Produced:

11/05/2022

Project Title

Assessing shoulder strength and range of motion in swimmers with and without shoulder pain

An Invitation

Hi, my name is **Kayla Botha**, and I am a Master's student at AUT University. I would like to personally invite you participate in our research project. The study aims to assess maximal shoulder strength and range of motion in normal and symptomatic swimmers.

What is the purpose of this research?

Swimming is a recreational and competitive sport that involves both the upper and lower body. Majority of the propulsion of the swimmers in the water originates from their upper extremities. Hence the occurrence of shoulder pain in swimmers is high. Research have found significant differences in shoulder range of motion (ROM) and strength in swimmers with and without shoulder pain. However, no studies have included ROM testing in the prone position in swimmers, and none have included eccentric shoulder strength in swimmers. The measurement of ROM in prone is sport specific as swimmers spend majority of their swimming training doing freestyle. This proposed study aims to assess shoulder ROM and strength in swimmers with and without shoulder pain. The findings of this study will help determine a sport specific screening method of the shoulder for swimmers that would be beneficial for researchers and practitioners managing these athletes. Additionally, the findings of this research may be used for academic publications and presentations.

How was I identified and why am I being invited to participate in this research?

I (the lead research) was put in contact with your swimming coach via a colleague who has worked with Swimming New Zealand for several years. Based on the study outline and requirements of participation, the lead researcher identified your training group for a presentation. You are eligible to participate in this study if you are (1) male and female between the ages of 16 and 30 years; (2) are healthy (no known medical conditions), (3) have no history of previous shoulder surgery; (4) have no history of shoulder injuries unrelated to swimming; (5) have no history of cervical and thoracic pathology; (6) English speaking; (7) able to complete questionnaires and give informed consent; (8) and have been participating in regular swimming sessions (3-5 sessions a week) for the past six months.

How do I agree to participate in this research?

If you agree to participate in this research, you can email me on kayla.botha.physio@gmail.com expressing your interest to participate. You will be asked to report to the AUT-Millennium SPRINZ laboratory space where you will be given written information about the testing procedure. Before signing the consent form, you will be given an opportunity to ask me any questions about the research study. Following this opportunity for questions or queries, you will be required to sign and date the consent form.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Once you have decided to participate in the study you will be asked to complete a 1-1.5 hour familiarisation session at the AUT-Millennium SPRINZ laboratory space. The study procedures are as follows:

Initially, you will complete a subscale of the Penn Shoulder Score (strenuous pain score) and the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire (sports module). Following this, the researcher will give a complete verbal explanation of the testing procedures and equipment. You will then complete a 5-10 minute shoulder warm-up. The warm-up will include active shoulder internal and external rotation using a stick, shoulder internal and external rotation with arm at your side using a yellow theraband, and push ups. The testing procedures will consist of maximal shoulder internal and external rotation using the Humac Norm dynamometer at 120°/s and measuring shoulder active range of motion in prone using an inclinometer. You will complete three strength tests with a 1 minute passive rest periods (i.e., 6 resisted tests on each shoulder).

The below pictures are of the equipment that will be used to assess your shoulder strength and range of motion.

Humac Norm Isokinetic Dynamometer

Inclinometer

What are the discomforts and risks?

You will be asked to perform maximal (very heavy intensity) exercises during the data collection. Therefore, you could potentially experience discomfort for a short period of time towards the concluding moments of these maximal assessments. The intensity of these exercises will be similar to what you experience during training and competition situations.

How will these discomforts and risks be alleviated?

Being an experienced swimmer who regularly competes and is familiar with training at high intensities, the exercise trials will be similar to what you experience within a typical week of training and competition. If you experience discomfort at any stage during the testing, you are encouraged to inform the researcher with you at the time so that they can best address the problem. If you have any questions regarding the risk of discomfort you may experience, please feel free to address these concerns to the researcher so that you always feel comfortable throughout this research process.

What are the benefits?

You will receive a sport-specific assessment of your shoulder joints. This will include an assessment of the shoulders' active range of motion (ROM) in prone and maximal shoulder internal and external strength. This information can be used to provide insight into muscle imbalances and reduced ROM that can be impacting your training capacity and race performance and contribute to potential injuries. The researchers will also benefit from this study as this sport-specific screening is a novelty. The results of this study will elucidate whether there is a difference in these measures among symptomatic and normal swimmers. This information can contribute to a swimmer's individualised injury prevention or rehabilitation programme. It will also assist how health professionals and coaches throughout New Zealand manage their swimmers both in the gym and the pool.

The results of this research are intended for publication and will contribute to part of my Master's Thesis and will also be submitted to peer-reviewed journals for publication.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Testing procedures and subsequent data collection may occur in small groups resulting in limited confidentiality during this period between those performing testing within the same session. No results will be imparted during the testing session. Your individual data will be protected and confidential from other participants in your testing group. Outside of the data collection, your privacy will be protected by the data being de-identified (your name will be replaced by a code, e.g., Swim 1, Swim 2 etc.), and the research will not disclose any person's participation in this study. No names or pictures will be used in the reporting (unless the participant gives explicit additional written consent for media purposes following AUT protocols and organised via the AUT university relations team). During the study, only the applicant and named researchers will have access to the data collected. The results of the study may be used for submission to peer-reviewed journals or submitted at conferences.

All data will be stored on password protected computers or in locked files. Following completion of data analysis your data will be stored by the AUT University SPRINZ research officer in the AUT University SPRINZ secure Ethics and Data facility at AUT Millennium campus. Given the progressive nature of research in this field, data will be kept indefinitely for the purposes of reanalysis (should future analysis methods arise) for purposes similar to that collected; however (as per above) all forms of data will be de-identified and kept secure for the entirety of the data's storage lifetime.

What are the costs of participating in this research?

Other than your time and effort, there will be no financial cost for you participating in this study. You will need to attend a 1-1.5 hour familiarisation session prior to testing sessions. The testing sessions will take approximately 1.5-2 hours.

You will receive a $20 petrol voucher for each testing session as koha for your time and travel.

What opportunity do I have to consider this invitation?

We would appreciate it if you could let us know within two weeks whether you would be available to take part in the study or not. After consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, upon completion each participant will receive a report regarding their shoulder range of motion and maximal strength. The report will indicate where there is muscle imbalance or reduced shoulder range of motion. It is your choice whether you share this information with your coach or other people.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Matt Brughelli, matt.brughelli@aut.ac.nz, (+649) 921 9999 ext 7025 or (+64) 27 221 7777.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz*, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Kayla Botha, kayla.botha.physio@gmail.com

Project Supervisor Contact Details:

Dr. Matt Brughelli, Sport Performance Research Institute New Zealand (SPRINZ), School of Sport and Recreation, Faculty of Health and Environmental Sciences, AUT University, Private Bag 92006, Auckland 1020, matt.brughelli@aut.ac.nz, 09 921 9999 ext 7025 or 027 221 7777.

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix 3: Participant Consent Form

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Consent Form

Project title: ***Assessing the reliability of peak torque and active range of motion in prone for assessing the shoulder joint.***

Project Supervisor: ***Dr Matt Brughelli***

Researcher: ***Kayla Botha***

- O I have read and understood the information provided about this research project in the Information Sheet dated 11/05/2022
- O I have had an opportunity to ask questions and to have them answered.
- O I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- O I understand that if I withdraw from the study then I will be offered the choice between having any data or tissue that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- O I am not suffering from any current injury, illness, or disorder that may impair my ability to perform the required tasks nor am I outside the limits of the required age range of 16 to 30 years.
- O I agree to provide answers to questions and provide a physical effort to the best of my ability throughout testing.
- O I agree to take part in this research.
- O I understand I have the option to be retested and my results to be included in Study Two.
- O I consent to the indefinite storage of my de-identified data for re-analysis, should future similar uses arise (please tick one): Yes O No O
- O I wish to receive a copy of the report from the research (please tick one): Yes O No O
- O I wish to have my performance information accessible to my coach (please tick one): Yes O No O

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on *type the date on which the final approval was granted* ***AUTEC Reference number*** *type the AUTEC reference number*

Note: The Participant should retain a copy of this form.

Consent Form

Project title: ***Assessing shoulder strength and range of motion in swimmers who have shoulder pain.***

Project Supervisor: ***Dr Matt Brughelli***

Researcher: ***Kayla Botha***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 11/05/2022.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data or tissue that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I am not suffering from any current injury, illness, or disorder that may impair my ability to perform the required tasks nor am I outside the limits of the required age range of 16 to 30 years.
- ○ I agree to provide answers questions and provide a physical effort to the best of my ability throughout testing.
- ○ I agree to take part in this research.
- ○ I consent to the indefinite storage of my de-identified data for re-analysis, should future similar uses arise (please tick one): Yes ○ No ○
- ○ I wish to receive a copy of the report from the research (please tick one): Yes ○ No ○
- ○ I wish to have my performance information accessible to my coach (please tick one): Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on *type the date on which the final approval was granted* ***AUTEC Reference number*** *type the AUTEC reference number*

Note: The Participant should retain a copy of this form.

Appendix 4: The Quality Appraisal for Reliability Studies (QAREL) Checklist

Quality Appraisal of Diagnostic Reliability (QAREL) Checklist

Item	Yes	No	Unclear	N/A
1. Was the test evaluated in a sample of subjects who were representative of those to whom the authors intended the results to be applied? (DEF: 3, 4, 5, 7, 8, 9)	☐	☐	☐	
2. Was the test performed by raters who were representative of those to whom the authors intended the results to be applied? (DEF 3, 4, 6, 7, 8, 9)	☐	☐	☐	
3. Were raters blinded to the findings of other raters during the study? (DEF 10)	☐	☐	☐	☐
4. Were raters blinded to their own prior findings of the test under evaluation? (DEF 11)	☐	☐	☐	☐
5. Were raters blinded to the results of the reference standard for the target disorder (or variable) being evaluated? (DEF 12)	☐	☐	☐	☐
6. Were raters blinded to clinical information that was not intended to be provided as part of the testing procedure or study design? (DEF 13)	☐	☐	☐	☐
7. Were raters blinded to additional cues that were not part of the test? (DEF 14)	☐	☐	☐	
8. Was the order of examination varied? (DEF 15, 16)	☐	☐	☐	☐
9. Was the time interval between repeated measurements compatible with the stability (or theoretical stability) of the variable being measured? (DEF 17)	☐	☐	☐	
10. Was the test applied correctly and interpreted appropriately? (DEF 18)	☐	☐	☐	
11. Were appropriate statistical measures of agreement used? (DEF 19, 20, 21)	☐	☐	☐	
TOTAL				

DEF numbers relate to items on the QAREL Data Extraction Form
To access the Data Extraction Form, please go to http://qarel.org

Appendix 5: JBI Critical Appraisal Checklist for Analytical Cross Sectional Studies

THE JOANNA BRIGGS INSTITUTE

JBI Critical Appraisal Checklist for Analytical Cross Sectional Studies

Reviewer___________________________________Date__________________________

Author ____________________________________Year_________Record Number______.

	Yes	No	Unclear	Not applicable
1. Were the criteria for inclusion in the sample clearly defined?	☐	☐	☐	☐
2. Were the study subjects and the setting described in detail?	☐	☐	☐	☐
3. Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
4. Were objective, standard criteria used for measurement of the condition?	☐	☐	☐	☐
5. Were confounding factors identified?	☐	☐	☐	☐
6. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
7. Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
8. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

____

____

____

Appendix 6: JBI Critical Appraisal Checklist for Cohort Studies

THE JOANNA BRIGGS INSTITUTE

JBI Critical Appraisal Checklist for Cohort Studies

Reviewer_________________________________Date_________________________

Author __________________________________Year_________Record Number______

	Yes	No	Unclear	Not applicable
1. Were the two groups similar and recruited from the same population?	☐	☐	☐	☐
2. Were the exposures measured similarly to assign people to both exposed and unexposed groups?	☐	☐	☐	☐
3. Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
4. Were confounding factors identified?	☐	☐	☐	☐
5. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
6. Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	☐	☐	☐	☐
7. Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
8. Was the follow up time reported and sufficient to be long enough for outcomes to occur?	☐	☐	☐	☐
9. Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	☐	☐	☐	☐
10. Were strategies to address incomplete follow up utilized?	☐	☐	☐	☐
11. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

____

____

____

Appendix 7: The JBI Levels of Evidence for Effectiveness

LEVELS OF EVIDENCE FOR EFFECTIVENESS

Level 1 – Experimental Designs

Level 1.a – Systematic review of Randomized Controlled Trials (RCTs)

Level 1.b – Systematic review of RCTs and other study designs

Level 1.c – RCT

Level 1.d – Pseudo-RCTs

Level 2 – Quasi-experimental Designs

Level 2.a – Systematic review of quasi-experimental studies

Level 2.b – Systematic review of quasi-experimental and other lower study designs

Level 2.c – Quasi-experimental prospectively controlled study

Level 2.d – Pre-test – post-test or historic/retrospective control group study

Level 3 – Observational – Analytic Designs

Level 3.a – Systematic review of comparable cohort studies

Level 3.b – Systematic review of comparable cohort and other lower study designs

Level 3.c – Cohort study with control group

Level 3.d – Case – controlled study

Level 3.e – Observational study without a control group

Level 4 – Observational –Descriptive Studies

Level 4.a – Systematic review of descriptive studies

Level 4.b – Cross-sectional study

Level 4.c – Case series

Level 4.d – Case study

Level 5 – Expert Opinion and Bench Research

Level 5.a – Systematic review of expert opinion

Level 5.b – Expert consensus

Level 5.c – Bench research/ single expert opinion

Appendix 8: Individual scoring of the QAREL Checklist

A summary of the critical appraising scoring of the reliability studies included in this review using the Quality Appraisal for Reliability Studies (QAREL) checklist

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Mandalidis et al., (2001)	Yes	Yes	N/A – one examiner	No	N/A	No	No	No – The order of limb dominance and IR/ER actions were randomised in the first session but were tested in the same order for the second session.	Yes	Yes	Yes
Awan et al., (2002)	Yes	Yes	No – one examiner measured and recorded the ROM	Yes	N/A	No	No	Yes	Yes	Yes	Yes
Plotnikoff et al., (2002)	Yes	Yes	N/A – one examiner	Unclear – blinding not stated	N/A	No	No	No – same protocol of testing was followed on subsequent test sessions	Yes	Yes	Yes
Van Meeteren et al., (2002)	Yes – no recruitment process mentioned	Unclear – only states “examiners”	Unclear – blinding not stated.	Unclear – blinding not stated.	N/A	No	No	Yes	Yes	Yes	Yes
Dauty et al., (2003)	Yes	Yes	N/A – one examiner	No	N/A	No	No	Yes	Yes	Yes	Yes
Kolber et al., (2012)	Yes	Yes	Yes	Yes - A trained assistant	N/A	Unclear	Unclear	No – No randomisation	Yes	Yes	Yes

				recorded all measurements from the digital inclinometer to ensure the investigators performing the measurements were blinded to the findings.				of measurements as the authors wanted a consistent physiological status for participants.			
Edouard et al., (2013)	Yes	Unclear – only states “examiner”.	N/A – one examiner only	Unclear	N/A	No	Unclear	No - The two shoulders were tested in random order for the first session; this order was the same for the second session.	Yes	Yes	Yes
Cools et al., (2014)	Yes	Unclear – only sex, height, and weight were provided.	No – first examiner recorded the second examiner’s findings and vice versa.	Yes – second assessor recorded the findings of the first assessor and vice versa.	N/A	No	Unclear	Yes	No – 10 seconds between trials	Yes	Yes
Furness et al., (2015)	Yes	Yes	No – one examiner recorded the findings of the other	Yes	N/A	No – no blinding to clinical information noted.	Unclear	No	Yes	Yes	Yes
Walker et al., (2016)	Yes	Yes	Yes - examiners were blinded to all test results	Yes - examiners were blinded to all test results	N/A	No	Unclear	No – shoulder ROM test order was standardised. Only swimmers	Yes	Yes	Yes

								were randomised to an examiner.			
Collado-Mateo et al., (2018)	Yes	Unclear – only states “raters”	Unclear – blinding not stated	Unclear – blinding not stated	N/A	Unclear	Unclear	Unclear – not stated	Unclear – period between tests not stated only that same test was performed three times on the same day.	Yes	Yes
Habets et al., (2018)	Yes	Yes	Unclear	Unclear	N/A	Unclear – no clinical information provided	Unclear	Yes	Yes	Yes	Yes

Note. **ER** – external rotation; **IR** – internal rotation; **N/A** – not applicable; **ROM** – range of motion

Appendix 9: Individual Scoring of JBI Checklist for Cohort Studies

A summary of the critical appraisal scoring of the cohort studies included in this review using the Joanna Briggs Institute Critical Appraisal Checklist

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Level of Evidence for Effectiveness
Beach et al., (1992)	NA – one group of Division I collegiate and club swimmers	NA	Yes – study stated intratester reliability for shoulder flexibility measurements.	Yes	Yes – Multiple regression analysis	NA	Yes	NA	NA	NA	Yes	3.e
Bak et al., (1997)	Yes – Danish National team	Yes	Yes – isokinetic dynamometer and HHD	Yes – sex, age, experience, training amount, strength training	No	NA	Yes	NA	NA	NA	Yes	3.c
Walker et al., (2012)	NA – one group of swimmers from five competitive swimming clubs in Melbourne.	NA	Yes – table stating the reliability of shoulder tests used.	Yes – one table with variables examined for association with shoulder injury and a table listing participant characteristics.	Yes – preliminary bivariate logistic regression analyses; backward stepwise binary logistic regression	NA	Yes	Yes	Yes	Yes	Yes	3.e
Holt et al., (2017)	NA – one group of Australian swimmers from the national team and Institute of Sport	NA	Yes – inter-rater reliability was assessed.	Yes – age, sex, dominance, swimming event, training load, and shoulder pain status	Yes – independent predictors of pain were examined using multiple regression models	NA	Yes	NA	NA	NA	Yes	3.e
Boettcher et al., (2019)	NA – one group of elite swimmers	NA	Yes – The testing procedure demonstrated	Yes – age, sex, height, weight, hand dominance, swimming event,	Yes – Mixed model analyses were used to evaluate difference in	NA	Yes	NA	NA	NA	Yes	3.e

			good to excellent intertester reliability.	training load, and pain status.	strength normalised to body weight and using fixed factors (dominance, sex, and pain status).							
Drigny et al., (2020)	NA – one group of adolescent swimmers from a national-level	NA	Yes – Con-Trex isokinetic dynamometer	Yes – age, sex, body weight, height, BMI, dominance, experience, front-crawl specialist, stroke, distance, shoulder injury history	Yes – regression analysis using an F-test and r-squared statistic.	NA	Yes	Yes – 38 weeks	Yes – 1x ACL injury, 2x pursued careers overseas and 2x did not wish to continue with follow up.	No	Yes	3.e
Tate et al., (2020)	NA – one group of collegiate swimmers from a division II university	NA	Yes – test-retest reliability was assessed.	Yes – table with participants demographics	No	NA	Yes	NA	NA	NA	Yes	3.e
Mise et al., (2022)	NA – one group of swimmer belonging to the same swimming club in Japan	NA	Yes – The examiners calculated the intraclass correlation coefficient and verified the intra-examiner reliability of each measurement	Yes – experience, training load (distance and session)	Yes – a backward stepwise binary logistic regression was used to examine the relationship between dependent and independent variables.	NA	Yes	Yes	No	No	Yes	3.e

Note. **ACL** – anterior cruciate ligament; **BMI** – body mass index; **NA** – not applicable

Appendix 10: Individual Scoring of JBI Checklist for Cross Sectional Studies

A summary of the critical appraisal scoring of the cross-sectional studies included in this review using the Joanna Briggs Institute Critical Appraisal Checklist

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Level of Evidence for Effectiveness
Tate et al., (2012)	No	Yes – multicentre study across youth, high school, and US Masters swim teams in Philadelphia and Pennsylvania areas.	No	Yes – Penn Shoulder Score and Disabilities of the Arm, Shoulder, and Hand outcome measure	Yes – table with participant demographics and another table with swimming exposure	Yes	Yes – inclinometer, HHD, scapular dyskinesis test, side bridge test, PALM palpation meter	Yes	4.b
Harrington et al., (2014)	Yes	Yes	Yes – previous intratester reliability stated	Yes – Sports and Symptom Survey Form	Yes – table of participants demographics	No	Yes – reliability and validity stated for each measure.	No	4.b
McLaine et at., (2018)	Yes	Yes – testing performed poolside, participants demographics described, recruitment process stated	Yes – HHD and positioning is standardised	Yes – questionnaire was completed that included questions on hand dominance, previous shoulder injury or pain, swim performance, training history.	Yes – included in the results tables	Yes	Yes – HHD	Yes	4.b

Note. **HHD** – handheld dynamometer; **PALM** – palpation meter

Appendix 11: A picture of the shoulder ROM assessment set up.

Appendix 12: Swimmer Functional Pain Scale (SFPS)